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БАЯНДАМАЛАРЫ

ДОКЛАДЫ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН

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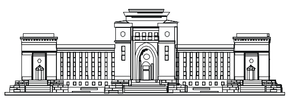

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STUDY AND MAPPING OF DEGRADATION OF THE ARALKUM DESERT

Abstract. Desertification is a land degradation in arid, semi-arid and dry sub-humid areas as a result of various factors, including climate change and human activities. The Aral Sea is called the once large, and now almost dry, salt lake, which today looks like a large salt desert. Its drying is considered one of the greatest environmental disasters of our time, because only 50 years ago it was one of the four largest lakes on our planet. In the 1990s, the western world learned about the environmental disaster of what used to be the fourth largest lake in the world - The Aral Sea. The abrupt drying of the Aral Sea led to the intensive development of desertification processes in the region and the formation of the new man-made Aralkum desert.

The main method for determining the soil degradation of the Aralkum desert is the calculation of indices. The selected methods are widely known and repeatedly applied in world practice methods for processing satellite images. So, all of the listed spectral indices are universal. The uniqueness of this technique lies in the determination of the exact ranges of values for each of the spectral indices in the identification of various indicators of desertification.

Key words: degradation, desertification, satellite images, Landsat-5, NDVI, SI, TCT.

Introduction. In the 1990s, the western world learned about the environmental disaster that occurred at the fourth largest lake in the world – the Aral Sea. The decline of the Aral Sea was called one of the worst environmental disasters of the 20th century and called “quiet Chernobyl [1]. The sharp drying of the Aral Sea led to the intensification of desertification processes in the region and the development of the new Aralkum desert on the dried up seabed. Over the past few decades, the open bottom has become a new “hot spot” of dust and salt storms in the region. The arid lands of South Kazakhstan, Uzbekistan and Turkmenistan have always been exposed to dangerous dust storms. However, in the last thirty years of the 20th century, dust storms have shown a significant downward trend throughout the region [2].

In the arid regions of Central Asia, dust storms are observed with frequencies that are among the highest in the world [3]. The emergence of an additional vast territory subject to wind erosion, namely the anthropogenic created Aralkum desert, inevitably led to the activation of dust emission processes [4].

The water level in the Aral Sea started drastically decreasing from the 1960s onward. The reduction in the volume and area of the sea has led to significant changes in the hydrological, chemical and natural biological structure of the water [5]. The Aral sedimentary basin with an area of 70 thousand km^2 occupies the north-western outskirts of the TuranPlate [6]. The Aral sedimentary basin extends from the Mugodzhar mountains in the north to Sultanuizdag in the south for more than 440 km. Its width from the Aral-Kyzylkum shaft in the west to the Akkyrsko-Kumkalinsky shaft in the east is about 210 km [7]. The engineering and geological conditions of logistic center territories of Aralsk and Turkistan citie’s determined by the development of loose rocks. They related with the manifistations of numerous hazardous geological processes like salinization, swamping, deflation, linear erosion, slope wash, the phenomenon of subsidence, etc. Their development conditions significantly depend on anthropogenic factor.Sand massifs are affected by active deflation processes and with the development of the territory can cover large areas [8].

Purpose of the research. The Aral Sea is a terminal salt lake in Central Asia, on the border of Kazakhstan and Uzbekistan. Since the 1960s of XX century, sea level has been rapidly dropping due to water abstraction from the main supply rivers: Amudarya and Syrdarya. Before the shallowing, the Aral Sea was the fourth largest lake in the world. Over-abstraction of water for irrigation of agricultural land has turned the fourth largest lake-sea in the world, formerly rich in life, into a barren desert [9]. Water is a tremendous value, a national treasure. The decision of all the most actual ecological and hydrogeoecological problems depends on the state of water resources [10].

Drying of the Aral Sea led to two different types of desertification. Recently dried seabed and artificial cutting of irrigated lands. As a result, a new Aralkum desert appeared in the center of the great deserts. The sandy-salt waste lies on the territory of Uzbekistan and Kazakhstan, on the northwestern extremity of the Karakum and Kyzylkum deserts. Aralkum covers an area of more than 38 thousand km² and is a powerful source of wind loss (figure 1) [11].

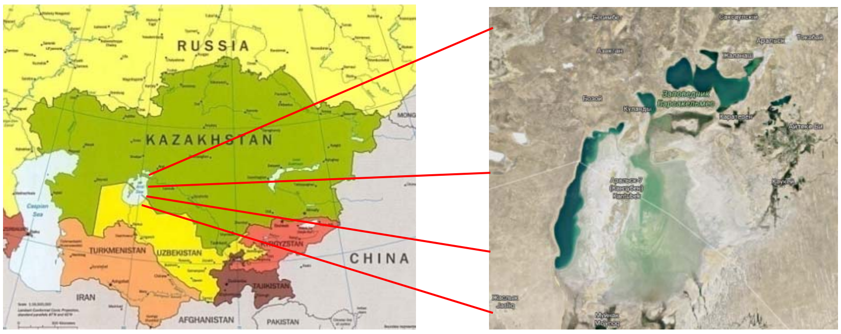

Figure 1 – Studyarea- Aralkum desert

The Aral Sea and the Aralkum are located within the Asiatic desert belt [12]. The climate of the surroundings of Aralkumis characterized by very cold winters and very hot summers. It is assumed that the effects of the drying of the Aral Sea were associated with climatic conditions. Current climate data show only a slight shift towards a more emphasized continentality [13]. Meteorological data show that in the Middle East region, annual rainfall has increased over the past 50 years [14]. This is due to all parts of the Turan Plain, as well as to high mountains on the outskirts [15]. Directly at the remnants of the Aral Sea, and at the Aralkum, at the stations on the former islands (Barsa-Kelmes, Lazarev, Vozrozhdeniya, Tigrovni) this trend cannot be traced significantly. However, those stations mostly have been closed since the middle or the end of the 1980s.Thus, only the last 15 or 20 years of observations would have been especially worthwhile. Only the Aral station clearly indicates an increase in precipitation within the 1950s, but within the last 40 years the mean precipitation seems to be stable [16].

Materials and methods. Currently, the quantitative characteristics of models of temporary and spatial plants with remote sensing data are of great interest for the study of Earth sciences and global changes. Spectral models and indicators are being developed to increase sensitivity to plants, taking into account the effects of the atmosphere and soil.

In the table below (table 1), a list of desertification indicators is given and the possibility of determining these indicators using remote sensing data is noted.

Table 1 – Spectral Indices

№	Desertification Indicators	Spectral Indices
1	Vegetation cover	NDVI
2	Soilsalinization	SI
3	Water	TCT

The Normalized Difference Vegetation Index (NDVI) is one of the most widely used plant indexes, and its usefulness for satellite-based assessment and monitoring of global vegetation has been well demonstrated over the past two decades [17].

IEEE Transactions on Geoscience and Remote Sensing, 32, 897−905.

Normalized Vegetation Index NDVI is a standardized index showing the presence and condition of vegetation (relative biomass). This index uses the contrast of the characteristics of two channels from a set of multispectral raster data – the absorption of chlorophyll by the pigment in the red channel and the high reflectivity of plant materials in the infrared channel (NIR).

NDVI isoften used around the world to monitor drought, monitor and forecast agricultural production, assist in forecasting fire hazard zones, and desert attack maps. NDVI is preferred for global monitoring of vegetation, as it helps to compensate for changes in lighting conditions, surface slope, exposure and other external factors. NDVI indices range from -1.0 to 1.0, where higher values relate to green vegetation and tiny ones relate to other widespread surface resources. Naked soil is indicated by NDVI values that are in contact with 0, and water bodies are characterized by negative NDVI values [18].

Different reflection in the red and infrared (IR) channels allows you to control the density and growth rate of green vegetation using the spectral reflection of solar radiation. Green leaves usually show better reflection in the near infrared wavelength range than in visible wavelength ranges. If the leaves are suppressed by water, fading or dead, they become more yellow and reflect much less in the near infrared range. Clouds, water and snow give a better reflection in the visible range than in the near infrared range, while the difference is almost zero for rocks and bare soil. NDVI processing creates a single-channel dataset that basically represents greenery. Negative values represent clouds, water and snow, and values close to zero represent rocks and bare soil.

The default documented NDVI equation:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{Red})}{(\mathrm{NIR}+\mathrm{Red})} \qquad (1),$$

where, NIR is reflection in the near infrared region of the spectrum, RED is reflection in the red region of the spectrum. The main research method was the analysis of the normalized relative vegetation index (NDVI – Normalized Difference Vegetation Index), which was first described by B.J. Rouse in 1973 [19].

NDVI provides accessible constructive information for distinguishing and interpreting vegetation cover that is widely used in remote sensing studies [20].

Salinization of the soil is the process of enriching the soil with soluble salts, which leads to obtaining information about the soil exposed to salt. Soil salinization in irrigated areas is becoming a serious problem for agriculture. Saline soil conditions have reduced the value and productivity of large areas of land around the world [21].Salinity usually occurs in irrigated soils due to the accumulation of soluble salts as a result of continuous use of irrigation water containing large or medium amounts of dissolved salts [22]. The main problems associated with arid and semi-arid areas are salinization and desertification. Soil salinization is the main form of land degradation in agricultural areas where information is needed on the degree and magnitude of soil salinity for better planning and implementation of effective soil reclamation programs.Irrigational evaporation of moisture from the surface or shallow depths within the profile and insufficient annual precipitation to leach salts from the rooting zone of plants contribute to the excessive accumulation of soluble salts in soils of arid and semi-arid regions, which makes such lands with minimal success [23].

Estimation of soil salinity can be applied using digital indices extracted from satellite images with different spectral bands [24]. The digital elevation model (DEM) can also be used to predict soil salinization based on the variographic morphology of the earth's surface in order to increase the accuracy of its prediction [25]. The rapid spread of salinization of the soil mainly depends on altitude, because the terrain controls the rate of salt transfer through different layers of soil [26].

It has been proven that remote sensing has advantages in predicting soil salinity. Meanwhile, the spatial distribution of soil salinity is apparently associated with one or more variables at the same time, depending on the characteristics of the study area [27]. Researchers have developed many approaches to studying and predicting soil salinity with multiple variables using statistical analysis [28].

Sixteen different spectral salinity indices developed in numerous studies related to salt detection and soil salinity mapping were studied for all Landsat images and seven salinity indices were most commonly used (NDSI, SI 1, SI 2, SI 4, SI 9, SI 10 , SI 14) taken into account in this study are given in table 2 [29].

Table 2 – The most common salinity indicators (A. Azabdaftari a, F. Sunarb, 2016)

Salinity indices	Equation	Reference
Normalized Differential Salinity Index	$NDSI=\frac{(R-NIR)}{(R+NIR)}$	(Khan, Rastoskuev et al. 2001)
Salinity Index 1	$SI1=\sqrt{B \times R}$	(Khan, Rastoskuev et al. 2001)
Salinity Index 2	$SI2=\sqrt{G \times R}$	(Douaoui, 2006)
Salinity Index 4	$SI4=\sqrt{G^2 + R^2}$	(Douaoui, 2006)
Salinity Index 9	$SI9=\frac{(B_5 \times B_6\ B_6 \times B_6}{B_5}$	(Bannari, Guedon et al. 2008)
Salinity Index 10	$SI10=\frac{B}{R}$	(Abbas, 2007)
Salinity Index 14	$SI14=\frac{R \times NIR}{G}$	(Abbas, 2007)

We have used the formula from the indices that determine the salinization of the soil, as follows:

$$SI2= \sqrt{Green \times Red} \quad (2)$$

Various analyzes, including remote sensing and spatial modeling using GIS, a regression model, and method validation, were used to determine the feasibility of remote sensing and a geographic information system for mapping salinity of the soil directly from the soil and indirectly from the vegetation.

Tasseled Cap Transformation (TCT) is calculated using the formula (table 3).

Table 3 – Tasseled Cap Transformation (TCT) calculation formula (Healey S.P., et al, 2005)

Tasseled CapTransformation	Formula
Brightness	0.3037 × (b1) + 0.2793 × (b2) + 0.4743 × (b3) + 0.5585 × (b4) + 0.5082 × (b5) + 0.1863 × (b7)
Green	0.2848 × (b1) – 0.2435× (b2) – 0.5436 × (b3) + 0.7243 × (b4) + 0.0840 × (b5) – 0.1800 × (b7)
Humidity	0.1509 × (b1) + 0.1973 × (b2) + 0.3279 × (b3) + 0.3406 × (b4) – 0.7112 × (b5) – 0.4572 × (b7)

TCT coefficients are used in the widest range of problems solved using Earth remote sensing data: from recognition of the coastline of water bodies to determination of forest disturbances [30]. This technique uses the Brightness coefficient TCT.

Results and Discussion. The selected methods are widely known and repeatedly applied in world practice methods for processing satellite images. So, all the listed spectral indices are universal, however, they are relative. The uniqueness of this technique lies in the determination of the exact ranges of values for each of the spectral indices in the identification of various indicators of desertification. This refinement was made possible thanks to field survey data. However, ground-based data were taken for one field season, therefore, the inclusion of more scientists in the calculation of ground-based survey data will allow us to more accurately determine the ranges of index values for each of the desertification indicators.

Landsat TM data for 2000 and 2008 years were taken for this work (table 4). The image has seven bands with a resolution of 30 m pixels. Image analysis was performed using ArcGIS 10.3.

Table 4 – Space imagery selection

Image type	Shooting date
Landsdat TM5	09.16.2000; 09.16.2000; 09.07.2000; 09.07.2000
Landsdat TM5	07.11.2008; 07.11.2008; 07.27.2008; 07.27.2008

Since all the data received from the satellite is nothing more than multispectral images, to obtain the information contained in them, it is necessary to interpret the data obtained and reveal their physical meaning.

The stage of Earth remote sensing data analysis, the main task of which is the recognition and identification of objects detected in the image, is called image decryption.

For Landsat-5 images, in accordance with the process of soil degradation, salinization, and desertification, the interpretation of these channel combinations was chosen, i.e., the color combination

7.5.3. This combination gives an image close to natural colors, but at the same time allows you to analyze the state of the atmosphere and smoke. Healthy vegetation looks bright green, grassy communities look green, bright pink areas detect open soil, brown and orange tones are typical for sparse vegetation. Dead standing vegetation looks orange, water - blue. Sand, soil and minerals can be represented by a very large number of colors and shades. This combination gives an excellent result in the analysis of deserts and desertified territories (figures 2, 3) [31].

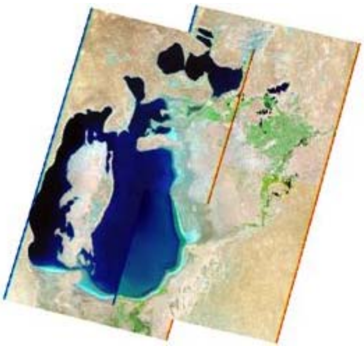

Figure 2 – Satellite image based on a combination of 7.5.3 colors in the Study area, 2000

Figure 3 – Satellite image based on a combination of 7.5.3 colors in the Study area, 2008

For Landsat-5 images, the normalized differential vegetation index (NDVI) was calculated as follows:

$$\mathrm{NDVI} = \frac{(\mathrm{band4}-\mathrm{band3})}{(\mathrm{band4}+\mathrm{band3})}. \quad (3)$$

Also, the SI formula (salinity index) for Landsat-5 images:

$$\mathrm{SI2} = \sqrt{\mathrm{band2} \times \mathrm{band3}} \quad (4)$$

The change in sea water was calculated by the formula TCT (Tasseled Cap Transformation):

$$\mathrm{TCT} = 0{,}304 \times (b1) + 0{,}279 \times (b2) + 0{,}474 \times (b3) + 0{,}559 \times (b4) + 0{,}508 \times (b5) + 0{,}186 \times (b7), \quad (5)$$

where, b1, b2, b3, b4, b5, b7 are the corresponding Landsat channels.

As a result, the Soil Degradation maps for 2000 and 2008were compiled (1:2500 000) (figures 4, 5).

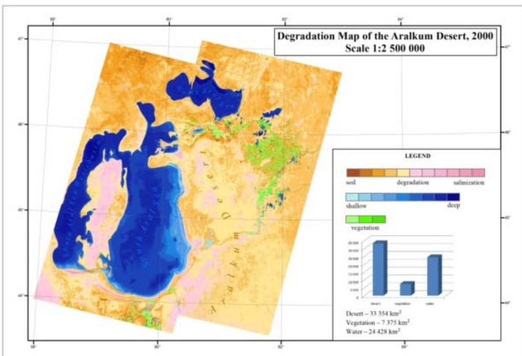

Figure 4 – Soil Degradation Map of the Aralkum Desert, 2000

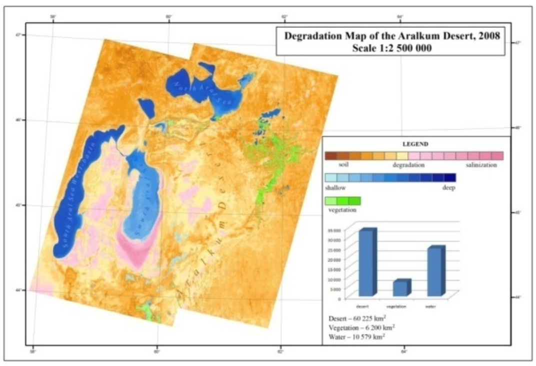

Figure 5 – Soil Degradation Map of the Aralkum Desert, 2008

The results of the calculation of the two-year index are presented in the following table. As a result, the desertification process in 2008 increased by 26,871km^{2}desert area compared to 2000, the bottom area was 13 849km^2, and the vegetation cover was reduced to 1175 km^2. As a result, the drying of the Aral Sea, the Aralkum desert increased, and the soil degraded significantly (table 5). The quantitative indicator for 2000 and 2008 obtained from the results of calculating the index is shown in diagram (figures 6, 7).

Table 5 – Dynamics of changes in objects of the Aral Sea and its region in 2000 and 2008

Calculated objects	Area	
	2000 year	2008 year
Desert	33 354km^2	60 225km^2
Vegetation	7 375km^2	6 200km^2
Water	24 428km^2	10 579 km^2

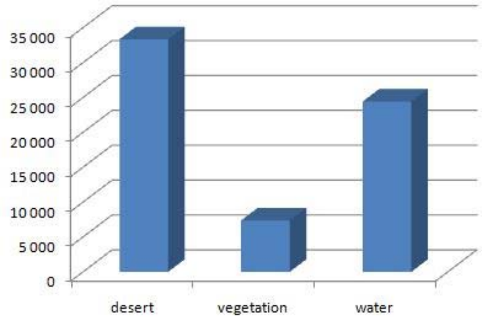

Figure 6 – Calculatedindexes, 2000.

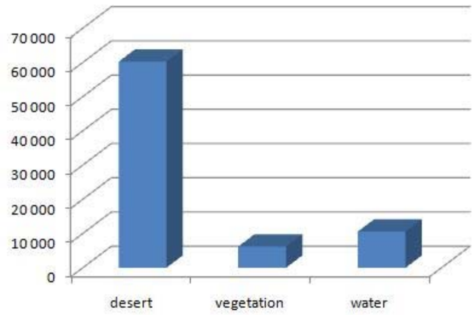

Figure 7 – Calculated indexes, 2008.

Conclusion. Desertification, a phenomenon related to land degradation in arid, semi-arid and arid sub-humid regions as a result of climate change and human activities, is considered one of the most serious environmental and socio-economic problems of our time. The study of its dynamics should be accompanied by a full-scale comprehensive study and ground-based route observation data. However, the observation of the underlying surface, that is, vegetation and open soil cover, as one of the main components of this complex process, is to some extent possible when using Earth remote sensing data.

This study performed several tasks related to desertification degradation. The main objectives are to increase the area of the Aralkum desert due to changes in the volume of the Aral Sea from year to year and determine the reduction of vegetation cover. Based on two-year satellite images, it is clear that the distribution of vegetation in the Aralkum desert is relatively small.For example, in 2008, the area of vegetation was reduced to 1175 км^2 compared with estimates of 2000. The area of sea water decreased by 13 849 км^2 compared with 2000. The current state of the youngest desert in the world of Aralkum is in the worst condition. Due to quantitative indicators of the process, salinization of the Aralkum desert makes it clear that the area of deserts is increasing. This is due to the fact that in 2000 the desert area was 33 354 км^2, and in 2008 60 225 км^2, that is, it increased to 26871 км^2. Due to the drying of sea water, some areas have degraded, and the risk of salinization is increasing. As a result of the research, the distribution of vegetation cover, the risk of degradation and the dynamics of the development of sea water were determined. And also the dynamics of changes in the objects of research is shown in the diagram and compiled, and maps of the degradation of desertification of the Aralkum in 2000 and 2008, at a scale of 1:2 500 000.

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АРАЛҚҰМ ШӨЛІНІҢ ДЕГРАДАЦИЯСЫН ЗЕРТТЕУ ЖӘНЕ КАРТОГРАФИЯЛАУ

Аннотация. Шөлейттену – әртүрлі факторлардың, соның ішінде климаттың өзгеруі мен адамның іс-әрекеті нәтижесінде құрғақ, шөлейт және құрғақ субгумидті жерлердегі алқаптардың деградациясы. Бұл жағдайда «жер» термині топырақтан, судан, өсімдіктерден, басқа да биомассадан тұратын биопродуктивті жүйені, сондай-ақ жүйенің ішіндегі экологиялық және гидрологиялық процестерді білдіреді. Жердің

деградациясы – жерді пайдалану нәтижесінде егістік жерлердің немесе жайылымдардың биологиялық және экономикалық өнімділігінің төмендеуі немесе жоғалуы. Ол аз мөлшерде жермен, өсімдіктердің батпақтануымен, топырақ біртектілігінің төмендеуімен сипатталады, нәтижесінде жылдам жел эрозиясы болуы мүмкін.

Арал теңізі – бір кездері ең ірі көл деп аталса, қазір тартылған, тұзды көл, ол бүгінде үлкен тұзды шөлге ұқсайды. Оның тартылуы біздің заманымыздағы орасан күрделі экологиялық апаттардың бірі болып саналады, өйткені осыдан 50 жыл бұрын ол біздің планетамыздағы ең ірі төрт көлдің бірі болған. 1990 жылдары батыс әлемі экологиялық апат туралы әлемдегі төртінші ірі көл – Арал теңізі туралы білді. Арал теңізінің күрт тартылуы аймақта шөлейттену процестерінің қарқынды дамуына және жаңа антропогендік Аралқұм шөлінің пайда болуына әкелді.

Шөлейттену процестерін және жердің деградация процестерін анықтау мониторингінің нағыз тәсіліне мыналар жатады: қашықтықтан зондтау деректеріне негізделген бақылау байқауының орындылығын айқындайтын табиғи объектілердің, шөлейттену процестерінің немесе құбылыстарының (индикаторларының) тізбесі; осы ескертулерді жүргізу кезеңдері мен мерзімдері; жүйелі түрде және көпжылдық негізде еркін таратылатын ғарыштық көріністердің түрлері, оларға бақылау жүргізу ұсынылады; бақылаудың негізгі кезеңдері, әрбір байқалған индикатор бойынша шығыс нәтижелерінің геоақпараттық нысаны және өзгерістер динамикасын бағалау.

Аралқұм шөлінің деградациясын анықтайтын негізгі әдіс – индекстерді есептеу. Таңдалған әдістер кең түрде танымал және әлемдік тәжірибеде бірнеше рет спутниктік суреттерді өңдеуде қолданылады. Сонымен, аталған барлық спектрлік көрсеткіштер әмбебап болып келеді. Бұл әдістің бірегейлігі шөлейттенудің әртүрлі көрсеткіштерін анықтауда спектрлік көрсеткіштердің әрқайсысы үшін нақты мәндер ауқымын анықтауда жатыр. Аралқұм шөлінің шөлейттенуі мен деградациялануының ғарыштық мониторинг әдістемесіндегі орындалған шешуші қадамдар: спутниктік суретке тапсырыс беру, оларды алдын ала өңдеу; спектрлік көрсеткіштерді есептеу; визуалды бажайлау; индекс мәндерінің қажетті диапазонын бөлу; шөлдену процесінің индекстік мәндері негізінде карта құрастыру; жердегі мәліметтерді пайдаланып, карталарды тексеру; алынған нәтижелерді талдау.

Түйін сөздер: деградация, шөлдену, ғарыштық суреттер, Landsat-5, NDVI,SI, TCT.

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КАРТОГРАФИРОВАНИЕ И ИССЛЕДОВАНИЕ ДЕГРАДАЦИИ ПУСТЫНИ АРАЛКУМ

Аннотация. Опустынивание – деградация земель в засушливых, полузасушливых и сухих субгумидных районах в результате действия различных факторов, включая изменение климата и деятельность человека. Понятие «земля» в данном случае означает биопродуктивную систему, состоящую из почвы, воды, растительности, прочей биомассы, а также экологические и гидрологические процессы внутри системы. Деградация земель – снижение или потеря биологической и экономической продуктивности пахотных земель или пастбищ в результате землепользования. Характеризуется маленьким количеством земли, увяданием растительности, снижением связанности почвы, в результате чего становится возможной быстрая ветровая эрозия.

Аральским морем называют некогда большое, а сейчас практически высохшее, соленое озеро, которое сегодня выглядит как большая соляная пустыня. Его пересыхание считается одной из самых катастрофических экологических проблем современности, хотя 50 лет назад оно входило в четверку самых больших озер нашей планеты. В 1990-х годах западный мир узнал об экологической катастрофе того, что когда-то было четвертым по величине озером в мире - Аральским морем. Резкое высыхание Аральского моря привело к интенсивному развитию процессов опустынивания в регионе и формированию новой антропогенной пустыни Аралкум.

Реальным способом мониторинга процессов опустынивания и процессов деградации земель является перечень природных объектов, процессов или явлений опустынивания (индикаторов), которые определяют осуществимость контрольных наблюдений на основе данных дистанционного зондирования; сроки и сроки этих замечаний; типы космических снимков, которые распространяются свободно на регулярной и долгосрочной основе, рекомендуется их мониторинг; основные этапы контроля, геоинформационная форма результатов расходов по каждому наблюдаемому показателю и динамика изменений.

Основным методом определения деградации пустыни Аралкум является расчет индексов. Выбранные методы являются широко известными и неоднократно примененными в мировой практике обработки космических снимков. Так, все перечисленные спектральные индексы являются универсальными. Уникальность же данной методики состоит в определении точных диапазонов значений по каждому из спектральных индексов при идентификации различных индикаторов опустынивания. Выполнены ключевые этапы методики космического мониторинга процессов опустынивания и деградации пустыни Аралкума: заказ космических снимков, их предварительная обработка; расчет спектральных индексов; визуальное дешифрирование; выделение необходимых диапазонов значений индексов; 1составление на основе значений индексов карт процессов опустынивания; верификация карт по наземным данным; анализ полученных результатов.

Ключевые слова: деградация, опустынивание, космические снимки, Landsat-5, NDVI,SI, TCT.

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