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Nuratdinov A.U.
Assistant teacher of the Geodesy, Cartography and Natural Resources Department
Karakalpak State University
Nukus, Uzbekistan

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

Abstract. This article describes the methodology for monitoring the ecological state of the Lower Amu Darya State Biosphere Reserve and creating an interactive web map based on the Google Earth Engine (GEE) platform. The study analysed spatial-dynamic changes in land cover, vegetation status, and water bodies based on Sentinel-2 satellite images. Using the Google Earth Engine platform allows for rapid processing of large-scale remote sensing data, visualisation of ecological processes, and creation of web-cartographic resources that support decision-making.

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

Нуратдинов А.У.
Ассистент кафедры геодезии и картографии и природных ресурсов
Каракалпакский государственный университет
Нукус, Узбекистан

СОЗДАНИЕ ИНТЕРАКТИВНОЙ ВЕБ-КАРТЫ НИЖНЕ-АМУДАРЬИНСКОГО ГОСУДАРСТВЕННОГО БИОСФЕРНОГО ЗАПОВЕДНИКА НА БАЗЕ ПЛАТФОРМЫ GOOGLE EARTH ENGINE

Аннотация. В данной статье описывается методология мониторинга экологического состояния Нижне-Амударьинского государственного биосферного заповедника и создания интерактивной веб-карты на основе платформы Google Earth Engine (GEE). В исследовании были проанализированы пространственно-динамические изменения земельного покрова, состояния растительности и водных объектов на основе спутниковых снимков Sentinel-2. Использование платформы Google Earth Engine позволяет быстро обрабатывать масштабные данные дистанционного зондирования, визуализировать экологические процессы и создавать веб-картографические ресурсы, поддерживающие принятие решений.

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

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 [3].

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 visualisation of large volumes of spatial data without local technical limitations [6].

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.

Materials and methods. 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 territory of the Lower Amu Darya State Biosphere Reserve is predominantly characterised by lowland landscapes, with absolute elevations ranging on average between 70 and 90 meters above sea level.

The territory is characterised 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 [7].

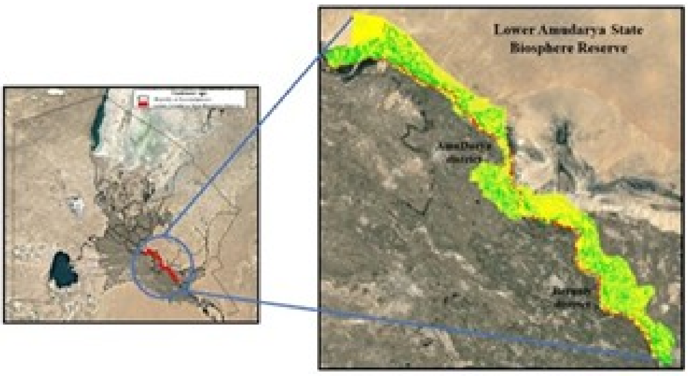

Figure 1. Lower Amu Darya State Biosphere Reserve.

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 analysing spatial and temporal dynamics of vegetation cover, surface water bodies, and land cover changes [1].

Methodology. In this study, open-access and reliable remote sensing datasets available within the Google Earth Engine (GEE) platform were utilised. 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 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 [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 minimised potential errors in the calculation of spectral indices.

To assess the ecological condition of the territory, key spectral indices characterising vegetation and surface water were computed. Among them, the

Normalised Difference Vegetation Index (NDVI) is widely applied for evaluating vegetation density and health status [4].

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 (Normalised 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 analysed. A decline in NDWI values clearly reflects the reduction of water surfaces and highlights areas experiencing increasing water scarcity [5].

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.

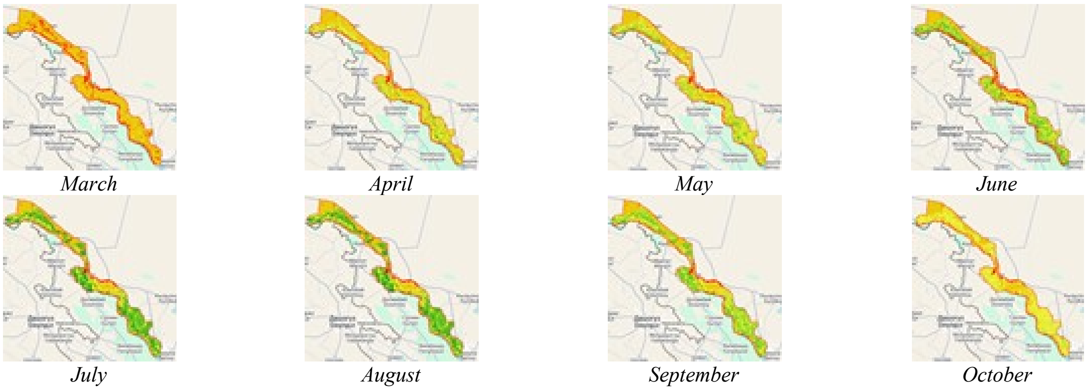

Figure 3. Monthly changes in NDVI vegetation cover in 2024 (in the GEE platform window).

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 [6].

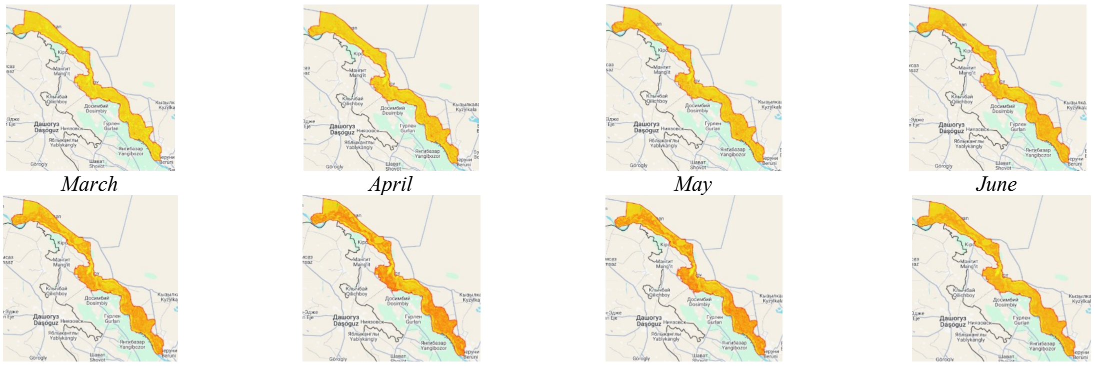

Figure 4. Monthly changes in NDWI vegetation cover in 2024 (in the GEE platform window)

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 [11].

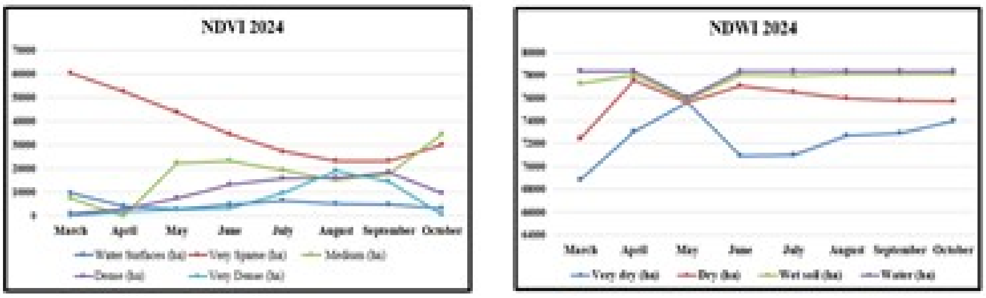

Figure 5. Monthly changes in NDVI and NDWI indices in 2024.

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 localised 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.

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, characterised by intensified photosynthetic activity and rapid biomass accumulation. Enhanced precipitation and improved soil moisture conditions in spring create favourable 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 vigour 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.

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 (Normalised Difference Vegetation Index) and NDWI (Normalised Difference Water Index) were calculated and classified on a monthly basis from

March to October using Google Earth Engine and Sentinel-2 satellite imagery [7].

The web application provides an interactive interface that enables users to visualise monthly index values, examine their classification by thematic classes, and assess the spatial distribution of each class in terms of area (hectares).

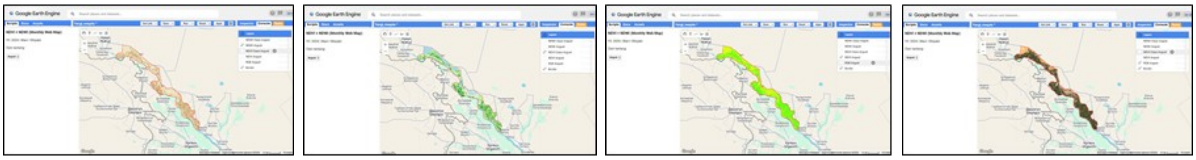

Figure 6. Interactive web map of the Lower Amu Darya State Biosphere Reserve. (https://ee-alishernuratdinov.projects.earthengine.app/view/lower-amu-darya-state-biosphere-reserve-web-maps)

This web application allows the user to view index values for each month in map format, analyse them based on classification, and statistically evaluate changes in the territorial area.

The NDVI index is divided into 5 classes to assess the state of vegetation in the reserve. This classification serves to identify zones of very low, low, medium, high and very high vegetation. In March 2024, NDVI indicators are observed mainly in the low and medium classes, which indicates that the vegetation has not yet fully developed. Starting from April, vegetation becomes active and the area of the high classes begins to expand. In May, June and July, NDVI approaches maximum values, and the high and very high classes occupy a large part of the reserve territory. Starting from August, vegetation decreases and the area of the high classes decreases. In September and October, the proportion of the low and medium classes increases, which indicates the end of the vegetation period. The web map calculates each class area separately and shows the dynamics of change from month to month.

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 [6]. 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 colour-coded visualisation of the spatial distribution of NDVI and NDWI for each month, while area statistics for each class are automatically calculated.

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 results of this study, a set of recommendations has been developed to enhance ecological monitoring within the Quyi Amudaryo davlat biosfera rezervati, to provide a scientific basis for nature conservation measures, and to promote the practical implementation of modern geoinformation technologies.

First, it is essential to establish a continuous and systematic ecological monitoring framework within the biosphere reserve. This system should be organised 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.

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), Normalised Difference Salinity Index (NDSI), and Land Surface Temperature (LST).

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 organisations responsible for managing the biosphere reserve, as well as ecological inspection authorities and research institutions.

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.

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 visualisation 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 characterises 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.

References

1. Drusch, M., Del Bello, U., Carlier, S., et al. (2012). Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote Sensing of Environment, 120, 25–36. https://doi.org/10.1016/j.rse.2011.11.026
2. ESA (European Space Agency) (2023). Sentinel-2 User Handbook. European Space Agency Publications.
3. FAO (2018). Remote sensing for sustainable agriculture and natural resources management. Food and Agriculture Organization of the United Nations, Rome.
4. Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031
5. Jensen, J. R. (2016). Introductory Digital Image Processing: A Remote Sensing Perspective. 4th Edition, Pearson Education, New York.
6. Nuratdinov A.U., Kannazarov Z.U., Berdimuratova M., Geodezik metodlar va sun'iy yo'ldosh ma'lumotlari asosida Quyi Amudaryo davlat biosfera rezervatining tuproq sho'rlanishini kartaga olish masalalari // Geodeziya, kartografiya va geoinformatika Ilmiy - texnik jurnali. – Toshkent, 4-son. 2025. B. 41-51.
7. Nuratdinov A.U., Reymov P., Kannazarov Z.U. Study of sustainable changes in the reserve zone of the Lower Amudarya State Biosphere Reserve based on remote sensing data//Science and Education in Karakalpakstan. ISSN 2181-9203 №4/1, 2025. –C. 116-123.

8. R. Oymatov, Z. Mamatkulov, M. Reimov, R. Makhsudov, R. Jaksibaev, Methodology development for creating agricultural interactive maps, IOP Conf. Ser. Earth Environ. Sci. 868. (2021)

9. Methodological instructions for geobotanical observations of agricultural crops in Uzbekistan. (Tashkent 1980).