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GLOBAL PLANNING STRATEGY FOR THE RESTORATION OF DEGRADED AND DESERTIFIED ECOSYSTEMS

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Abstract

The aim of the research was to reveal the current global progress and landmark results in the field of preventing the negative effects of desertification and degradation. The research objectives included: obtaining materials from public access data from various search engines (Web of Science Core Collections, Scopus) and their classification, describing the results and summarizing the main successes and significant achievements. **Materials and methods.** A polysystem methodological approach was used to search and synthesize information. The study is based on a structured review of modern world scientific research, from which it is possible to highlight knowledge about the current development of global trends in the field of driving factors of desertification and degradation, as well as ways and methods of their prevention. **Results and conclusions.** There are four main research areas: 1) the main driving forces of desertification and degradation; 2) remote sensing of the Earth from space and digitalization of desertification monitoring; 3) the role of biotechnologies in eliminating and preventing degradation and desertification processes; 4) global, regional and national programs in the field of solving climate problems, restoring and preserving biodiversity. The driving mechanism of desertification under the complex influence of an extremely dry climate and intensive human activity is considered based on the analysis of modern data. Much attention was paid to regions where there is rapid population growth, which relies mainly on natural resources as a source of livelihood. A global strategy for planning the restoration of degraded and desolate lands in arid, subarid and dry subhumid regions is presented. The modern nature and mechanism of desertification risk management to increase the stability of disturbed ecosystems are shown.

Keywords*: land degradation, desertification risks, remote sensing of territories, strategy to combat desertification.*

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ГЛОБАЛЬНАЯ СТРАТЕГИЯ ПЛАНИРОВАНИЯ ВОССТАНОВЛЕНИЯ ДЕГРАДИРОВАННЫХ И ОПУСТЫНЕННЫХ ЭКОСИСТЕМ

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Работа проводилась в рамках реализации проекта общегосударственного значения № 123072100084-4 «Расширение системы климатического и экологического мониторинга и прогнозирования на территории Российской Федерации в целях обеспечения адаптационных решений в отраслевом и региональном разрезах, включая борьбу с опустыниванием»

Целью исследований являлось раскрытие текущего мирового прогресса и знаковых результатов в области предотвращения негативных последствий опустынивания и деградации. В задачи исследований входило: получение материалов из данных общего доступа различных поисковых систем и их классификация, описание результатов и обобщение основных успехов и знаковых достижений. **Материалы и методы**. Для поиска и синтеза информации был использован полисистемный методологический подход. Исследование основано на структурированном обзоре современных мировых научных исследований, из которых можно выделить знания о текущем развитии мировых тенденций в области движущих факторов опустынивания и деградации, а также способов и методов их предотвращения. **Результаты и выводы.** Выделено четыре основных исследовательских направления: 1) основные движущие силы опустынивания и деградации; 2) дистанционное зондирование Земли из космоса и цифровизация мониторинга опустынивания; 3) роль биотехнологий в ликвидации и предотвращении процессов деградации и опустынивания; 4) глобальные, региональные и национальные программы в сфере решения климатических проблем, восстановления и сохранения биоразнообразия. Рассмотрен движущий механизм опустынивания под комплексным влиянием экстремально сухого климата и интенсивной деятельности человека на основе анализа современных данных. Большое внимание уделялось регионам, где отмечается быстрый рост населения, которое в качестве источника средств к существованию полагается в основном на природные ресурсы. Представлена мировая стратегия планирования восстановления деградированных и опустыненных земель в аридных, субаридных и сухих субгумидных регионах. Показан современный характер и механизм управления рисками опустынивания для повышения стабильности нарушенных экосистем.

Ключевые слова: *деградация земель, риски опустынивания земель, дистанционное зондирование территорий, стратегия борьбы с опустыниванием.*

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Авторский вклад. Все авторы настоящего исследования принимали непосредственное участие в планировании, выполнении или анализе данного исследования. Все авторы настоящей статьи ознакомились и одобрили представленный окончательный вариант.
Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Introduction. Land degradation on a global scale is an indicator of the state of land calculated by integrating three sub–indicators (trends in soil cover, carbon stocks and land productivity), in which a negative change in any of them is interpreted as degradation. Land degradation can be defined as the depletion of an ecosystem, a decrease in its ability to fulfill its natural role, and the loss of land resilience to climate change and land use. The causes and consequences of degradation often occur simultaneously, suppressing or aggravating each other [1]. The level of such interactions depends on the dominant climatic, geological, topographic systems and management [2]. Improper management of land resources is one of the consequences of degradation [3, 4].

The concepts of "degradation" and "desertification" are closely interrelated. The process of interaction between land degradation and aridization, including droughts, and manifesting itself as an acute environmental problem, is characterized as desertification. In other words, desertification refers to degradation in arid, subarid and dry subhumid regions, which account for 47% of the world's land. Desertification is the result of interactions between biological, physical, social, political, cultural and economic factors.

About 33% of the total land area of the Earth (> 4,900 million hectares) is subject to degradation and desertification, which makes these territories extremely vulnerable to overexploitation and improper land use [5, 6, 7]. Currently, the processes of degradation and desertification threaten the balance of ecosystems and the livelihoods of 38% of the world's population in arid, subarid and dry subhumid regions of the world. The scale of anthropogenic changes makes ecosystem restoration an integral part of humanity's survival strategy. People in the affected areas prefer to migrate to better places. The economic development of these regions is ultimately also under threat [8].

It is difficult to find a single explanation for the causes of desertification due to the breadth, complexity and dynamism of this process. The soil and vegetation complex and climate of different regions have different natural conditions and an unequal contribution to the desertification process. It is often difficult to determine the vulnerability of ecosystems to the risk of desertification and to uncover the driving forces of the evolution of this process.

The problems associated with the ecological systems of drylands are as follows, Figure 1.

The stability of ecosystems is determined by their ability to reorganize and restore their fundamental structure and functioning processes under the influence of stressful factors (drought, fire, overgrazing) [10]. A prerequisite for understanding the stability of the environment and related factors is the monitoring and analysis of the state of ecosystems, which is important for effective management, the introduction of rational farming methods and the promotion of the conservation of soil and plant resources. Incorrect indicators can lead to ineffective management decision-making methods. To accurately assess the quality of the environment, it is necessary to analyze factors that have significant characteristics and can be combined [11].

The relevance of research lies in the need to identify areas at risk of desertification and degradation in order to restore them and prevent the emergence of new foci, improve socio-economic indicators, reduce losses and environmental damage, and strengthen food security.

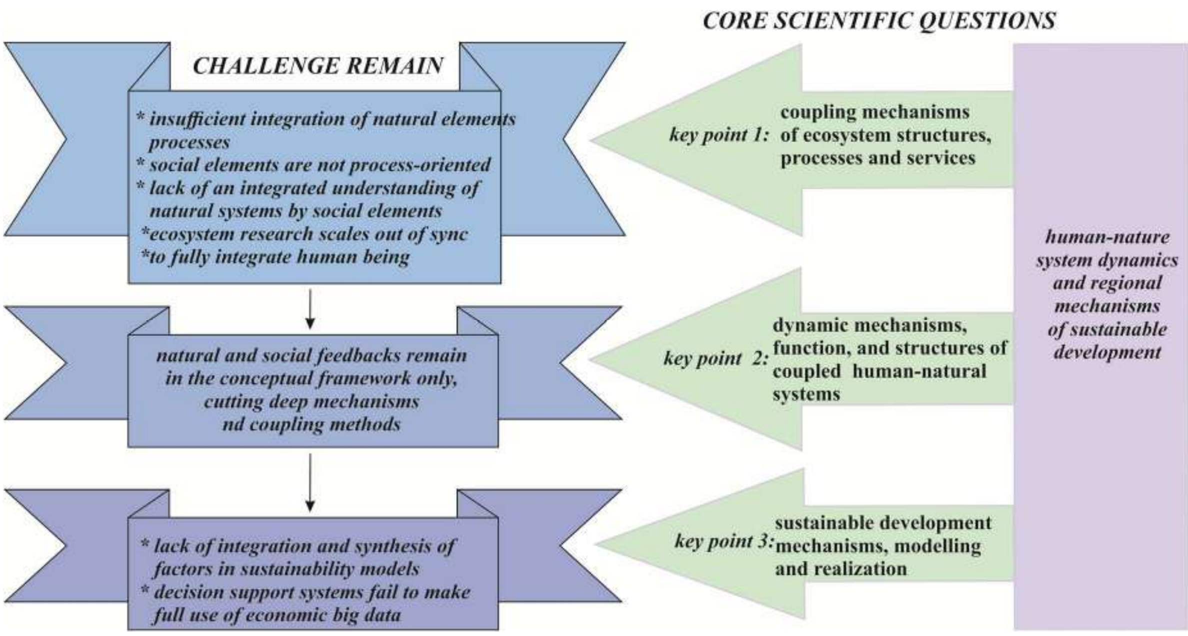

Figure 1 – Key scientific issues and challenges for drylands [9]

1. Research methods. The purpose of the research was to identify the current global progress and landmark results in the field of preventing the negative effects of desertification and degradation.

The research objectives included: obtaining materials from public access data from various search engines (Web of Science Core Collections, Scopus) and their classification, describing the results and summarizing the main successes and significant achievements. The criteria for the selection of literature included: keywords, years of research, regions of research, etc., Table 1. Although there has been a very large amount of research on this issue, we have selected the necessary minimum to try to uncover this problem in terms of several key issues. 112 publications were reviewed. The analysis was carried out based on the data of articles and monographs published from 2000 to the present. Much attention was paid to regions where there is rapid population growth, which relies mainly on natural resources as a source of livelihood.

Table 1 – Criteria for selecting information sources for problem analysis

Indicators	Information
1. Years of research:	2000-2023
2. Keywords:	Degradation, desertification risk, climate, anthropogenic factor, remote sensing, desertification control strategy, loss of biodiversity, adaptation to climate change, overexploitation of pastures.
3. Research regions:	Arid, subarid and dry subhumid regions of the world, whose lands are subject to degradation and desertification processes.
4. The focus of the reviews:	Ecology, agriculture, adaptive land use, agroforestry, planning, management.
5. Justification of the choice to include data from the information source:	The processes of analysis and synthesis (evaluation of the main results obtained taking into account the review and comparison with other studies), focus and target audience.
6. Information on the number of documents that have been assessed for compliance with the criteria and included in the review, indicating their source:	112 papers, including those published in the periodical press Web of Science Core Collections and Scopus: Agriculture – 1, Agronomy – 2, Am. Meteorol. Soc. – 1, Arid Ecosystems – 8, Arid Environments – 1, Adaptive feed production – 1, Atmosphere – 1, Case Studies in Chemical and Environmental Engineering – 2, Catena – 2, Climate Change – 1, Climate Services – 1, Cham. – 1, Comptes Rendus Biologies – 1, Conserv Biol. – 1, Current Science – 1, Earth Syst. Environ. – 1, Earth System Governance – 4, Ecol. Indic. – 1, Environ Monit Assess. – 2, Environ. Impact Assess. – 1, Environmental Politics – 1, Environmental Research Letters – 1, Exploration of the Earth from space – 1, Euphytica – 1, Global Environmental Change – 1, Geoderma Reg. – 1, Geology, Geography and global energy – 1, Geographical environment and living systems – 1, Geographical Bulletin – 1, Journal of Resources and Ecology – 1, The Journal of Environment & Development – 1, J Adv Nurs. – 1, Int. J. Appl. Earth Obs. Geoinf. – 1, IOP Conference Series: Earth and Environmental Science – 1, Land – 5, Land Degrad. Dev. – 2, Natural Hazards – 1, Nat Ecol Evol. – 1, Nigeria journal of education, healthand technology research (njehetr) – 1, New Forests – 1, Nature Journal of Cleaner Production – 1, Nature communications – 1, Plants – 2, Proceedings of the Nizhnevolzhsky Agrouniversity complex: Science and higher professional education 1, Reg. Res. Russ. – 1, Rend. Fis. Acc. Lincei. – 1, Remote Sensing – 7, Remote Sensing of Environment – 1, Renewable and Sustainable Energy Reviews – 1, Research on Crops – 1, Sci. Total Environ. – 1, Sensors – 1, Sustainability – 8, Scientific African – 2, Science of The Total Environment – 3, Water Polic – 1, Fundamental and applied climatology – 1; as well as 19 monographs or chapters from monographs.

A polysystem methodological approach was used to search and synthesize information. The study is based on a structured review of modern world scientific research, from which it is possible to highlight knowledge about the current development of global trends in the field of driving factors of desertification and degradation, as well as ways and methods of their prevention. The research method is based on a scientific understanding of methods for managing the potential of degraded and desolate territories from various points of view. The method is transparent, comprehensive, and independent and is confirmed by use in the fields of various sciences [12].

The materials presented do not cover all aspects of the issue under study, as the information on it is too extensive. Only the most relevant topics were considered. There are four main research areas: 1) the main driving forces of desertification and degradation; 2) remote sensing of the Earth from space and digitalization of desertification monitoring; 3) the role of biotechnologies in eliminating and preventing degradation and desertification processes; 4) global, regional and national programs in the field of solving climate problems, restoring and preserving biodiversity.

2. Results and discussions. *2.1 The main drivers of desertification and degradation.*

The processes of degradation and desertification are nonlinear processes influenced by many factors [13, 14]. The main driving forces of desertification and degradation are climate change (temperature rise, low rainfall, wind conditions) and anthropogenic pressure (intensification of agriculture, expansion of arable land, deforestation, growth of livestock and overgrazing) [15, 16, 17, 18, 19]. Soil pollution, salinization, and loss of biodiversity are facilitated by the use of inorganic fertilizers, pesticides, and irrigation systems [20]. Areas with higher elevation and higher terrain slope have a higher risk of desertification [21].

Population growth, irrational extraction of natural resources and minerals, and urbanization also has a great impact on the expansion of degraded lands [22]. Demographic pressure accelerates the processes of fertility depletion, erosion, acidification, salinization and soil compaction. The increase in resource consumption due to the overpopulation of the planet leads to their depletion, especially where there is excessive reliance on these resources. According to experts, the world's population will reach 9.7 billion by 2050, and 10.9 billion by 2100 [23]. Most of the projected growth will come from poor countries whose populations depend on natural sources for their livelihood. 25% of the world's population growth will be concentrated in Central and South Asia, 25% in sub-Saharan Africa and Southeast Asia. This will significantly affect the expansion of degraded and desolate lands [24].

The climate factor is one of the primary problems in the prevention of degradation and desertification. Over time, in many parts of the world, the winter season is getting colder and the summer season is getting hotter [25]. The average air temperature on the Earth's surface has increased by about 1°C since 1900 by 2023. By 2100, air temperatures in the Mediterranean region are expected to rise by 1.20-7.07°C, in the Caribbean – by 0.94-4.18°C, in the Indian Ocean – by 1.05-3.77°C, in the North Pacific – by 1.00-4.17°C [26]. Droughts, as one of the manifestations of climate change, affect vast territories and are one of the most serious natural disasters, cause socio-economic losses and environmental damage, pose a threat to agriculture and food security around the world, and affect rising food prices [22, 24]. In Europe, the largest increase in drought losses (up to 10%) due to a reduction in regional agricultural production is observed in the southern and western parts, and the total annual losses from drought amount to 9 billion euros per year [13]. In China, where this problem has become nationwide, economic losses from drought in a dynamic scenario can reach 86.84 ± 38.06 billion US dollars [14]. Damage to terrestrial arid ecosystems has far-reaching consequences.

Droughts are subject to global climatic patterns, but are conditioned by regional climatic conditions [27, 28]. Recently, the global climate environment has become drier. An increase in the frequency of droughts, their maximum duration and maximum intensity is observed in many parts of the world [16]. The most serious aridization trends are observed in Australia, the Middle East, South and North Africa, the Amazon basin, Europe and Central Asia, which puts these regions at risk of further land degradation [17].

Drought is becoming a serious problem for agricultural production in many parts of Africa. Sub-Saharan Africa is the most severely affected by degradation in the world [15]. Long-term droughts are common here, which some scientists perceive as a transitional phase of climate change. Their duration in the semi-arid tropics of Nigeria ranges from a month to 80 months [29]. In the Korahe zone of the Somali regional state of Ethiopia, an increase in the frequency of droughts since 2015 has led to a lack of water, a decrease in the quantity and quality of feed and mass deaths of livestock [30].

In India, climate change is expected to reduce GDP by 10% by 2100 [26]. Since the early 2000s, 24 out of 29 states (96.4 million hectares or 29.3% of the total area of the country) have already been exposed to various mechanisms of degradation and desertification here [31, 32]. A particularly large number of drought episodes are predicted in central India in the sub-basins of Vardha, Vainganga, Pranita, parts of Indravati and Lower Godavari, which will affect the reduction of rice production. During the worst drought, 41% of rice production losses were recorded here. The frequency of severe and extreme droughts in this region will increase [33].

Aridity of the climate and irrational land use practices are important factors of desertification in Asian countries. In Southeast Asia, precipitation is projected to decrease, increase and widespread droughts in the next 30-90 years (Thailand, Malaysia, Singapore, Indonesia, Philippines, and Vietnam) [34].

In South Korea, the period of the worst drought in the last 50 years on a national scale occurred in 2014-2015. The scale of damage caused by the dry period continues to grow [35].

In Europe, the areas most susceptible to degradation and desertification are in the Mediterranean region (Portugal, Spain, Italy, Greece, and Turkey). The number of unstable areas here is growing every year. In the European Union and the United Kingdom, the total annual losses from drought are expected to increase to ≥65 billion euros per year (currently 9 billion euros per year). The largest increase in losses is observed in the southern and western parts of Europe, where a 10% reduction in regional agricultural production is likely as a result of drought [13]. The territories of Southern and Southeastern Europe are seriously affected by climate change and an increase in the frequency and intensity of droughts. In Romania, the desertification process affects territories in the central part of the Dobrudja plateau (1,236 km^2, of which 147.65 km^2 is pasture), in the center and east of the Romanian Plain (5,253.87 km^2), in the south of the Western Plain (2,431.92 km^2). The sandy area in the west of the Romanian plain was prone to desertification due to the destruction of the irrigation system and the decrease in the area of forests and forest protection belts [36].

In the semi-arid Certan region in northeastern Brazil, where the area of degraded land in 2015 reached 246,783 km^2 (total area of 1.13 million km^2), droughts resulted in losses of rain-fed crops, reduction of water reserves in lakes and reservoirs and conflicts between water users. Climate forecasts indicate that the frequency and number of droughts will increase in the future, which may have far-reaching negative socio-economic consequences [28, 37].

Drought is also a common occurrence in the Australian climate. But despite the fact that there are many adaptation strategies in Australia aimed at solving drought problems, these approaches are ineffective, especially given the forecasts of an increased risk of drought due to anthropogenic influence [38].

2.2 Remote sensing of the Earth from space and digitalization of desertification monitoring.

Monitoring the condition of desolate and degraded areas is essential for the development of plans to limit their impact. Remote sensing of the Earth plays an important role in assessing the degradation and desertification of territories, greatly facilitating research of problem regions and providing access to extensive sets of geospatial data. When conducting remote sensing of the Earth, it is important to use a set of data with global coverage, which are freely available and reflect: population density (WorldPop), demography (DHS), population migration (Integrated Public Use Microdata Series Internationa and Migration Flows), etc. State security data is only available through FEWSNET and NASA. Data on land and water resources can be obtained from intact Forest Landscapes (IFL), NASA's GRACE trends (for gravity recovery and climate experiment), etc. [4].

Modern technologies of remote sensing of the Earth from space have also improved the monitoring, assessment and prediction of the onset of dry periods. Indicators and indexes that correspond to the objectives of the Strategic Framework of the United Nations Convention to Combat Desertification are freely available [39]. Earth observation data from space provide for analysis for large-scale monitoring such indicators as Albedo, evapotranspiration, land surface temperature, as well as various assessment index systems: normalized vegetation index (NDVI), normalized difference vegetation index (GNDVI), soil-adjusted vegetation index (SAVI), wet index, heat Index (LST), Drought Index (NDBSI), Earth Remote Sensing Environmental Index (RSEI), etc. The remote sensing method implements fast data extraction with high accuracy, on a large scale and with long time series.

Currently, particularly active research of desolate and degraded territories using remote sensing of the Earth from space is being conducted in China, where desolate lands reach 27.2% of the total area of the country (261.16 million km^2). Highly vulnerable areas are the Gobi Desert, the lower reaches of rivers and the oasis-desert transition zones [40]. According to experts, dry periods will continue to intensify on the mainland of the country. When the temperature rises to 4 °C, according to static and dynamic scenarios, economic losses from drought can reach 164.00 ± 67.58 and 86.84 ± 38.06 billion US $ [14]. The relationship between the development of desertification and the benefits of land use shows a strong correlation and remains relatively stable [41].

Monitoring of the Qilian Mountains of the Tibetan Plateau (China) based on three remote sensing indicators (Albedo, GNDVI and FVC) using the Google Earth Engine (GEE) platform for accessing Landsat 5/7/8 remote sensing data showed spatial and temporal changes in desertification areas from 2000 to 2020. The main reason for the risk of desertification is climate change and natural disasters. The role of human activity (inappropriate land use methods, deforestation, overgrazing) on the occurrence of the risk of desertification has been proven. Currently, the region is experiencing a decrease in the risk status of desertification. But due to climate change, this status is projected to increase [21].

Remote sensing also gives good results in diagnosing changes in the state of the land after the work carried out aimed at restoring and improving the territories. In the Ulanbug Desert (China), under the combined influence of human activity and climate change, there is an upward trend in NDVI (from 2007 to 2022: 0.0015 per year). This indicates the restoration of vegetation [42]. In the central part of the Mongolian Highlands of China, the share of the region with an upward NDVI trend increased from 52.2% in 2000-2009 to 67.9% in 2010-2019. Forecasts show that the overall NDVI trend in these territories will be stable with a slight decrease in the future, and the recovery potential will be higher for pasture ecosystems and water bodies [43].

Using a modified model of the vegetation index adjusted for MSAVI-Albedo soil, a tendency to decrease desertification in the sandy lands of China has been revealed. The factors influencing the change in the status of the territory were: soil, meteorology, topography, economic development, demography, agriculture [44].

In Gansu Province (China), desolate lands occupy 45.2% (19.2 million hectares) of the province's land area. When constructing a modified model of the Earth Remote Sensing Ecological Index (MRSEI) using a combination of RSEI, NDVI, WET, LST, NDBSI and the desertification index (DI) in Lanzhou city, it was revealed that the deterioration in the quality of the ecological environment was caused by an anthropogenic factor combined with temperature and precipitation [45].

A significant ecologic and ecological problem is rocky desertification, which includes soil erosion, reduced land productivity, land degradation, and similarity to a desert landscape. Desertification of karst rocks affects local agriculture and forestry, hinders sustainable socio-economic development [46]. Remote sensing technologies are the main means of monitoring the desertification of rocks, and allow obtaining data from remote areas. Thus, the analysis of the structure and function of the landscape of the South Chinese karst on the Guizhou Plateau, which is the largest ecologically vulnerable area, using the Shannon diversity indices (SHDI), homogeneity (SEDI), fragmentation (FN), distribution (CONTAG), fractional dimension (FD) and aggregation (AI) indicates stabilization and ecological restoration of the landscape [47].

In the south of the European part of Russia, according to ERA5-Land data, between the climatic periods 1991-2020 and 1961-1990, processes that influenced the development of desiccation of the territory were identified: positive trends in the divergence of air humidity in the steppe zone and negative trends in the dry steppe zone [48]. The satellite indicator of land degradation (albedo) shows a significant positive trend of degradation in arid subhumid and semi-arid areas and an unstable positive trend in subhumid regions of Russia. In the subhumid and dry subhumid zones of the East European and West Siberian plains, the frequency of droughts reaches 3-5 in 10 years [6].

Analysis of the dynamics of land productivity in Uzbekistan for the period 2001-2020 using the materials of the Terra-MODIS (Moderate-resolution Imaging Spectroradiometer) system indicates that the practice of rational land management leads to a decrease in the proportion of degraded lands compared to the average (from 25-40% to 10-20%). This trend indicates the success of regional policies that help to adapt to adverse climate changes. The instability of the ongoing changes is confirmed by the high dynamics of degraded foci and improved lands, depending on climatic fluctuations [49].

Decreasing trends in NDVI (15.1%) are observed in some areas of Romania over the period 2001-2020 [36].

In the north-east of Brazil, there was no convincing evidence of a significant impact of precipitation patterns on the spatial distribution of degraded lands. The best representation of degraded lands was provided by RESTREND analysis, or forecasting annual NDVI based on historical annual precipitation, calculating the difference between observed and predicted NDVI, and applying the nonparametric Mann-Kendall trend test to a linear trend line [28, 50].

The development of Earth remote sensing technologies and the popularity of machine learning algorithms have led to the emergence of effective methods for assessing the aboveground biomass of desert plant communities. Studies conducted in the Ulanbuk Desert (China) have established that the aboveground biomass forecasting model based on LiDAR data is a valuable tool for assessing the productivity of desert ecosystems, can be used in carbon reserves research and environmental assessment of the region [51].

When studying modern spatial and temporal changes in vegetation in China using artificial neural networks (INS) from 1980 to 2018, it was found that the average annual air temperature and the average annual concentration of carbon dioxide in the atmosphere have a strong influence on the interannual variability of FPAR. FPAR or fraction of absorbed photosynthetically active radiation is a biophysical parameter used to assess vegetation productivity and carbon fluxes in terrestrial ecosystems. The highest FPAR values in different parts of China's terrestrial ecosystems were found over forests: in the South – 0.59, in the South-East – 0.57, in the Central – 0.52, in the South-West – 0.50 and in the North-East – 0.39. Low FPAR values were found in meadows and desert areas: in the Northwestern part of China and the Tibetan Plateau - 0.20, in Inner Mongolia – 0.25, in Northern China – 0.36 [52].

When assessing land sensitivity to desertification, the MEDALUS multifactorial flexible land use Model has performed well, which takes into account a large number (14-98) indicators of sensitivity to desertification as the main quality indicators and is successfully used worldwide: Italy [53], Greece [7; 54], Turkey [55], India [56], Asia [57, 58].

2.3 The role of biotechnologies in the elimination and prevention of degradation and desertification processes

The assessment of land potential carried out within the framework of the Global Agroecological Zones Study (GAEZ) showed that the land balance is very unevenly distributed across regions and countries. The countries with transition economies, where there is practically no vacant land, have the least potential of land resources for rain-fed agriculture. The lands of developing countries, especially Latin America and the Caribbean, as well as sub-Saharan Africa, have great potential (https://www.fao.org/3/y4252e/y4252e06.htm#P4_3, the date of access to the link is 19.12.2023), table 2.

Climatic fluctuations, land degradation and desertification, or, conversely, their improvement, contribute to changes in the scale and characteristics of land resources in arid, subarid and dry subhumid areas. The dominant causes of fluctuations in rain-fed agricultural production are droughts and aggressive farming. Climate change and loss of biodiversity are closely related concepts. Climate change inevitably affects soil moisture, plant phenology and habitat, and leads to a sharp decrease in crop yields. According to [59], conducting aggressive agriculture can affect the reduction of crop yields by 50% in 2050.

Such fluctuations can be countered by investments in irrigation or food imports, but this is not always feasible or economically justified. Biotechnologies are economical and practical measures [60]. Their effectiveness varies widely. To combat soil erosion, sandy desertification and ecosystem degradation, restoration of plantations and grasslands is widely used worldwide, which involve the formation of vegetation cover capable of improving carbon dioxide absorption, evaporation and transpiration, as well as reducing erosion and improving the physic-chemical properties of soils [61]. Afforestation is the most important and successful means of securing sandy massifs, serves as a carbon repository, mitigates the effects of climate change, is an important tool for replenishing groundwater reserves, and plays a vital role in maintaining ecological balance and improving the living conditions of people in arid regions [62].

The demand for food, wood, improved communications (roads), and the need for living space for the population over the past 8 thousand years have led to the loss of >½ of the world's forest area [63]. Currently, deforestation is occurring at the fastest rate in Africa and South America. In West Africa, since the 1980s, there has been a decrease in the number of 79% of tree species, most of them were of great socio-economic importance [64]. At the end of 2018, there was a catastrophic increase in the rate of deforestation in the Amazon basin of Brazil [65]. Deforestation also remains a serious problem for many countries in Asia, Oceania and Central America. However, some developing countries (Bangladesh, Algeria, Vietnam, India, China, etc.), realizing the potential of forest plantations in restoring the environment, mitigating the effects of climate change, ensuring food security and reducing poverty, are increasing the area of forests [66].

Table 2 – Lands with the potential for the production of rain-fed crops (https://www.fao.org/3/y4252e/y4252e06.htm#P4_3, the date of access to the link is 19.12.2023)

Countries	Total area, million hectares	Total usable land, million hectares (%)	Potentially very suitable land, million hectares	Potentially suitable, million hectares	Potentially moderately suitable lands, million hectares	Potentially poorly suitable land, million hectares	Potentially unsuitable lands, million hectares
Developing countries, including:	7302	2782 (38)	1109	1001	400	273	4520
Sub-Saharan Africa (43 countries)	*2287*	*1031 (45)*	*421*	*352*	*156*	*103*	*1256*
Latin America and the Caribbean (35 countries)	*2035*	*1066 (52)*	*421*	*431*	*133*	*80*	*969*
The Middle East/North Africa (20 countries)	*1158*	*99 (9)*	*4*	*22*	*41*	*32*	*1059*
East Asia (22 countries)	*1401*	*366 (26)*	*146*	*119*	*53*	*48*	*1035*
South Asia (6 countries)	*421*	*220 (52)*	*116*	*77*	*17*	*10*	*202*
Industrialized countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom; Iceland, Malta, Norway, Switzerland; Canada, USA; Australia, New Zealand; Israel, Japan, South Africa)	3248	874 (27)	155	313	232	174	2374
Countries with economies in transition (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, The former Yugoslav Republic of Macedonia, Yugoslavia; Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan; Estonia, Latvia, Lithuania)	2305	497 (22)	67	182	159	88	1808
The world (including some countries not covered by this study)	13400	4188 (31)	1348	1509	794	537	9211

Pasture lands are resources and serve as a "reserve" for the economic development of livestock breeders. As an intermediate link in the study of ecologically vulnerable areas, pastures provide important information for a proper understanding of the relationship between man and the earth [67]. Modern methods of agroforestry are used as an integrated land management system by small farmers around the world. Livestock breeders, in order not to depend on changes in the natural environment, apply a strategy of adaptation of pasture farming to changing conditions, which make it possible to prepare for possible extreme climatic events. The characterization of droughts is one of the primary conditions for the development of measures to improve pasture ecosystems. Studying the effect of drought on vegetation contributes to effective productivity management and prevention of natural disaster risks [18, 68]. Many plant growers are engaged in mulching, changing planting dates, cultivating drought-resistant and salt-resistant crops, afforestation, reducing production to reduce crop losses, reducing the load of animals on grazed areas [69, 70, 71, 72, 73]. The unsatisfactory condition of arid, subarid and dry subhumid pasture ecosystems indicates the need to use phytomelioration methods that have high bioenergetic and economic efficiency. At the same time, cultivated plants must be compatible with the nature of the area and the factors that affect them [74, 75]. The effects of desertification can be mitigated by drought- and salt-resistant plant species, which play an important role in fixing sand, restoring vegetation, are considered an important source of feed for livestock and food for humans, and increase soil fertility [8, 76]. In Central America, it is practiced to plant more than a dozen species of plants on plots of no more than one tenth of a hectare. In the Mediterranean region of Europe, especially in Spain and Portugal, a system of extensive forest pastures has proven itself well. In India, the agroforestry farming system produces high yields of wheat (4-5 tons/ha) and wood with a 10-year crop rotation of trees. Often, the ultimate goal of these practices is not the cultivation of trees, but the production of human food and animal feed [64].

2.4 Global, regional and national programs in the field of solving climate problems, restoring and preserving biodiversity.

The current estimated rate of decline in global biodiversity is 10-100 times higher than the average rate over the past 10 million years. In order to identify the drivers and consequences of this decline, it is important to understand the processes that support biodiversity, assess the successes and failures of historical and modern biodiversity management strategies, and identify the best ways to conserve it [77]. An analysis of the current global situation, the driving factors affecting the sensitivity of lands to desertification, a forecast of evolutionary trends and an understanding of the main contradictions help formulate a strategy for effectively combating desertification. The basis for creating effective projects for the restoration of various ecosystems (atmosphere, biosphere, hydrosphere) is to understand the interactions between them and model future changes on a national, regional and global scale [78, 79].

Global warming is an urgent international political topic. Various initiatives to mitigate the effects of climate change around the world have been discussed for a long time. Factors such as the historically established view of environmental policy as a domestic or international problem and the official role of ministries in international climate negotiations play a special influence on the development of legal approaches developed to address the challenges of mitigating the effects of climate change. In order to achieve the Sustainable Development Goals, which are aimed at solving the global climate problem, the cooperation of all countries and stakeholders is necessary. As a result of the UN Conference on Environment and Development, held in Rio de Janeiro, the United Nations Framework Convention on Climate Change (1994) was adopted, which was approved by 194 States. The UN Climate Change Conference in Glasgow (2021) set goals aimed at reaching a climate agreement to keep global warming below 2°C compared to pre-industrial levels, which will require zero CO_2 emissions between 2030 and 2050 [80, 81, 82, 83, 84, 85].

At the regular session of the Assembly of Heads of State of the African Union, held in Ethiopia (2007), 11 countries adopted the initiative of the Pan-African Great Green Wall project. The initiative involves the construction of 7,000 km of reforestation zones and is aimed at managing natural resources, combating desertification and poverty of the population [86]. The Egyptian National Program to Combat Desertification is being implemented on the territory of Egypt, which ranks first in the world in terms of the phenomenon of desertification among countries, and where 30 thousand acres of the best agricultural lands fall into disrepair every year. It includes regional projects in various agricultural ecological areas, such as: "Assessment and monitoring of desertification", "Improvement of pastures", "Stabilization of sand dunes", "Irrigated agriculture", "Rain-fed agriculture" [3]. Protective measures (controlled seasonal grazing, protected areas, etc.) contributed to the reduction of sand movement on Tunisian lands [87].

In India, 91.2 million hectares of land (27.8% of the geographical extent of the country) were degraded over the period 2015-2016, and 97.85 million hectares (29.7% of the geographical extent of the country) over the period 2018-2019. Moreover, >1/2 of the area of degraded lands falls on rain-fed agricultural land and forest. The increase in the area of desolate lands in India was observed in 28 of the 31 states and union territories in the period from 2011 to 2019. In order to prevent degradation and desertification, India has successfully implemented the "Integrated Watershed Management Program", "Desert Development Program" (1995), "National Afforestation Program" (2000), "National Action Program to Combat Desertification (2001). India is working to restore 26 million hectares of degraded land by in 2030 [3, 88].

In the USA, the Law on Agriculture (2014) reduced the total number of environmental protection programs by almost 2 times due to their consolidation or liquidation. Four main strategies for the conservation of soil and water resources have emerged: the removal of environmentally sensitive lands from agricultural production; improvement of the environment on cultivated agricultural lands; protection of natural resources and agricultural lands; solving regional environmental problems. The "Regional Partnership Program in the field of nature Protection" received a lot of funding. Within the framework of one initiative, the "Wetland Reserves Program", the "Pasture Reserves Program" and the "Agricultural Land Protection Program" were combined, which were focused on environmentally sensitive lands. The "Agricultural Water Resources Improvement Program", the "Joint Conservation Partnership Initiative", the "Chesapeake Bay Watershed Program" and the "Great Lakes Basin Soil Erosion and Sediment Control Program" have been merged [89, 90]. The Environmental Quality Incentives (EQIP) environmental program is working for farmers, ranchers and forest owners, which is aimed at improving water and air quality, preserving groundwater and surface waters, reducing soil erosion, improving wildlife habitat, mitigating the effects of drought [9]. In 2023, the Environmental Protection Service of the Ministry of Agriculture of the Russian Federation (NRCS) additionally increased 19.5 billion US $ for the implementation of the "environmental quality under the incentive program", "conservation management program", the Program "Provision of conservation easement" and the "Conservation regional partnership program" aimed at climate optimization of agriculture (https://www.nrcs.usda.gov/ programs-initiatives, the date of access to the link is 19.12.2023).

In northeastern Brazil, the emergence of desolate lands is facilitated by irrational land management, especially during dry periods [91]. The effects of the 2012-2017 drought on these lands bring to the fore the solution of issues to reduce the social and economic vulnerability of small farms [92].

The fight against degradation and desertification is currently being actively conducted in Asia, where investments in projects to combat desertification have significantly reduced the area of desertification, and the trend of environmental degradation has begun to be restrained. In China, to minimize the economic consequences of drought, the "National Emergency Plan for Flood and Drought Management" was issued, a number of modern programs and technologies for drought prevention and drought resistance were developed: "Integrated management of soil and water conservation and erosion", "Lakes, meadows and sandy areas", "Protection and restoration of desert meadows", "Integrated protection and systematic management of mountains, water resources and forests", "Restoration of degraded forests", "Three Northern Protective forests", other regional programs that improve the quality of the ecological environment and reduce the area and degree of desertification [14, 44, 45, 66].

After the implementation of a number of projects on environmental protection, afforestation and the return of land to agricultural use ("Protective belt of the Three Northerns", "Natural protection of forests", "Ecological Migrant"), since 2000, a slowdown in degradation and improvement of the ecological situation has been observed in the territories of the Alxa League desert area. During the period 2000-2020, desertification was prevented on an area of 4211.9 km^2 [93].

Protected areas have a significant deterrent effect on the expansion of desertification. The creation of the Qilian Mountains National Park had a positive impact on combating desertification in the northeastern outskirts of the Tibetan Plateau (China). Projects for the restoration of forests and grasses, the conservation of soils and water resources were effectively implemented in this territory, environmental control over the development of deposits was carried out, and rotational grazing systems were used [21]. Over the past 20 years, the proportion of lands subjected to extremely severe desertification has been significantly reduced (from 29.22% to 5.62%) by programs to combat desertification on the Mu Us sandy land in China (one of the nine most environmentally sensitive areas in the world). [44]. The Slope Land Transformation program also plays a significant role in improving the ecological environment and ensuring rural development. Over 20 years, the program has doubled the forest fund, and the poverty rate has decreased by 7.5%. The program contributed to an increase in farm income by 5.2% [94].

The consequences of the drying up of the Aral Sea have significantly affected the entire Central Asian region, especially Uzbekistan and Kazakhstan. The development of Aralkum, which is currently a source of severe salt and dust storms, has led to the degradation of two million hectares of former arable land, reduced yields due to increased salinity and environmental degradation for the local population [95, 96]. In order to minimize the effects of desertification and mitigate environmental stress, a project on afforestation of the dried seabed was launched in the Aral Sea region. Testing of large-scale plantings was carried out on sandy and moderately saline areas. It is predicted that the project will improve the hydro-climatic regime, protect the soil from wind erosion, weaken the influence of hot winds, mitigate droughts, and increase the yield of forage crops [97, 98, 99].

In Russia, desertification issues are particularly relevant for the territory in the south-east of the European part of the country [19, 49, 100, 101, 102, 103, 104, 105]. In the semi-arid zone of the Northwestern Caspian Sea, the loss of pasture productivity as a result of desertification annually reaches 1052.7 thousand fodder units and increases with increasing aridity of the climate and deterioration of soil and hydrological conditions [106]. Modern, large deflationary foci of light soils are rapidly expanding, and the possibility of their self-growth in the foreseeable future is practically excluded [107]. The intensification of desertification processes and the high rate of land degradation are characteristic of the Astrakhan region and the Republic of Kalmykia, which have turned into an ecological disaster zone [6, 108, 109]. Regular dust storms on the Black Lands and Kizlyar pastures cover valuable territories with sand, such as the UNESCO Kizlyar Bay Biosphere Reserve [67, 110, 111]. Federal Targeted Programs (FTP) aimed at the development of agricultural land reclamation through agroforestry, phytomelioration and cultural measures are widely supported in the regions [112].

The plans for cooperation between China, Mongolia and the Russian Federation to prevent the effects of droughts, degradation and desertification, and preserve the integrity of ecosystems include the creation of an "economic belt: China-Mongolia-Russia» [40].

Conclusions. The analysis of modern literature sources on research related to the concepts of "degradation" and "desertification" is carried out. 112 works were analyzed and systematized, as a result of which a global strategy for planning the restoration of degraded and desolate lands in arid, subarid and dry subhumid regions was revealed. The main conclusions include the following theses:

1. Modern studies of desert and arid ecosystems devoted to the driving mechanisms, spatial risks and evolutionary processes of degradation and desertification have led to significant scientific results. Particularly great successes in this area have been achieved in the monitoring and assessment of degraded and desolate lands by remote sensing methods. The sensitivity of lands to desertification has spatial heterogeneity and temporal dynamics. Remote sensing provides large-scale, long-term data support for monitoring territories and allows for effective analysis of the evolution of desertification.

2. A promising area is the application of technologies for managing the biodiversity of desolate and degraded lands. Studies of long-term dynamic changes in arid, subarid and dry subhumid territories of the Earth have shown that environmental projects give impetus to the restoration of ecological balance, vegetation growth, and ensure overall economic growth. National biodiversity strategies and action plans are the main means of combating the factors leading to the loss of biodiversity and play a key role in curbing the growth of desertification.

3. Global climate change, depletion of non-renewable resources, loss of biodiversity, degradation and desertification are global problems and require international cooperation and practical interactions to solve them. If management measures are not applied to improve land quality in areas that have been degraded and desertification, millions of people will be at risk of hunger and poverty. To combat desertification, it is necessary to continue the implementation of programs aimed at sustainable land use: agroforestry landscaping, the development of environmentally sustainable farming models, the introduction of effective irrigation methods.

Заключение. Проведен анализ современных литературных источников по исследованиям, связанным с понятиями «деградация» и «опустынивание». Проанализировано и систематизировано 112 работ, в результате чего выявлена мировая стратегия планирования восстановления деградированных и опустыненных земель в аридных, субаридных и сухих субгумидных регионах. Основные выводы включают следующие тезисы:

1. Современные исследования пустынных и засушливых экосистем, посвященные движущим механизмам, пространственным рискам и эволюционным процессам деградации и опустынивания, привели к существенным научным результатам. Особенно большие успехи в данной области были достигнуты в вопросах мониторинга и оценки деградированных и опустыненных земель методами дистанционного зондирования. Чувствительность земель к опустынива-

нию имеет пространственную неоднородность и временную динамику. Дистанционное зондирование предоставляет крупномасштабную, долговременную поддержку данных для мониторинга территорий и позволяет проводить эффективный анализ эволюции опустынивания.

2. Перспективным направлением является применение технологий управления биоразнообразием опустыненных и деградированных земель. Исследования долгосрочных динамических изменений аридных, субаридных и сухих субгумидных территорий Земли показали, что экологические проекты придают импульс восстановлению экологического баланса, росту растительности, обеспечивают общий экономический рост. Национальные стратегии и планы действий в области сохранения биоразнообразия являются главным средством борьбы с факторами, приводящими к утрате биоразнообразия, и играют ключевую роль в сдерживании роста опустынивания.

3. Глобальное изменение климата, истощение невозобновляемых ресурсов, утрата биоразнообразия, деградация и опустынивание являются мировыми проблемами и для решения требуют международного сотрудничества и практических взаимодействий. Если в районах, подвергшихся деградации и опустыниванию, не применять управленческие меры для улучшения качества земель, то под угрозой голода и нищеты окажутся миллионы людей. Для борьбы с опустыниванием необходимо продолжать реализацию программ, направленных на устойчивое землепользование: агролесомелиоративное обустройство ландшафтов, разработку экологически устойчивых моделей земледелия, внедрение эффективных методов орошения.

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STUDYING THE EFFECTIVENESS OF INNOVATIVE BRANDS OF MINERAL FERTILIZERS IN THE CULTIVATION OF CHICKPEAKES ON LIGHT CHESTNUT SOILS IN THE VOLGOGRAD REGION

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Introduction. Possessing high drought and heat tolerance, chickpeas provide more stable yields compared to other leguminous crops. Stable high market conditions for its grain make this crop economically attractive for many farms in the Lower Volga region. However, the relatively low yield of chickpeas forces scientists to search for effective methods to increase the productivity of this crop. The emergence of new brands of mineral fertilizers on the market contributes to the study of this urgent problem. **Purpose of research.** Evaluation of the effectiveness of pre-sowing application of various forms of complex fertilizers on the yield of chickpeas on light chestnut soils. **Object**. The object of the study was the chickpea variety Volzhanin. **Materials and methods.** In accordance with the stated goal and objectives of the study, a scheme of field experiment for applying mineral fertilizers to chickpeas was developed, including the following options: 1). APAVIVA NP 12:52; 2). APAVIVA NP(S) 20:20(14); 3). APAVIVA NPK(S) 15:15:15(10); 4). APAVIVA NPK(S) 8:19:29(3); 5). APAVIVA NPK(S) 10:20:20(6); 6). APAVIVA NPK(S) 8:24:24(3). Place of the experiment: Volgograd region, Gorny settlement, crop rotation plot in the Innovation Village National Democratic Institution of the Volgograd State Agrarian University. Agrochemical characteristics: the soil of the experimental plot is light chestnut, heavy loamy, humus 1.7%, pH level 7.5. Content of ammonium nitrogen (NH4) – 5.5 mg/kg, nitrate nitrogen (NO3) – 12.5 mg/kg, mobile phosphorus (P2O5) – 40.8 mg/kg, exchangeable potassium (K2O) – 338 mg/kg soil. Conducting a small-plot field experiment (plot size – 20 m2, option - 80 m2). Total experience area: 480 m2. Repetition – 4 times. The previous crop was spring barley, after harvesting which deep moldboard plowing at 0.25-0.27 m with a PN – 4 – 35 plow was used as the main soil treatment. **Results and conclusions.** During research on the application of mineral fertilizers, it was found that the height of plants according to the experimental options ranged from 29.7 to 31.7 cm on the options NP(S) 20:20(14), NPK(S) 10:20:20(6), NPK(S) 15:15:15(10), plants were taller than on the variants NP 12:52, NPK(S) 8:24:24(3) and NPK(S) 8:19:29(3) by 1-2 cm, respectively. The number of formed beans in the NPK(S) 8:24:24(3) variant was maximum – 28 pieces. on variants NPK(S) 10:20:20(6), NPK(S) 15:15:15(10) the number of beans decreased to 27 and the smallest number was formed on variants NP(S) 20:20(14), NPK (S) 8:19:29(3), NP 12:52 – 26, 25 and 24 pieces, respectively. The number of grains per plant for all experimental variants did not differ significantly from 29 to 31 pieces. but the grain weight was different, which in turn affected the yield. The maximum yield was recorded in the NPK(S) 8:19:29(3) option – 2.47 t/ha. On the NPK(S) 15:15:15(10) and NP 12:52 options, the yield decreased to 2.32 and 2.24 t/ha. The lowest rates of less than 2 t/ha were observed in the variants NPK(S) 8:24:24(3), NP(S) 20:20(14), NPK(S) 10:20:20(6) – 1.97, 1.93 and 1.87 t/ha, respectively. Pre-sowing application of NP 12:52, NPK(S) 15:15:15(10), NPK(S) 8:19:29(3) at a dose of 150 kg/ha helps to obtain a yield of 2.24 to 2.47 tons /ha with production profitability from 197 to 242%.

Keywords: *mineral fertilizers, chickpea cultivation, chickpea cultivation technologies, chickpea yield, mineral fertilizer brands.*

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