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DESERTIFICATION ASSESSMENT AND MAPPING : A CASE STUDY OF TURKMENISTAN, USSR

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ABSTRACT

The paper deals with desertification study of Turkmenistan arid lands which are vulnerable to such desertification types as degradation of the vegetative cover, wind erosion, water erosion and technogenic desertification. In Turkmenistan. 25% of the territory is not prone to desertification. Methodology for preparation of small scale desertification maps by application of space photos has been described and discussed alongwith criteria of desertification.

INTRODUCTION

Desertification is the process of degradation of arid ecosystems leading to reduction of all forms of biological life in the desert, and at last, it causes reduction of the economic potential. Due to population growth and intensification of natural resources exploitation, the global ecological situation is becoming worse from year to year. Specially, developing countries of Asia and Africa suffer from severe desertification.

In the USSR with planned socialist economy, desertification is not considered a disaster. But desertification here can occur on account of some objective and subjective reasons e.g., technogenic sands inevitably appear because of construction and other works in the desert. But these sands can be stabilized in 3-5 years.

Desertification is not a new problem. Its age is equal to the age of the human civilization. From the point of view of the impact on the natural environment, the human activity can be divided into four stages which are shown in Fig. 1. One can find these stages in many desert regions : they characterize different degrees of desertification.

Desertification occurs in the form of processes collectively termed as desertification types. The FAO, (1981) considers the following four as the main desertification types : degradation of the vegetative cover, wind erosion, water erosion, and soil salinization. Reduction of organic matter in the soil, formation of soil crusts, and accumulation of substances toxic to animals and plants are the secondary processes. The Desert Institute, USSR (Kharin *et al.*, 1983) has proposed two additional types

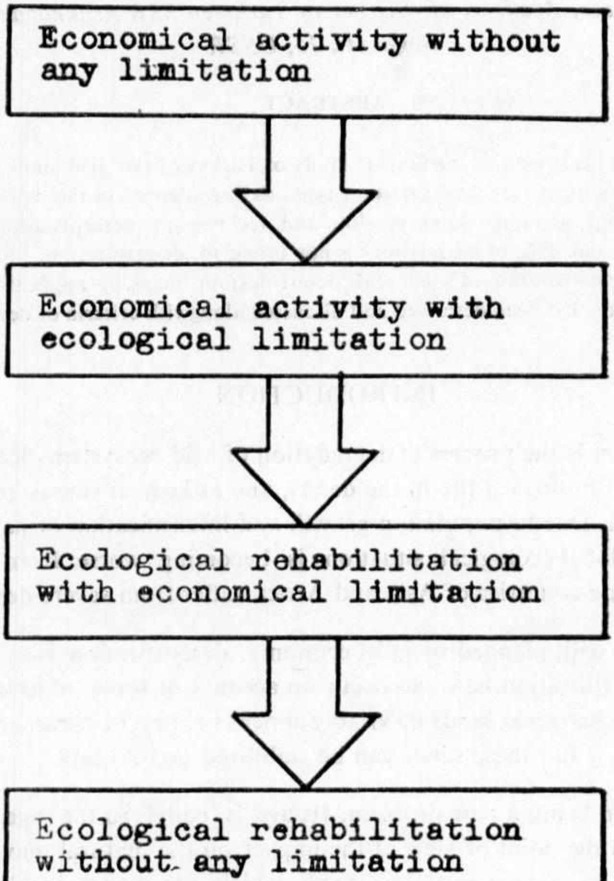

Fig. 1. Change of interrelation between economy and ecology depending on the disturbance of natural environment (Fedorenko and Reimers, 1982).

of desertification : soogenic and technogenic. Soogenic desertification is caused by the activity of desert animals. Technogenic desertification includes all types of destruction caused by machinery employed in prospecting, construction and other works in the desert.

The main goal of scientists investigating the desertification problem is to recognize and categorize desertification processes into two types : natural and man-made. Soviet scientists (Kharin *et al.*, 1983 and Mensching, 1980) support this idea. These both types of processes usually occur together and often cannot be divided (Mensching, 1980). In Sahel, desertification is caused mainly by high variability of annual precipitation rate (Mensching, 1980). Desertification has also been considered (Mensching, 1980) as a process of expansion of deserts limits.

But Soviet scientists (Kharin and Petrov, 1977) are of the opinion that desertification process may be reflected in the expansion of desert limits or it may as well be confined to comparatively limited area. In the last case, desertification is reflected in the accentuation of desertic conditions. The definition of desertification proposed by FAO (1981) supports this idea.

Such terms as indicators, aspects and criteria of desertification need to be understood clearly. Nechaeva (1978) describes the physical, biological and social indicators. In her opinion, "indicator is an instrument for diagnosis of desertification". Indicators can be qualitative and quantitative e.g., the reduction of plant communities productivity can be considered as a desertification indicator.

Some authors give only quantitative indicators. Zhu (1984) studied desertification in China. He divided the desertified lands into four groups : latent desertification, on going desertification, severe desertification, and very severe desertification. As indicators of desertification he proposed the following two criteria : percentage of land occupied by moving sand dunes, and percentage increase in the area of moving sand dunes.

The following criteria are considered as desertification aspects : status (S), rate (R), inherent risk (IR), animal pressure (AP), population pressure (PP), desertification hazard (DH). According to FAO (1983) DH is calculated as follows :

$$DH = S + R + IR + AP + PP$$

Desertification criteria are quantitative indices showing the degree of degradation of arid ecosystems. Status criteria give the idea about changes in desert environment compared to the zero level which is a state of desert environment not prone to desertification. Estimation of the zero level always causes some difficulty because of human activities in all deserts. Rate criteria characterize the intensity of the process during a period of time (usually 5-10 years). Desertification hazard is a prognostic criterion showing the trend of desertification in future as compared to the present state.

DESERTIFICATION CRITERIA

The territory of the Turkmen SSR where we carried out studies occupies an area of 4.88 million sq. km. The human population in 1983 reached 3.042 millions. The Karakum desert occupies the main part of the Republic. The climate of Turkmenistan is typically continental and extremely dry. The mean annual temperature is 11-13°C in the north and 15-18°C in the south. The annual precipitation does not exceed 100 mm in northeast and 150 mm in the central Karakum; in the piedmont zone precipitation it reaches 260 mm.

Aridity index varies from 8.0 to 16.0. The dryness of the territory and active wind regime are the main causes of wind erosion. The number of days with dust storms (15 m/sec) are 5-10 days per annum in central Karakum and 3-8 days in southeast Karakum. In the northwest areas near the Caspian Sea the half days with dust storms are 40 and in Amudarya valley it is 54 days per annum.

The soil cover of Turkmenistan has been formed acccording to climatic conditions, topography and parent rocks. The zone of light grey brown soil is confined to the piedmont plains 250-500 m above MSL. The depth of soil is 40-50 cm. Clay and clayloam soils prevail. The upper horizons of this soil are usually not salinized. This soil is suitable for cultivation of several agricultural crops. Typical grey brown soil is common at 400-1000 m above MSL.

Among other soils are the takyr and takyr-like soils. Takyrs are seen on ancient delta plains and takyr-like soils on plains of alluvial or proluvial origin. Hydromorphic solonchaks are also common, mainly having sulphate salinization. Secondary solonchaks may appear after unlimited watering of irrigated lands in the Karakum canal bordering areas.

The number of plant species in the vegetation cover of Turkmenistan reaches 2700. But the bulk of these plants is confined to mountain areas, which occupy comparatively limited portion of the Republic's territory. Not more than 650 species are common in the plains of Turkmenistan.

Large shrubs are the dominant life-forms in the sandy desert. These are *Haloxylon persicum*, *H. aphyllum*, *Salsola richteri*, *Ephedra strobilacea*, and *Calligonum* spp. Ephemeral vegetation includes numerous species of Gramineae, Cruciferae, Compositae and Leguminosae families. These plants form good pastures suitable for sheep and camel during the whole year. But the productivity of pastures in not high; the yield of pastures doesn't exceed 0.15-0.20 t.

Vegetation of gypseous desert occupies vast areas in northwest part of Turkmenistan. Plant cover is formed by dwarf shrubs and semi-shrubs which are *Artemisia kemrudica* and many *Salsola* species e.g., *S. arbuscula, S. orientalis* and *S. gemascens.* Pasture plants of this desert are readily grazed by animals in autumn and winter. The yield of these pasture reaches 0.25-0.30 t.

Clay deserts occupy vast areas in southwest, northern and southern parts of Turkmenistan. Vegetation is sparse here. Such species as *Climacoptera lanata, C. transoxana, C. turkomanica, Gamanthus gamocarpus* and *Halimochemis karelini* are met on saline soil. Pastures have low productivity; they can be used by sheep and camels in autumn and winter.

Loess desert in piedmont areas has vegetation cover consisting mainly of ephemerals and ephemeroids (*Poa bulbosa, Carex pachystylis* etc.). Some *Artemisia* species common here are *A. badhysi, A. turanica.*

Vegetation in mountains is distributed in accordance with vertical zonation. *Artemisia kopetdaghensis, A. turcomanica, A. stenocephale* dominate in the lower mountain belt. *Poa bulbosa, Carex pachystylis* and *Bromus tectorum* are common herbs here. In the middle belt the following species are met : *Poa relaxa, Bromus kopetdaghensis, Stipa caucasica, Cousinia triflora, Cramb cotshyana* and *Astragalus* sp. etc. In gorges the following shrubs and trees can be seen : *Amygdalus turcomanica, Crataegus pantica, Rubus angustifolia* etc. Stands of *Juniperus turcomanica* remain in the upper mountain belts. Mountain xerophytes also grow here.

The types of desertification observed in the Republic are degradation of the vegetative cover, wind erosion, water erosion and salinization of irrigated soils. The last type of desertification is not discussed in this paper. We only describe the processes that occured in the natural ecosystems. Information about the soil salinization on irrigated lands in Turkmen SSR has been published earlier from the Desert Institute (Kharin *et al.*, 1983).

Criteria of the vegetative cover degradation are given in Table 1 (Kharin, 1985). In this and other tables the abbreviations used are : F-field study, LT-literature sources, SP-space photos, AP-aerial photos, TM-thematic maps, PR-project data, TP-topographic maps, AN-analytical data, (the sources of information).

Criteria for assessment of wind erosion proposed by the Desert Institute are given in Table 2 and those for assessment of water erosion in Table 3. Wind erosion in Turkmen SSR mainly occurs in Karakum desert and water erosion is common in piedmont and mountain areas. Criteria for assessment of technogenic desertification are given in Table 4. They have been developed by the author (Kharin, 1985).

Table 1. Criteria for assessing Degradation of vegetative cover.

Aspects	Assessment factors	Class limits				Sources *vide* text
		Slight	Moderate	Severe	Very severe	
Status	1. Characteristics of vegetative cover	Climax communities slightly changed	Long existing secondary communities	Ephemeral secondary communities	Destruction of vegetative cover	F, LT, SP, AP
	2. Present productivity, per cent of potential	>90	90-60	60-30	<30	LT, PR
Rate	1. Decline of biomass production per ha, per cent	<10	10-25	25-50	>50	LT, F
	2. Pasture degradation, per cent per year	<2.5	2.5-5.0	5.0-7.5	>7.5	SP, AP, TM,
	3. Forest cutting, annual per cent of area not regenerated	<2.5	2.5-5.0	5.0-7.5	>7.5	PR, LT
	4. Decrease in forage production; per cent per year	<1	1-4	4-7	>7	LT, PR
Inherent risk	1. Stability of ecosystems	Stable ecosystems of clay, loamy clay and gravel deserts	Comparatively stable ecosystems of loess desert, ecosystems with loamy-sand soil and ecosystems on gentle slopes of mountains	Non stable ecosystems of river valley forests ecosystems on moderate slopes of mountatains and ecosystems of clay piedmont plains	Non stable ecosystems of sandy desert, ecosystems of steep slopes of mountains and bad lands	LT, TM, TP, SP
	2. Potential of reclamation, per cent area to be reclaimed per year	<3	3-5	5-10	>10	

Table 2. Criteria for assessing wind erosion

Aspects	Assessment factors	Class limits				Sources
		Slight	Moderate	Severe	Very severe	*vide* text
Status	1. Wind erosion features	25 per cent covered with precipiced blow outs	25-50 per cent are a covered with blow outs, sand ripples on bare surface	Slip slopes formed on shifting sand	Movement of sand on total area	F, AP
	2. Sod cover, per cent	50-30	30-10	<10	—	F, AP
	3. Ratio of per cent shrub density per cent and sod cover	20-30 / 40-80	20-5 / 40-10	5-1 / 10-5	<1 / <5	F
Rate	1. Increase in eroded area, per cent per year	<1	1-2	2-5	>5	TM, SP, AP, LT
	2. Amount of sand per year transported over the 1 m line, m^3	<5	5-10	10-20	>20	LT
Inherent risk	1. Wind erodability groups (texture of soil)	Sandy clay loam, sandy loam, silt	Rest of the textural classes	Loamy sand	Sand	TM, LT
	2. Mean annual wind speed at 2 m height, m/s	<0. 1	0. 1-0. 2	0. 2-0. 4	>0. 4	LT
	3. Active wind frequency, per cent of total number of winds per year	<5	5-15	15-25	>25	LT

Table 3. Criteria for assessing water erosion

Aspects	Assessment factors	Class limits				Sources (*vide* text)
		Slight	Moderate	Severe	Very severe	
Status	1. Surface features	Gravel and stones cover 10 per cent or less	Gravel and stones cover 10-25 per cent	Boulders and rocks cover 25-50 per cent	Boulders and rock exposures cover 50 per cent or more	F, TM
	2. Type of water erosion	Slight surface flood and rill erosion	Moderate surface flood and rill erosion	Severe surface flood and gully	Very severe surface flood and gully	SP, AP
	3. Number of ravines, gullies ruts per km line	<5	5-10	>10	>10	AP, TM
	4. Subsoil exposed, per cent	<10	10-25	50	>50	AP, SP
	5. Soil thinkness, cm	>90	90-50	50-10	<10	F
	6. Loss of soil depth over root-inhabiting layer, per cent :					
	(a) Original soil depth 1 m	<25	25-50	50-75	>75	F
	(b) Original soil depth 1 m	<30	30-60	60-90	>90	F
Rate	1. Increase in eroded area, per cent per year	<1	1-2	2-5	>5	F, LT
	2. Soil loss, MT/ha/year	<0.5	0.5-1.0	1.0-5.0	<5.0	F, LT
	3. Sediment deposition in reservoirs :					
	(a) watershed 500 km^2 m/km/year	<60	60-200	200-500	>500	LT, AN
	(b) watershed 500 km^2	<40	40-100	100-250	>250	LT, AN
	4. Annual loss of storage, per cent	<0.2	0.2-0.4	0.4-1.0	>1.0	LT, Pr
Inherent risk	1. Topography	Slighty undulated	Hilly	Mountains with gentle and steep slopes	Mountains with steep slopes and talus	TM, AP

(Continued)

1	2	3	4	5	6	7
	2. Slopes	<5°	5-15°	15-30°	>30°	
	3. Density of shrub and tree vegetation (or semi-shrub), per cent	>30	30-15	15-5	<5	AP, F
	4. Per cent of area covered with sold (in the areas with dominant herbacious vegetation)	>50	50-30	30-10	<10	AP, F
	5. Coefficient of hydrographic net density (ratio of the total length of river-beds, km, to watershed size, km²)	<0.5	<0.5	0.5	>0.5	TP, SP

Table 4. Criteria for assessing technogenic desertification.

Aspects	Assessment factors	Class limits				Sources of information
		Slight	Moderate	Severe	Very severe	
Stutus	1. Destruction of the vegetative cover :					
	(a) cutting trees and shrubs, per cent of the forested area;	<25	25-50	50-70	>70	SP, AP
	(b) destruction of the sod cover per cent	<25	25-50	50-70	>70	AP, F
	2. Per cent eroded areas caused by spontaneous movement of vehicles in the desert	<10	10-25	50-70	>70	SP, AP
	3. Per cent areas covered with technogenic sand	<10	10-25	25-50	>50	SP, AP
Rate	Increase in area with technogenic disturbances (per cent for the last 5 years)	<2	2-5	5-10	>10	SP, AP,TM
Inherent risk	Texture of soil	Silt clay, loam	Sandy loam	Loamy sand	Sand	RP

FAO (1983) recommends use of the following method for estimation of animal pressure : Potential pasture capacity is to be calculated on the basis of correlation between winter precipitation (R) and palatable forage reserve (CF) by the equation:

$$CF = 2.17R - 103.7$$

This equation is valid for the conditions of Mediterranean region. For Sahel zone of Africa summer precipitation should be used for calculation. In this case the equation is :

$$CF = 1.03R + 42.2$$

It is recommended to correct the equation by taking into account soil conditions. In case of optimal soil conditions the potential pasture capacity is increased by 25%. For poor soil conditions the final calculation is decreased by 25% and for very poor conditions by 50%. For the estimation of the animal units (250 kg in weight) the following coefficients are recommended: goat 0.1; sheep 0.1; cattle 1.0; camel 1.1; buffalo 1.0; pig 0.3; horse 1.1; donkey 0.8; mule 1.0. The forage need of one animal unit per annum is estimated as 2000 kg.

These criteria are not suitable for the conditions of the USSR arid zone. We have now pasture productivity maps covering the whole territory of the arid zone. These maps allow direct estimation of forage reserve (Nikolaev *et al.*, 1984). These are two main animals grazing in Turkmen SSR - camels and shee - Calculation of animal unit in USSR differs from that of the FAO. The annual consumption of forage for sheep is estimated at 950 kg and for camels (dromedaries) at 5700 kg (dry weight). For animal units calculation one camel is equal to 6 sheep (Nikolaev *et al.*, 1984).

In our study (for rural country) was estimated on population density, we used population density maps (Atlas of Turkmen SSE, 1982). For the Turkmen SSR territory we estimated the following scale of PP: slight (less than 1 person per 1 km^2), moderate (1-10 persons), severe (10-25 persons), very severe (more than 25 persons).

METHODOLOGY OF DESERTIFICATION MAP COMPILATION

The change in environmental features by desertification usually causes changes in the radiation balance. Albedo and spectral reflectance coefficients (SRC) are changed. So, we believe that by great changes in environmental features desertified areas may be identified on aerial and space photos. Some examples are being discussed in the following text.

Warren and Hutchison (1982) studied the correlation between SRC of plants and pastures degradation in one of the New Mexico areas (USA). They identified three degradation stages on optical indicators: 1 decrease of the herbacious species density accompanied by dominants changes 2, increase of ruderal shrubs, and 3. destruction of the vegetative cover and erosion appearance. Space and aerial photos were used in Africa, especially in Sahel (Mensching, 1980). French scientists carried out an interesting study of desertification in Niger where use of space photos allowed preparation of maps of sand dune distribution (Mainguet *et al.*, 1976). The works of the Soviet soil and ecological expeditions in Libya may also be mentioned here (Kharin *et al.*, 1980). A set of thematic maps was prepared in this project (erosion, ecological, pasture and other maps). Areas vulnerable to water and wind erosion and degraded pastures as well were identified.

Some attempts have been now made to develop the computer methodology for preparation of desertification maps. International organizations (FAO and UNEP) prepared, using computerized techniques, maps of desertification in Africa on the scale 1: 25000000. The following maps were prepared: soil constraints, water action, wind action, salinization, animal pressure, and population pressure (FAO/UNEP 1984). Each of these factors was estimated on four classes of desertification: slight, moderate, severe, and very severe.

Remote sensing techniques are also used to study desertification in some countries of Asia. Of great interest are works on preparation of desertification maps in China (Wang 1984). The Institute of Desert Research, Academy of Sciences of China, prepared desertification maps of an area in Inner Mongolia, on the scale 1:50000. According to the terminology used in the USSR these maps may be divided into two groups: maps of desertification status and maps of desertification rates. But these maps have a shortcoming that the criteria used are not quantitative but qualitative.

The following space photos are used in the USSR to study desertification processes; "Meteor" of small (1000-1200m) and medium (500-600) ground resolution (Fig.2) Photos of "Salut", "Soyuz-22" and others with 60-80 m ground resolution are also used. We also apply aerial photos (black-and-white, false colour and colour) of different scales.

We consider the degradation of the vegetative cover caused by undergrazing as a special type of desertification. Many Soviet scientists believe that limited grazing is not only destructive for vegetation but in some cases also stimulates the regeneration of pasture plants. Vast areas in Transunguz Karakum have the dense cover of desert moss (*Tortula desertorum*). Synusium of moss developed by undergrazing prevents the regeneration of higher plants. In some area this synusium covers 50-70% of the ground. Such areas are clearly identified on photos.

Optical indicators of desertification are shown in Fig. 3. The destruction of vegetation causes the changes of SRC and desertified areas are clearly pictured on space photos.

In some cases the status of the vegetative cover may be estimated on space photos directly by photographic tone, colour on texture of the image. First of all, the areas with severe changes are identified. The degraded pastures have higher SRC (till 0.40) than non-changed land (0.30-0.35). Panchromatic photos give the best results to study the vegetation degradation. In particular these photos allow identification of the areas with cut shrubs and traces of fire damage. The destruction of "tugai" forests (forests in river valleys) is better identified by false colour photos.

The land prone to wind erosion is also clearly identified on space photos. The water erosion features in mountains and piedmonts can also be estimated by space and aerial photos in direct or indirect way. These are : surface features, number of gullies and percentage of soil erosion.

Mad-made desertification is confined to the areas of human activity in the desert (construction of canals, roads, and prospecting works etc). Man-made changes in environment are more often identified on space photo by photographic tone and geometric outlines (lineal and quadrangular features).

We have also proposed the analogous criteria to other desertification types mentioned above.

The preparation of the desertification map was carried out in the following sequence :

Fig. 2. The desert lands of Turkmenistan pictured on space photo "Meteor". The Caspian Sea is seen on the left.

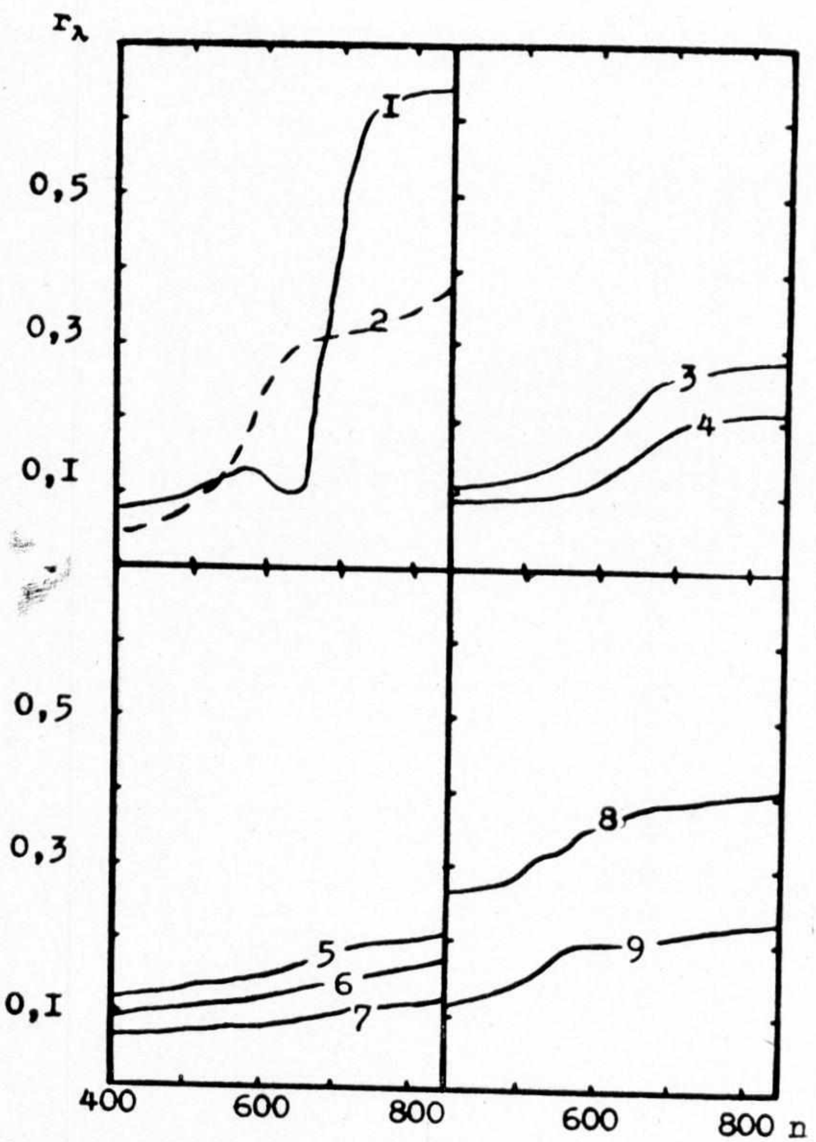

Fig. 3. Optical indicators of desertification. 1—leaves of *A. turcomanicum*; 2—the same leaves from the tree damaged by fire; 3—the surface of s and with herbaceous vegetation destroyed by overgrazing; 4—the surface of sand covered with dense herbaceous vegetation; 5, 6, 7—the surface covered with desert moss (25%, 50% and 90% of coverage); 8—the surface of barkhan; 9—the surface of technogenic sand by the canal construction.

Table 5. Vulnerability of the Turkmen SSR territory to desertification (percentage).

Desertification classes	Desertification types					Improvement of natural conditions				Not vulnerable to desertification	Total
	Degradation of vegetation cover	Wind erosion	Water erosion	Soil salinization	Technogenic desertification	Forest plantations in sand dunes	Protective belts along the railroads	Canal bordering areas	Reserves		
Not vulnerable to desertification						0, 95	1, 36	4, 78	2, 78	25, 28	35, 25
Slight	4, 01	3, 30	3, 33	0, 41							11, 05
Moderate	6, 57	0, 65	1, 61	6, 21	0, 61						15, 65
Servere	0, 63	2, 31	0, 18	1, 94	0, 20						5, 26
Very severe	0, 13	1, 34		2, 40							3, 87
Severe around the desert wells (5 per cent of the total surface)	24, 98										24, 98
Severe around the desert wells (5-10 per cent)	1, 87										1, 87
Water bodies										2, 07	2, 07
Total	38, 19	7, 59	5, 12	10, 97	0, 81	0, 95	1, 36	4, 78	2, 78	27, 45	100

– Literature study on desertification of the desert lands. At this stage we also elaborated the map legend and quantitative critreria of desertification.

– Laboratory interpretation of space photos of the whole territory to be mapped, using photo interpretation keys prepared during earlier investigation. In the process of this work the areas to be checked in the field were selected. Aerial photos covering these areas were prepared.

– Field work for checking the results of laboratory interpretation. The desertification, criteria proporses earlies, were also checked in the field.

– Improvement of the map on the basis and illumination of the desertification map.

Compilation of desertification maps is the first and necessary step in desertification control of arid lands. Investigations of the Desert Institute has shown that 25% of the Turkmen SSR territory are not vulnerable to desertification (Babaeva, 1984). Severe and very severe desertification occurs according to our investigations on 90% of the territory. These areas mainly include lands with degraded vegetative cover, wind erosion and technogenic desertification. 27% of the territory have local desertification - desertification spots around the watering points in the desert. Table 5 gives the information about development of desertification of the Turkmen SSR territory.

CONCLUSIONS

Desertification as a process of arid ecosystems degradation is wide spread in arid regions of the world. In the Turkmen SSR territory desertification processes are confined to comparatively limited areas. The planned socialist economy of our country provides proper control over desertification (Zonn *et al.*, 1981). It may be expected that desertification processes in our country would decline in the near future. Our plans of the development of the economy includes measures on desertification control.

Our study has shown that desertification criteria are not universal. They should be elaborated on the basis of local conditions. The first stage of desertification control should include development of criteria and compilation of desertification maps. Remote sensing techiques allow to speed up this work.

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