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CREATING AN INTERACTIVE WEB MAP FOR THE LOWER AMU DARYA STATE BIOSPHERE RESERVE BASED ON THE GOOGLE EARTH ENGINE PLATFORM

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Abstract. This study presents the development of an interactive web-based mapping system for monitoring the ecological condition of the Lower Amu Darya State Biosphere Reserve using the Google Earth Engine (GEE) platform. The research utilizes high-resolution Sentinel-2 satellite imagery to analyze spatial and temporal changes in vegetation cover, water bodies, and land surface conditions. Spectral indices, including the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI), were calculated to evaluate vegetation health, moisture distribution, and seasonal ecological dynamics across the reserve. The methodological framework involves cloud-based processing of remote sensing data, statistical analysis of spectral indices, and visualization of results through an interactive web map interface. The developed web application enables users to examine monthly ecological changes, classify index values, and assess spatial distributions of vegetation and water resources. The results demonstrate that integrating remote sensing technologies with cloud-based geospatial platforms significantly improves environmental monitoring, supports sustainable ecosystem management, and enhances decision-making processes in protected natural areas.

Keywords: Google Earth Engine, web map, remote sensing, Sentinel-2, environmental monitoring, biosphere reserve.

Introduction.

In recent years, the intensification of environmental problems on a global scale, in particular climate change, depletion of water resources, increased desertification processes and reduction of biodiversity, creates the need for continuous and systematic monitoring of protected natural areas. In particular, biosphere reserves located in river deltas and semi-arid regions are considered the most vulnerable ecosystems in terms of ecology, and assessing their condition based on modern scientific approaches is one of the urgent tasks.

Traditional field observations and monitoring methods based on statistical data are limited in their ability to cover large areas, continuously monitor over time, and determine the dynamics of ecological processes. Therefore, innovative approaches based on remote sensing and geoinformation technologies are widely used in ecological research. These technologies allow obtaining high-precision, regularly updated and spatially rich information about the state of the earth's surface.

In this process, the Google Earth Engine has emerged as one of the largest and most advanced geoinformation tools at the global scale. By integrating a multi-year archive of satellite imagery, powerful cloud-based computational resources, and code-driven analytical capabilities, the platform has elevated environmental monitoring to a new level. Google Earth Engine enables the rapid analysis and visualization of large volumes of spatial data without local technical limitations.

Among remote sensing datasets, Sentinel-2 satellite imagery holds particular significance for environmental monitoring. Its high spatial resolution, broad spectral range, and short revisit period provide a reliable basis for detecting changes in vegetation cover, water bodies, and land cover. Spectral indices derived from these data allow for the quantitative assessment of ecological processes.

The primary objective of this study is to assess the ecological condition of the Lower Amu Darya State Biosphere Reserve using the Google Earth Engine platform and Sentinel-2 satellite data, to identify key ecological processes through spectral indices, and to present the results in the form of an interactive web map. This approach contributes to the development of a sustainable ecological monitoring framework for biosphere reserves, provides a scientific basis for environmental protection measures, and supports evidence-based territorial management and decision-making processes.

Materials and method:

Study area. This study was conducted within the Lower Amu Darya State Biosphere Reserve, located in the northwestern part of the Republic of Uzbekistan, within the Republic of Karakalpakstan, and encompassing the lower reaches of the Amu Darya River. The reserve represents one of the most significant river–delta ecosystems in Central Asia and is distinguished by its unique natural conditions and rich biodiversity.

The territory of the Lower Amu Darya State Biosphere Reserve is predominantly characterized by lowland landscapes, with absolute elevations ranging on average between 70 and 90 meters above sea level. From a geomorphological perspective, the area is defined by deltaic formations and alluvial plains. As a result of the long-term fluvial activity of the Amu Darya River, the landscape includes numerous abandoned river channels, wetlands, and extensive alluvial deposits.

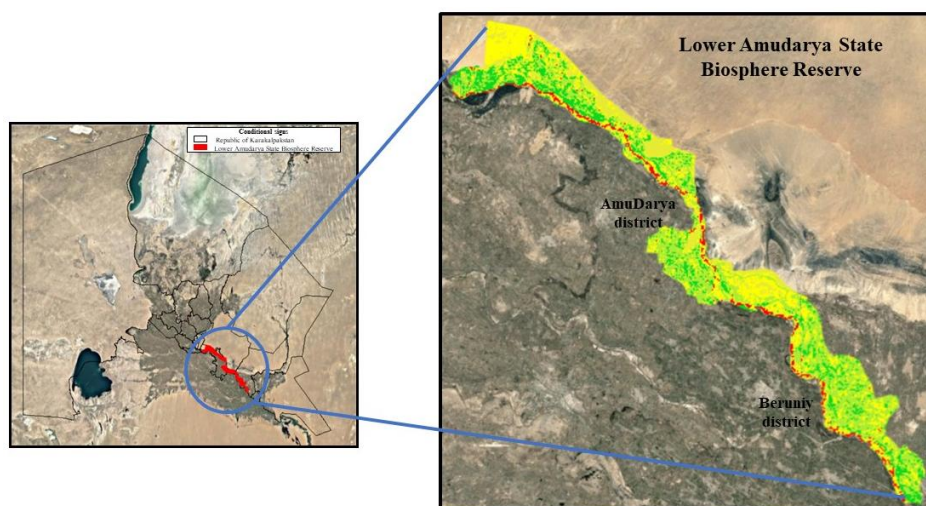


Figure 1. Lower Amu Darya State Biosphere Reserve.

The territory is characterized by a sharply continental climate, with extremely hot and arid summers and relatively cold winters. Annual precipitation is low and occurs predominantly during the winter and spring months. Elevated air temperatures combined with high evapotranspiration rates adversely affect the regional moisture regime, thereby accelerating processes of desertification and soil salinization [7]. These climatic conditions constitute one of the principal limiting factors for maintaining the ecological stability of the Lower Amu Darya State Biosphere Reserve.

The hydrological regime of the Lower Amu Darya State Biosphere Reserve is entirely dependent on the discharge of the Amu Darya River. In recent decades, intensive water withdrawal in the upstream reaches, the expansion of irrigation networks, and the impacts of climate change have led to a marked reduction in water inflow to the downstream areas. This decline has resulted in the contraction of wetland ecosystems, degradation of tugai forests, and a progressive loss of biodiversity [11].

Within the reserve, tugai forests constitute the dominant vegetation cover. These floodplain forests are characteristic of the Amu Darya delta and represent highly water-dependent and ecologically sensitive ecosystems. A decline in water availability has led to the desiccation of tugai stands, shifts in species composition, and the transformation of certain areas into open and bare lands. In addition to tugai forests, extensive reed beds, aquatic vegetation, and semi-desert landscapes are widely distributed across the territory. Given the vast spatial extent of the Lower Amu Darya State Biosphere Reserve, comprehensive assessment of its ecological condition through conventional field-based observations alone remains limited. In this context, satellite remote sensing data provide an effective and scalable solution. In particular, high-resolution imagery from Sentinel-2 plays a crucial role in detecting and analyzing spatial and temporal dynamics of vegetation cover, surface water bodies, and land cover changes [8].

Methodology. In this study, open-access and reliable remote sensing datasets available within the Google Earth Engine (GEE) platform were utilized. To ensure a comprehensive assessment of the ecological condition of the study area, satellite imagery operating in the optical spectral range was selected as the primary source of information.

Imagery acquired by the Sentinel-2 mission served as the principal dataset. With a spatial resolution of 10–20 meters and a revisit cycle of approximately five days, Sentinel-2 enables continuous monitoring of vegetation dynamics, surface water bodies, and land cover changes in complex ecosystems such as the Lower Amu Darya State Biosphere Reserve [3].

For the purposes of this research, imagery corresponding to the 2024 vegetation period was selected, allowing for the analysis of both seasonal and intra-annual variations. Only scenes with cloud cover below 10% were retained, thereby improving the accuracy and reliability of the results.

The administrative boundaries of the Lower Amu Darya State Biosphere Reserve were adopted as the study area. The boundaries were defined in vector (polygon) format and imported into the GEE environment. Accurate delineation of the study area is essential for the proper calculation of spectral indices and for ensuring the statistical validity of spatial analyses [2].

After defining the ROI (Region of Interest), all satellite images were clipped strictly to the boundaries of the study area. This procedure reduced redundant data volume and significantly improved computational efficiency during subsequent processing steps.

Satellite imagery was retrieved from the Google Earth Engine archive, specifically from the Sentinel-2 *COPERNICUS/S2_SR_HARMONIZED* collection. This dataset consists of atmospherically corrected surface reflectance products, providing physically consistent spectral reflectance values from the Earth's surface.

The imagery was filtered according to the following criteria:

Spatial filtering based on the study area boundaries;

Temporal filtering covering the period from March to October 2024;

Cloud cover constraint (*CLOUDY_PIXEL_PERCENTAGE* < 10%).

This stage ensured high data quality and minimized potential errors in the calculation of spectral indices.

To assess the ecological condition of the territory, key spectral indices characterizing vegetation and surface water were computed. Among them, the Normalized Difference Vegetation Index (NDVI) is widely applied for evaluating vegetation density and health status.

It was calculated using the following formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

where:

NIR refers to the near-infrared band (Sentinel-2: B8);

RED refers to the red spectral band (Sentinel-2: B4).

Higher NDVI values indicate dense and healthy vegetation, whereas low or negative values correspond to bare land, water surfaces, or degraded areas.

The NDWI (Normalized Difference Water Index) was used to identify water bodies and monitor moisture conditions. The index was calculated using the following formula:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where:

GREEN – green spectral band (B3),

NIR – near-infrared band (B8).

Positive NDWI values indicate the presence of water bodies, while negative values correspond to dry areas.

The NDWI index enables the identification of open water bodies and the assessment of their spatial distribution. Using this index, river channels, reservoirs, seasonal lakes, and wetlands can be delineated, and their dynamic changes throughout the vegetation period can be analyzed. A decline in NDWI values clearly reflects the reduction of water surfaces and highlights areas experiencing increasing water scarcity [5].

```

1 var s2 = ee.ImageCollection("SENTINEL2/S2_SR_HARMONIZED")
2   .filterBounds(table)
3   .filterDate("2024-06-01", "2024-06-30")
4   .filter(ee.Filter.lt("CLOUDY_PIXEL_PERCENTAGE", 10));
5
6 print("S2 count:", s2.size());
7 // 2) Kompozit
8 var img = s2.median().clip(table);
9 // 3) NDWI = (B3 - B8) / (B3 + B8)
10 var ndwi = img.normalizedDifference(["B3", "B8"]).rename("NDWI");
11
12 // 4) NDWI klassifikatsiya (4 sinif)
13 var ndwiClass = ee.Image(0);
14   .where(ndwi.lt(0.1), 1) // Suda quruq
15   .where(ndwi.gte(0.1).and(ndwi.lt(0.3)), 2) // quruq
16   .where(ndwi.gte(0.3).and(ndwi.lt(0.5)), 3) // nam
17   .where(ndwi.gte(0.5), 4) // suv
18   .rename("NDWI_Class");
19   .clip(table);
20
21 // 5) Har sinif maydoni (m2 va ha)
22 function classArea(v) {
23   v = ee.Number(v);
24   var mask = ndwiClass.eq(v).rename("mask");
25   var area_m2 = ee.Number(
26     mask.multiply(ee.Image.pixelArea())
27     .reduceRegion({
28       reducer: ee.Reducer.sum(),
29       geometry: table,
30       scale: 10,
31       maxPixels: 1e11
32     })
33   );
34   return ee.Dictionary({
35     "class": v,
36     "area_m2": area_m2,
37     "area_ha": area_m2.divide(10000)
38   });
39 }
40

```

Inspector Console

Use print(...) to write to this console.

S2 count: 3508

23

NDWI sinflari maydoni: 3508

*List (4 elements)

*0: Object (3 properties)

area_ha: 71896.38333396682

area_m2: 718963833.3396682

class: 1

*1: Object (3 properties)

area_ha: 5437.770661920456

area_m2: 54377066.61920456

class: 2

*2: Object (3 properties)

area_ha: 678.4539440409515

area_m2: 6784538.9440409515

class: 3

*3: Object (3 properties)

area_ha: 382.8258063651141

area_m2: 3828258.063651141

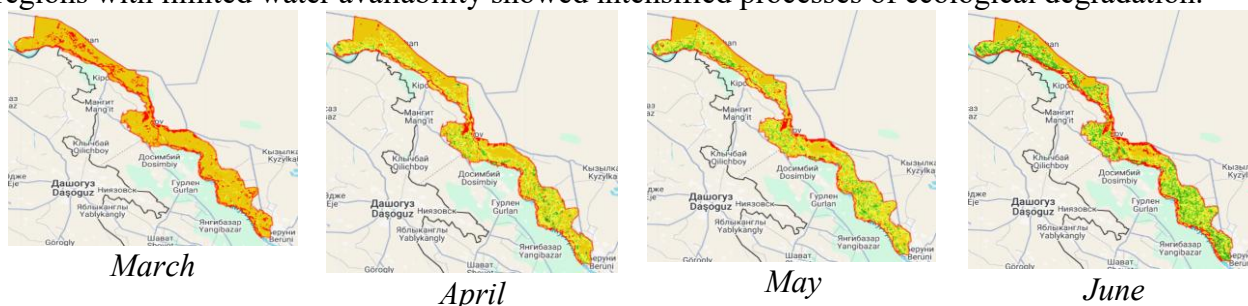
class: 4

Figure 2. Plot of NDWI indices by region, by month.

Spectral indices were calculated based on annual and seasonal mean values. This approach allowed for the assessment of temporal dynamics of ecological processes. Using the statistical functions of Google Earth Engine, the monthly minimum, maximum, and mean values of NDVI and NDWI across the study area were determined, enabling an evaluation of ecological change trends.

Results and discussion. Using Sentinel-2 satellite imagery processed within the Google Earth Engine environment, the ecological condition of the Lower Amu Darya State Biosphere Reserve was comprehensively assessed. The calculated spectral indices indicated a high degree of spatial variation in ecological processes across the reserve.

The results of NDVI and NDWI analyses revealed that ecological patterns are strongly influenced by the hydrological regime, topographic features, and soil conditions. In particular, vegetation cover in the low-lying areas along the Amu Darya River remained relatively stable, while regions with limited water availability showed intensified processes of ecological degradation.



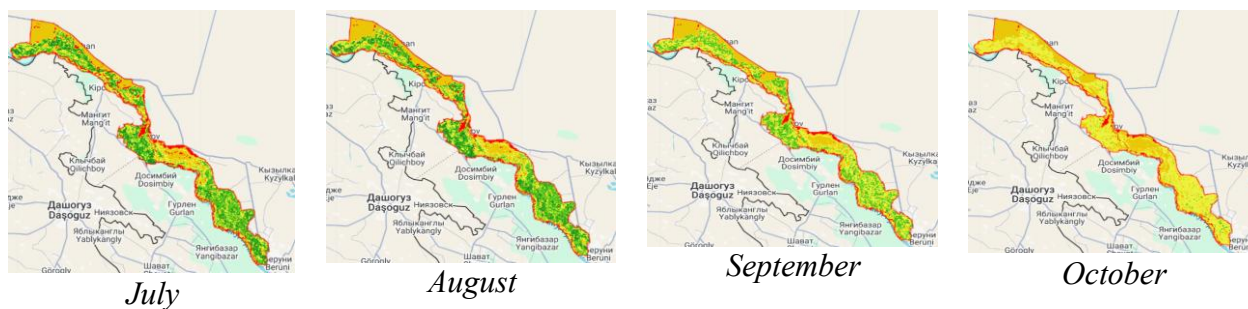


Figure 3. Monthly changes in NDVI vegetation cover in 2024 (in the GEE platform window).

The seasonal dynamics of the NDVI index throughout 2024 were clearly observed. In March, vegetation was not yet fully developed, resulting in low NDVI values. During April and May, the spring growth phase commenced, and NDVI values increased rapidly. From June to July, vegetation reached its peak development stage, with the index attaining its highest values. Starting in August, reduced moisture availability led to a slight decline in NDVI. In September and October, vegetation weakened, and NDVI values fell to moderate and low levels.

Overall, the NDVI dynamics were found to be directly linked to the seasonal climatic conditions and the hydrological regime of the region [10].

Temporal variations in NDVI (time-series) provide valuable functional information on crop productivity and can be used to identify and highlight anomalies in growth patterns. NDVI enables the detection of areas with reduced productivity caused by disease, natural disasters, or other stress factors during the vegetation season.

Since functional productivity data are based on field observations and measurements, calibration and validation are required before applying them to other regions [11].

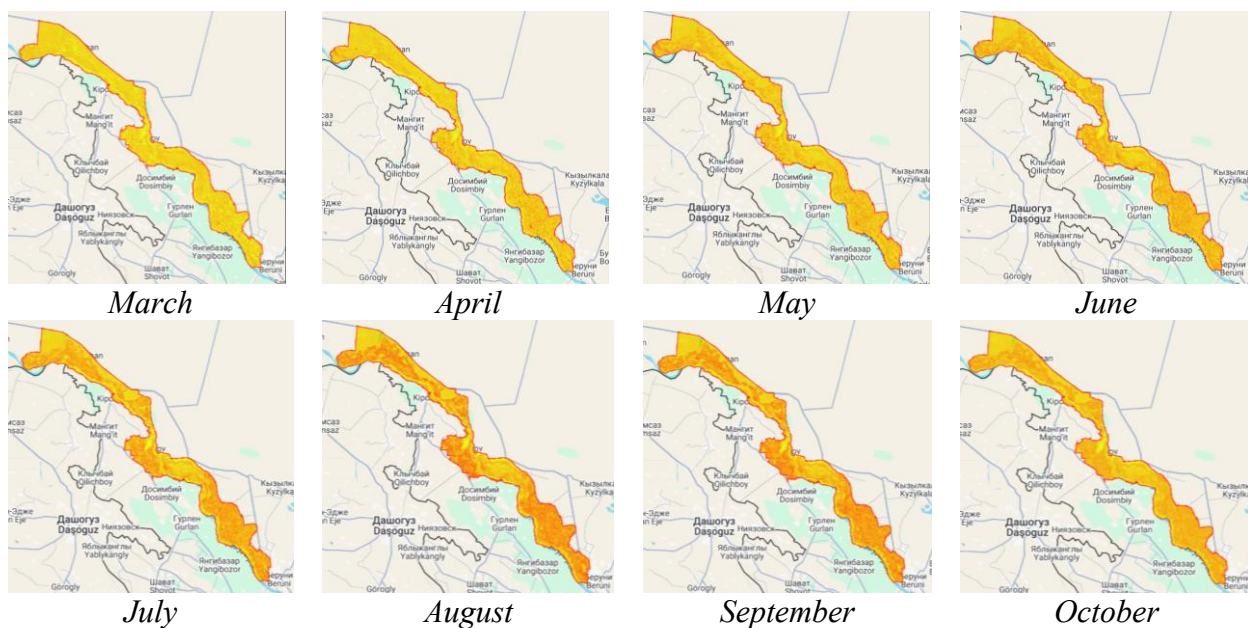


Figure 4. Monthly changes in NDWI vegetation cover in 2024 (in the GEE platform window)

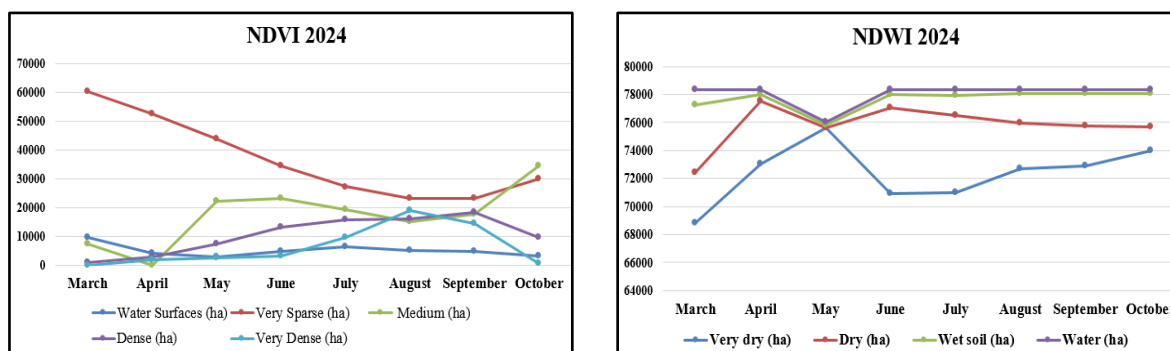


Figure 5. Monthly changes in NDVI and NDWI indices in 2024.

The 2024 data indicate a predominance of arid conditions across the study area. Throughout the year, the majority of the territory fell under the “very dry” category, reflecting the region’s climatic characteristics, including high summer temperatures and intensive evapotranspiration processes.

During the spring months (March–April), soil moisture remained relatively stable; however, starting in May, the proportion of very dry areas increased. In the summer months (June–August), drought conditions persisted, with dry and very dry areas dominating the landscape. At the same time, slight increases in moist soil were observed in certain locations around mid-summer, likely due to irrigation or localized water accumulation.

At the beginning of autumn (September), a relative increase in moist soils was noted, attributed to lower temperatures and reduced evaporation. Nevertheless, by October, dry conditions once again prevailed.

Overall, while seasonal variations in soil moisture were observed in 2024, dry and very dry lands consistently constituted the largest proportion of the territory. Water bodies remained limited in extent throughout the entire year.

The analysis demonstrates that during the spring months, an increase in NDWI values (indicating higher surface and soil moisture availability) leads to a corresponding rise in NDVI. This pattern reflects the transition of vegetation into an active growth phase, characterized by intensified photosynthetic activity and rapid biomass accumulation. Enhanced precipitation and improved soil moisture conditions in spring create favorable environmental settings for vegetation development. During the summer season, vegetation typically reaches its peak growth stage, and NDVI records its highest values. In certain areas, NDWI remains relatively stable due to irrigation practices or the persistence of moisture in the soil profile. In irrigated landscapes in particular, the positive correlation between NDWI and NDVI becomes more pronounced, as artificial water supply sustains vegetation vigor despite elevated temperatures and increased evapotranspiration rates. In autumn, declining precipitation and intensified evapotranspiration processes result in reduced moisture availability, reflected by decreasing NDWI values. Consequently, NDVI also declines, indicating a reduction in vegetation density and biomass. This seasonal pattern corresponds to the phenological transition toward the end of the growing period. Overall, NDWI represents one of the principal natural drivers of vegetation dynamics and exhibits a positive correlation with NDVI. The observed relationship between these two indices is of considerable scientific and practical significance for assessing regional ecological conditions, analyzing moisture–vegetation system dynamics, and evaluating the influence of climatic factors on ecosystem functioning.

Discussion of the results obtained based on the web map. The developed web map was created using the Google Earth Engine (GEE) platform, where NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) were calculated and classified on a monthly basis from March to October using Google Earth Engine and Sentinel-2 satellite imagery [12].

The web application provides an interactive interface that enables users to visualize monthly index values, examine their classification by thematic classes, and assess the spatial distribution of

each class in terms of area (hectares). This functionality allows for dynamic analysis of vegetation and moisture conditions throughout the growing season, facilitating both temporal comparison and spatial assessment of environmental changes.

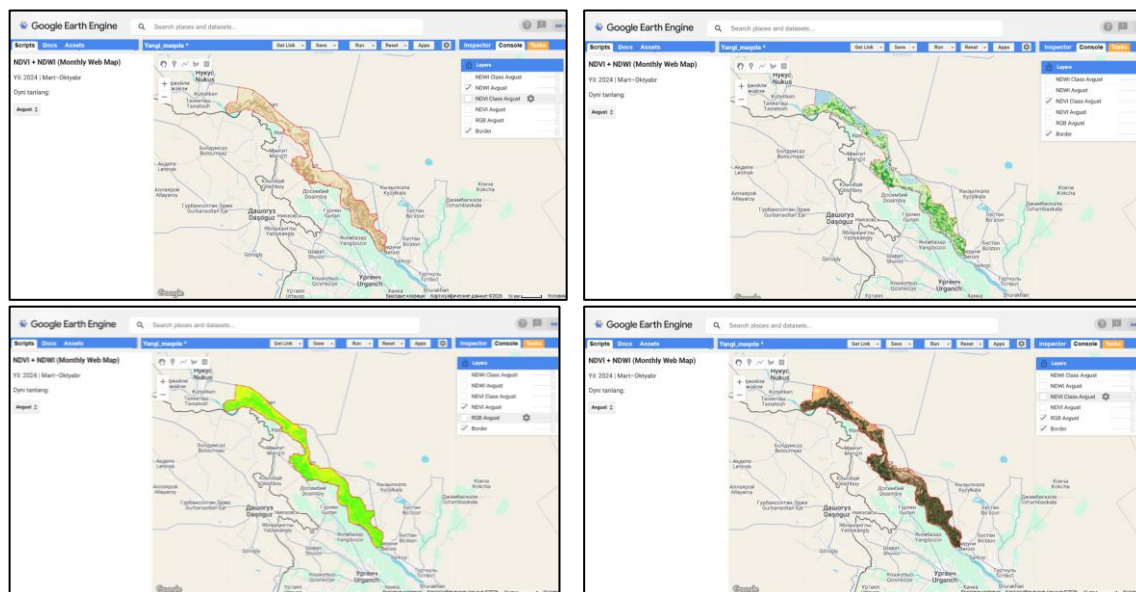


Figure 6. Interactive web map of the Lower Amu Darya State Biosphere Reserve.
(<https://ee-alishernuratdinov.projects.earthengine.app/view/lower-amu-darya-state-biosphere-reserve-web-maps>)

This web application enables users to visualize monthly index values in a map format, analyze these values according to classification, and conduct a statistical assessment of changes within the territorial domain.

The NDVI index is categorized into five classes to evaluate the state of vegetation within the reserve. This classification facilitates the identification of zones characterized by very low, low, medium, high, and very high vegetation. In March 2024, NDVI values predominantly fall within the low and medium categories, suggesting that plant development is not yet at its peak. Commencing in April, there is observable increased plant activity, leading to an expansion of the area classified under the higher categories. Throughout May, June, and July, NDVI values approach their maximum, with the upper and very high classifications encompassing a significant portion of the reserve's territory. Beginning in August, a decline in plant numbers is noted, accompanied by a reduction in the area represented by the higher classes. In September and October, an increase in the proportion of lower and medium classes is evident, indicating the conclusion of the growing season. The web map computes the area of each class individually and illustrates the month-to-month dynamics of change.

The NDWI index was classified into four categories to assess the water and moisture regime of the study area: very low moisture, low moisture, moderate moisture, and high moisture zones. In March 2024, NDWI values were generally at a moderate level, with higher moisture conditions observed in certain low-lying areas. In April and May, due to spring runoff and increased moisture availability, the spatial extent of high-moisture classes expanded. Beginning in June, rising air temperatures led to a reduction in moisture availability, and NDWI values exhibited a declining trend. In July and August, the area covered by low-moisture classes increased, reflecting typical summer arid conditions. In September and October, moisture conditions partially recovered, resulting in a renewed expansion of moderate and high-moisture classes. The interactive web map provides a color-coded visualization of the spatial distribution of NDVI and NDWI for each month, while area statistics for each class are automatically calculated. This functionality enables precise analysis of seasonal vegetation dynamics and water–moisture regime variations within the reserve, supports the

assessment of ecological processes, and contributes to the effective organization of environmental monitoring.

In general, the created web map allows:
remote ecological monitoring of the area,
rapid assessment of vegetation and moisture changes,
use as a visual analysis tool for scientific research and dissertation work,
creation of a database for making management decisions.

Thus, the developed NDVI–NDWI web map is an effective, modern and interactive monitoring tool for displaying the seasonal ecological dynamics of the area.

Suggestions and recommendations. Based on the findings of this study, a series of recommendations has been formulated to enhance environmental monitoring within the Lower Amudarya State Biosphere Reserve, provide scientific justification for environmental protection measures, and promote the integration of contemporary geoinformation technologies into practice.

First, it is essential to establish a continuous and systematic ecological monitoring framework within the biosphere reserve. This system should be organized on the basis of Google Earth Engine and supported by Sentinel-2 satellite imagery to ensure regular observation of vegetation cover, water bodies, and land cover dynamics. Such an approach would enable the early detection of negative ecological trends and facilitate timely management interventions.

Second, in assessing vegetation conditions and water regimes, it is recommended not to rely solely on NDVI and NDWI, but also to incorporate additional spectral indices such as Soil-Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), Normalized Difference Salinity Index (NDSI), and Land Surface Temperature (LST). The integration of these indices would allow for a more comprehensive evaluation of ecological processes related to soil salinity, moisture dynamics, and thermal conditions.

Third, to improve the reliability of remote sensing results, systematic validation through field observations and laboratory analyses is necessary. Comparing in situ measurements of soil salinity, vegetation condition, and water quality with satellite-derived data would significantly enhance the accuracy and credibility of monitoring outcomes.

Fourth, the developed interactive web map should be integrated into the operational activities of organizations responsible for managing the biosphere reserve, as well as ecological inspection authorities and research institutions. The application of this tool would facilitate the identification of environmentally vulnerable areas, rapid assessment of monitoring results, and the scientific substantiation of management decisions.

Fifth, for future studies, it is advisable to integrate artificial intelligence and machine learning algorithms—such as Random Forest and change detection models—into the Google Earth Engine environment to enable automated identification of ecological processes. This approach would reduce human-induced errors in land cover change detection and improve the overall efficiency and objectivity of environmental monitoring.

Conclusion. This study developed a modern web-cartographic approach for assessing and monitoring the ecological condition of the Lower Amu Darya State Biosphere Reserve using the capabilities of the Google Earth Engine platform. A complete technological workflow for remote sensing data processing was implemented, covering all stages from delineation of the study area to the calculation of spectral indices and the visualization of results in the form of an interactive web map.

Sentinel-2 satellite imagery was selected as the primary data source. Its high spatial resolution and regular revisit frequency enabled dynamic monitoring of ecological processes within the complex ecosystem of the biosphere reserve. The spatial and temporal variability of the NDVI index, which characterizes vegetation cover conditions, proved to be a significant indicator for identifying degradation and regeneration processes in tugai forests. Furthermore, the NDWI results clearly reflected reductions in water body extent and changes in the moisture regime.

The findings demonstrate that the web-cartographic approach functions not only as a scientific analytical tool but also as an accessible and practical platform for organizations involved in

environmental protection, regional administrative authorities, and ecological specialists. By presenting ecological information in an interactive and comprehensible format, this approach strengthens evidence-based decision-making and contributes to the establishment of a sustainable management framework for biosphere reserves.

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СОЗДАНИЕ ИНТЕРАКТИВНОЙ ВЕБ-КАРТЫ НИЖНЕАМУДАРЬИНСКОГО ГОСУДАРСТВЕННОГО БИОСФЕРНОГО ЗАПОВЕДНИКА НА ОСНОВЕ ПЛАТФОРМЫ GOOGLE EARTH ENGINE

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Аннотация. Данное исследование посвящено разработке интерактивной веб-картографической системы для мониторинга экологического состояния Нижнеамударьинского государственного биосферного заповедника с использованием платформы **Google Earth Engine (GEE)**. В исследовании применяются спутниковые снимки высокого пространственного разрешения **Sentinel-2** для анализа пространственно-временных изменений растительного покрова, водных объектов и состояния земной поверхности. Для оценки состояния растительности, распределения влаги и сезонной динамики экологических процессов были рассчитаны спектральные индексы **NDVI (Normalized Difference Vegetation Index)** и **NDWI (Normalized Difference Water Index)**. Методологический подход включает облачную обработку данных дистанционного зондирования, статистический анализ спектральных индексов и визуализацию результатов в виде интерактивной веб-карты. Разработанное веб-приложение позволяет пользователям анализировать ежемесячные экологические изменения, классифицировать значения индексов и оценивать пространственное распределение растительности и водных ресурсов. Результаты исследования показывают, что интеграция технологий дистанционного зондирования и облачных геоинформационных платформ значительно повышает эффективность экологического мониторинга, способствует устойчивому управлению экосистемами и улучшает процесс принятия решений на охраняемых природных территориях.

Ключевые слова: Google Earth Engine, веб-карта, дистанционное зондирование, Sentinel-2, экологический мониторинг, биосферный заповедник.

GOOGLE EARTH ENGINE ПЛАТФОРМАСЫ НЕГІЗІНДЕ ТӨМӨНГІ АМУДАРІЯ МЕМЛЕКЕТТІК БИОСФЕРАЛЫҚ ҚОРЫҒЫНЫҢ ИНТЕРАКТИВТІ ВЕБ-КАРТАСЫН ҚҰРУ

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Аңдатпа. Бұл зерттеу Google Earth Engine (GEE) платформасын пайдалана отырып, Төменгі Амудария мемлекеттік биосфералық резерватының экологиялық жағдайын бақылаудың интерактивті веб-картографиялық жүйесін әзірлеуге арналған. Зерттеуде өсімдік жамылғысының, су объектілерінің және жер бетінің жағдайының кеңістіктік-уақыттық өзгерістерін талдау үшін Sentinel-2 жоғары кеңістіктік ажыратымдылығы бар спутниктік суреттер қолданылады. Өсімдіктердің жай-күйін, ылғалдың таралуын және экологиялық процестердің маусымдық динамикасын бағалау үшін NDVI (Normalized Difference Vegetation Index) және NDWI (Normalized Difference Water Index) спектрлік индекстері есептелді. Әдістемелік тәсіл қашықтан зондтау деректерін бұлтты өндеуді, спектрлік индекстерді статистикалық талдауды және нәтижелерді интерактивті веб-карта түрінде визуализациялауды қамтиды. Әзірленген веб-қосымша пайдаланушыларға ай сайынғы экологиялық өзгерістерді талдауға, индекстердің мәндерін жіктеуге және өсімдіктер мен су ресурстарының кеңістіктік таралуын бағалауға мүмкіндік береді. Зерттеу нәтижелері қашықтықтан зондтау технологиялары мен бұлтты геоақпараттық платформалардың интеграциясы экологиялық мониторингтің тиімділігін айтарлықтай арттыратынын, экожүйелерді тұрақты басқаруға ықпал ететінін және қорғалатын табиғи аумақтарда шешім қабылдау процесін жақсартатынын көрсетеді.

Түйін сөздер: Google Earth Engine, веб-карта, қашықтықтан зондтау, Sentinel-2, экологиялық мониторинг, биосфералық қорық.