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DETERMINING THE SPECIES COMPOSITION OF FOREST VEGETATION IN THE KOSTANAY REGION USING REMOTE SENSING DATA

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During the scientific investigation, woody species of forest vegetation were identified and a map of forest vegetation in the Kostanay region was produced using various data sources: field materials, Earth remote sensing data, and ArcGIS10.9 software. An algorithm was developed to detect tree species based on Landsat 9 satellite imagery, characterized by high spatial resolution. Recognition of dominant tree species was performed using various combinations of spectral bands from Landsat 9 imagery, analysis of vegetation indices (NDVI, EVI) across different seasons, and supervised local adaptive classification. The obtained data were validated against field research materials (August-September 2023) and forest management records. The chosen algorithm implements contemporary approaches to acquiring and processing necessary data from satellite remote sensing imagery. Further differentiation and creation of the forest vegetation map of the Kostanay region were based on the established map of tree species, digital elevation model, geological-geomorphological features, field research, thematic maps, and physical geography of the region. As a result of the conducted research, six classes of forest stands were delineated in the Kostanay region, including light-coniferous and deciduous tree species such as pine, birch, aspen, larch, shrubbery, and meadow vegetation. These research findings and the algorithm developed can be applied to other study areas and hold practical significance.

Keywords: forest vegetation, tree species, Kostanay Region, spectral channels, decoding, geographic information systems.

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INTRODUCTION

Remote sensing data is the main and essential means and mechanism for assessing the state of forest resources. The development of the field of space monitoring of the natural environment in the modern world helps address many important scientific tasks related to the conservation and restoration of natural resources.

Modern space technologies are capable of providing data through Earth remote sensing in visible and infrared channels of spectral visibility. Remote sensing methods serve as an indispensable tool that allows obtaining timely information about the areas, quality status of forest resources, and forest-forming tree species. The reliability of information obtained from aerial and satellite images depends on the accuracy of photogrammetric data processing and their decoding. The intensity and visibility of pixels in different spectral ranges depend on the specific reflective characteristics of the territory object by electromagnetic waves in a particular range. It should be noted that a zonal image is capable of depicting the characteristics of landscape elements, which is utilized in interpreting land surface classes and monitoring the natural environment. For decoding and representing forest vegetation and tree species, the optimal solution would be the application of red, infrared, or green spectral channels.

It should be noted that data from Landsat 9 A - B satellites exhibit the best combination of spatial, spectral, and temporal characteristics among open-access Earth remote sensing satellite data.

Currently, one of the modern processing

methods involves transforming raw images using vegetation indices and subsequently creating index images.

The decoding and mapping of tree species in forests are important applications of space imagery data. Low-resolution satellite images (Terra/Aqua MODIS, SPOT-Vegetation) and medium-resolution images (Landsat) provide the opportunity to create cartographic materials that assist in identifying tree species (Shikhov A.N. et al., 2020).

The analysis of literature in the field of space monitoring of the natural environment, including forests, has revealed a vast body of work dedicated to the application of remote sensing data (development of methodological approaches to decoding forest-forming tree species) in the study of forests.

The issues of conducting various types of forest monitoring and methods of decoding forest cover are described in the works of Lupyana E. A. et al.(2011), Bartalev S. A., Egorov V. A. et al. (2016, 2007). Marchukova V. S. et al. (2012), Zharko V. O. et al. (2014), Zhirina V. M. (2014), Isaeva A. S. et al.(2014), Rouse J.W. et al. (1973). Czaplewski R. (1994). Epting, J. et al. (2005) and so on.

In the studied region, two large forest provinces can be identified – the Trans-Urals-Obagan Forests and the Turgai Belted Pine Forests, which are located within the boundaries of the forest-steppe and steppe natural zones.

The area of the state forest fund in the Kostanay Region is 1 million 146 thousand hectares. The regional akimat manages 457 thousand hectares of forest resources, with the majority of the forest resource fund falling under the Republican administration. Out of the land designated for the regional management's forest fund, the projected forest cover constitutes about 240 thousand hectares. The remaining portion of the fund consists of agricultural lands (arable land, hayfields, pastures), transportation routes, etc.

The forest cover of the Kostanay Region is predominantly composed of birch, aspen-birch forests, and pine groves. White poplar, weeping willow, bird cherry, wild apple, and larch are also found. Deciduous forests form large continuous expanses in the central part between the Tobol and Obagan rivers, aspen groves thrive in moist depressions to the west, and birch groves occupy drier terrain depressions.

The region of ancient pine forest belts of the ancient Tobolsk depression occupies the northern part of the steppe zone in the Kostanay Region. Pine forests here grow on the tops of high sandy ridges and the upper parts of their slopes. Birch and aspen forests are associated with the lower parts of the slopes of sandy ridges and often adjoin the shores of saline lakes.

It should be noted that the forests of the Kostanay Region include unique relict pine groves interspersed with birch and aspen clusters, such as the Arakaragai forest massif, the Kazanbasy and Amankaragai groves, and the groves of the Naurzum State Nature Reserve (the small protected strip forest Tersyk-Karagai and the pine grove Naurzum-Karagai) (Pugachev P.G., 1994, Vilesov E.N. et al., 2009).

The goal of this study is an experimental assessment of the possibilities for recognizing tree species in the forests of the Kostanay Region based on the analysis of seasonal changes in their spectral reflectance characteristics using Landsat 9 satellite data.

MATERIALS AND METHODS

To determine the tree species in the forest vegetation of the studied region, we systematically carried out the following tasks:

– The existing possibilities of using Earth remote sensing data have been investigated as the primary foundational information for modern monitoring and the creation of cartographic representations of forest vegetation;

– An action algorithm has been developed for identifying tree species in forests based on Landsat 9 satellite imagery characterized by high spatial resolution;

– The use of vegetation indices NDVI (Normalized Difference Vegetation Index), EVI (Enhanced vegetation index) has been investigated, and their values have been analyzed to determine tree species in the forest vegetation of the researched region;

- The data for identifying tree species in the Kostanay Region have been verified using field research and forestry materials.

The Kostanay Region was chosen as the study area to investigate the potential use of spectral channels for identifying tree species in forest vegetation based on Landsat 9 A-B satellite data. According to field research data (August-September 2023) and an analysis of specialized literature on the studied region, it was identified that the Kostanay Region is mainly characterized by coniferous (light-coniferous) and deciduous (small-leaved) forests, with dominant tree species being pine, birch, and aspen.

The main tree-forming species in the forest zone of the Kostanay Region (dark-coniferous, light-coniferous, and small-leaved) are sufficiently distinguishable in the spectra on medium and high-spatial resolution satellite images, especially in the presence of near-and mid-infrared channels.

The existence of differences in the phenological dynamics of tree species allows us to hypothesize the possibility of detecting variations in the dynamics of their spectral reflectance characteristics based on regular satellite imagery acquired with sufficiently high frequency.

The success of decoding satellite imagery also largely depends on the seasonal acquisition period. With the appropriate selection of satellite images from different seasons, it is possible to identify forest-forming tree species.

RESULTS AND DISCUSSION

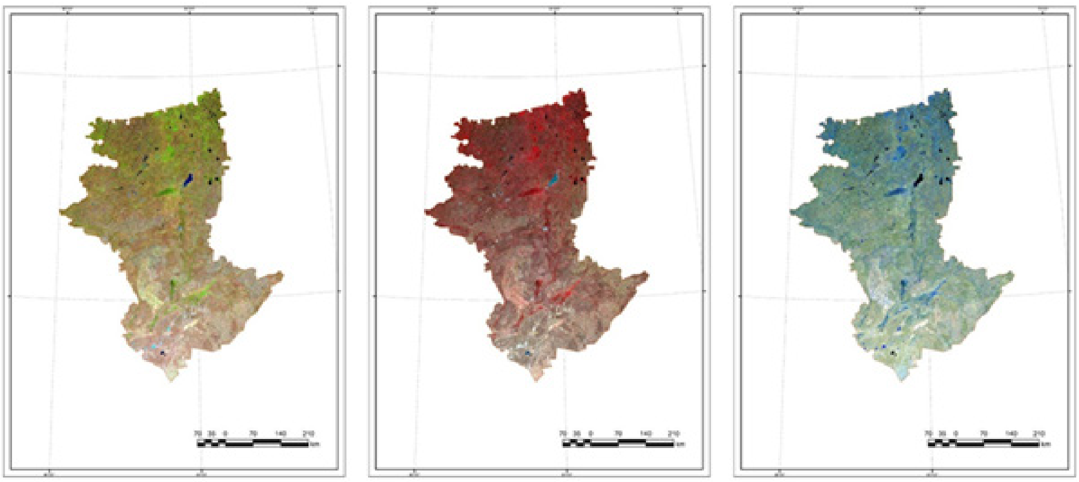
During the experiment, the changes in spectral reflectance characteristics for different tree species were investigated (Figure 1). Overall, the coefficients of spectral brightness for different types of forests vary differently across different parts of the electromagnetic spectrum depending on the season.

Figure 1 displays various combinations of Landsat 9 image channels. During the experiment, a visual assessment was conducted to determine the most suitable combination for distinguishing different tree species.

We analyzed the synthesis of Landsat 9 channels in the SWIR1(Shortwave Infared 1)-NIR (Near Infared) -RED range, where dark coniferous and light coniferous forests appear in dark green, while deciduous and small-leaved forests take on a bright green color hue.

The mixed composition of forests can be distinguished by various color transitions, primarily depending on the percentage of coniferous forests in the forest-forming tree species, as well as the age-related characteristics of the trees.

The synthesis of spectral channels in the NIR-RED-GREEN range takes on a reddish color tone. In summer season images, light-coniferous and dark-coniferous forests stand out with dark-red hues, deciduous forests primarily with a bright red color, and mixed forests acquire transitional colors (from red to bright red). Combining SWIR-NIR-RED channels allows for the differentiation of pine tree species, which exhibit a distinctive reddish tone, enabling their distinction from deciduous tree species (Figure 1).



a *b* *c*

Fig.1. *Composite images from combinations of spectral channels: a) SWIR1-NIR-RED; b) Composite image from combinations of spectral channels NIR-RED-GREEN; c) Composite image from combinations of spectral channels SWIR2 (Shortwave 2)-SWIR1(Shortwave 1)-NIR*

A distinctive feature of pine forests is often a higher brightness in the mid-infrared range of the spectrum, as well as in the visible channels.

Pine forests mainly grow on sandy soils, and the ground cover there is relatively sparse. Areas devoid of vegetation often affect spectral visibility and imagery, resulting in pronounced brightness in the mid-infrared channel and to a lesser extent in the red channel of the visible spectrum.

Thus, when using a combination of channels involving infrared, red, and green channels, coniferous forests in July images appear red, as they are the only ones containing chlorophyll in their leaves.

The combination of spectral channels SWIR1-NIR-SWIR2 does not include any channel from the visible range, and coniferous forests appear blue. This combination most distinctly highlights coniferous vegetation.

For reliable decoding of tree species in forests from satellite images during the summer period, data from the near-infrared channel is sufficiently reliable. In this channel, the crowns of leaves from small-leaved trees are visible in the images and have a higher reflectance coefficient compared to, for example, dark-coniferous and light-coniferous trees. It is also worth noting that the Red Edge spectral channel (transitional between red and near-infrared) (Shikhov A.N. et al., 2020).

Thus, during the summer months, there is a general sharp increase in the near-infrared channel for all tree species, but the difference between species remains.

It should be noted that in the visible spectrum, the differences in spectral brightness between different tree species in images during the autumn period are more informative than in the summer.

The study of vegetation indices has shown that they also effectively reflect the stages of phenological development. However, for the most effective recognition, it is necessary to use the vegetation index not as a static feature. A characteristic feature, especially for deciduous tree species, is not the vegetation index itself but its temporal changes, which reflect the succession of phenological phases. Since the difference in the rate of phenological development between different tree species can be about a week, it is advisable to select May and October images with a one-week interval, which is possible for satellites like Landsat or, for example, Landsat 9.

Table 1

The changes in NDVI values characterize tree species in different months (Munzer Nur., 2021).

	April	May	June	July	August	September	October
Birch	0,223388	0,520894	0,70422	0,599157	0,505741	0,51295	0,310513
Elm	0,187917	0,518598	0,706061	0,602858	0,493664	0,515241	0,300569
Oak	0,21253	0,514159	0,720115	0,603434	0,507393	0,526989	0,298002
Spruce	0,279356	0,467238	0,650801	0,527463	0,446498	0,48188	0,343209
Willow	0,158225	0,495745	0,681883	0,610151	0,489762	0,533074	0,317474
Maple	0,188796	0,495663	0,712973	0,609266	0,544594	0,517567	0,282917
Linden	0,208917	0,48909	0,723287	0,608096	0,500902	0,517264	0,285788
Larch	0,19222	0,530846	0,691004	0,589156	0,487296	0,506282	0,280621
Alder	0,17962	0,4714	0,692859	0,603993	0,50622	0,51977	0,324855
Aspen	0,210263	0,497455	0,694743	0,582292	0,499274	0,511341	0,294668
Rowan	0,225226	0,4809	0,61932	0,600558	0,519563	0,561196	0,371189
Pine	0,28086	0,481667	0,63969	0,531283	0,45109	0,476954	0,369742
Ash	0,159276	0,449726	0,663223	0,578212	0,466309	0,485688	0,257846

For the most effective recognition, it is necessary to use a combination of different vegetation indices. More comprehensive information about the on-site situation is provided by index images. Among the numerous spectral indices, vegetation indices are of the greatest interest for identifying tree species in forest vegetation (Munzer Nur., 2021). Based on the analysis of literary sources, spectral index indicators (NDVI, EVI, SAVI, NDMI) were calculated for differentiating the species composition of forest vegetation, and they differ in the complexity of computational operations. In the process of analyzing the results of mapping index calculations, it was found that the most indicative indices for determining tree species in forest vegetation at the level of individual indicators, based on Landsat 9 A-B data, are the normalized NDVI and EVI indices.

We analyzed the NDVI (Normalized Difference Vegetation Index), which is one of the most common vegetation indices widely used in remote sensing tasks. The advantage of using this index lies in having spectral brightness coefficients measured in each of the channels in both the numerator and denominator, allowing a significant reduction in the influence of the atmosphere and observation geometry. This enables a more accurate comparison of measurements taken at different times. The seasonal dynamics of chlorophyll content in tree leaves can be visually represented through graphs showing the seasonal dynamics of NDVI. Table 1 presents the average NDVI values by month for tree species.

The change in average values of the Normalized Difference Vegetation Index (NDVI) allows for the classification of the forested area into classes based on the values of this index. This is because different tree species have distinct periods of vegetation, leaf unfolding, and leaf fall, which is well reflected in the NDVI vegetation index and allows for the identification of certain tree species. Based on the analysis of NDVI map values, the following conclusions were drawn for the territory of the Kostanay region.

These indices provide the ability to make a detailed distinction between deciduous forests against the dominance of coniferous tree species and classify deciduous species into broad-leaved (birch) and other broad-leaved. NDVI and other spectral vegetation indices are not perfect indicators of plant biomass, but with careful analysis, they can be effective in differentiating the species composition of forest vegetation (Figure 4).

The research revealed that during the period of leaf unfolding and canopy establishment from May to September, the NDVI values for deciduous trees increase. The NDVI values for deciduous trees range from 0.55 to 0.60, while coniferous forests, such as pine, have values ranging from 0.48 to 0.35 according to our calculations. During the summer months, the NDVI values for deciduous trees show an increase.

Clearly, during the period of leaf fall and leaf unfolding from October to April, coniferous vegetation will have the highest NDVI values, allowing for the differentiation of coniferous species from deciduous ones.

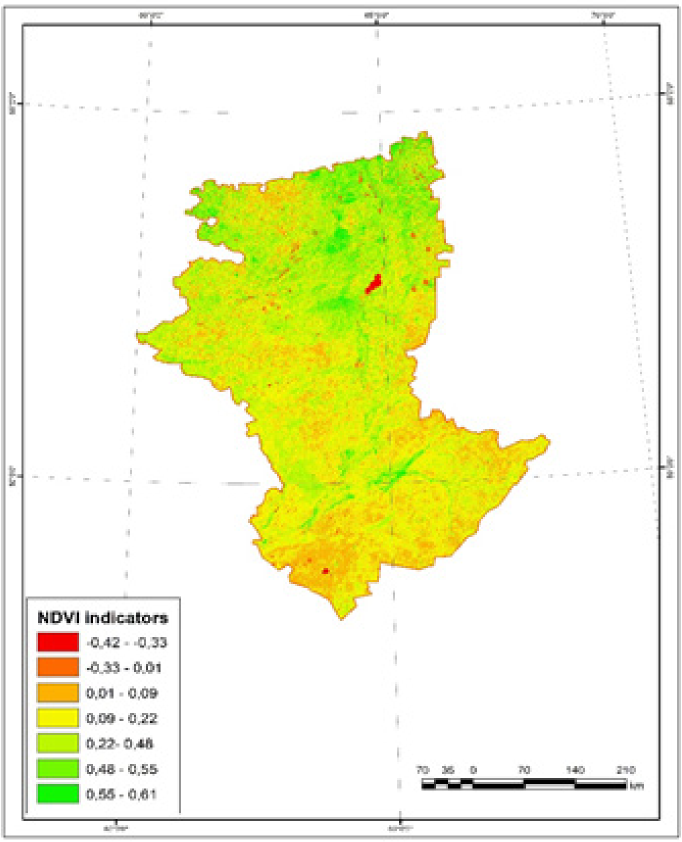


Fig. 2. *Indicators of the normalized vegetation index (NDVI) for the Kostanay region based on the materials of the Landsat 9 satellite survey, July 2023*

Closer to October, a decline in the NDVI values of deciduous trees is observed. When analyzing the seasonal dynamics of NDVI, it was found that the values of the index are higher in the summer months (June-July) than in the autumn months (September and October). This can be explained by the seasonal dynamics of the vegetation index, as plants go through all stages of vegetation during the season. As the phases of vegetative development change, the composition and content of pigments in plant leaves change, and the biomass increases, along with the amount of chlorophyll in green leaves.

As chlorophyll accumulates, the brightness of plants decreases in the visible part of the spectrum, increases in the red, and especially in the infrared region. This explains the increase in the value of the normalized difference vegetation index (NDVI).

With the breakdown of chlorophyll in the autumn months, the opposite picture is observed – brightness increases in the red zone, and decreases in the near-infrared, as seen in the analysis of the October image. NDVI values in October for deciduous forests are significantly lower than in the summer months. The decrease in index values is associated with vegetation drying out and, consequently, low chlorophyll content. This fact indicates the reliability of the applied methods in analyzing vegetation conditions.

It is known that forests of different species can demonstrate different dynamics of phenological development. For example, the appearance of leaves on birch trees usually occurs earlier than on other trees. May images generally confirm this fact, as birch, willow, maple, and rowan have the highest index values compared to other species.

The existence of differences in the phenological dynamics of tree species allows for the possibility of detecting differences in the dynamics of their spectral reflectance characteristics based on regular high-frequency satellite observations. This dynamic is particularly evident in early May, September, and early October images, as confirmed by principal component images where vegetation differentiation is maximal. It is also worth noting that the most significant differences in dynamics occur in these months, and the difference in phenological development can be about a week. This underscores the requirement for timely imaging, which should coincide with these periods. Open satellite data that meet such timeliness requirements include images from the Copernicus project's Landsat 9 satellites.

Materials from high spatial resolution satellite imagery provided the opportunity to ensure the high accuracy of reference data.

They are an integral part of the stage of performing a controlled (with training) classification necessary for the further creation of a map of woody species of forest vegetation of the Kostanay region according to the data of the Landsat 9 A-B satellite survey.

Image classification is an important part of remote sensing, image analysis, and pattern recognition. Among the possible options for supervised classification, the Mahalanobis distance method was chosen. The advantage of this classification method lies in taking into account multiple variables that are correlated with each other. Based on the data of the performed classification, a map of tree species of forest vegetation in the Kostanay region was compiled and prepared. Further differentiation and grouping into forest cover classes in the Kostanay region were carried out according to the data of the digital elevation model, the geological-geomorphological features of the research region, field studies conducted in 2023, thematic maps, and the physical geography of the studied area (Pugachev P.G., 1994, Vilesov E.N. et al. 2009, A.R. Medeu et al., 2010).

As a result of the conducted research, we identified 6 classes of forest stands in the Kostanay region, associated with specific geological-geomorphological areas and characterized by zonal features (Figure 3).

According to the geological-geomorphological features, the forest stands in the Kostanay region were differentiated into the following classes: 1) Forests of residual, erosion-denudation small watersheds (hilly watershed and hilly-valley plains) (300...450 meters above sea level); 2) Forests of abrasion-denudation layer-pedestal plains (low-undulating and hollow-basin with eluvial cover) (250...350 meters above sea level); 3) Forests of accumulative-denudation layer plains (200...300 meters above sea level);

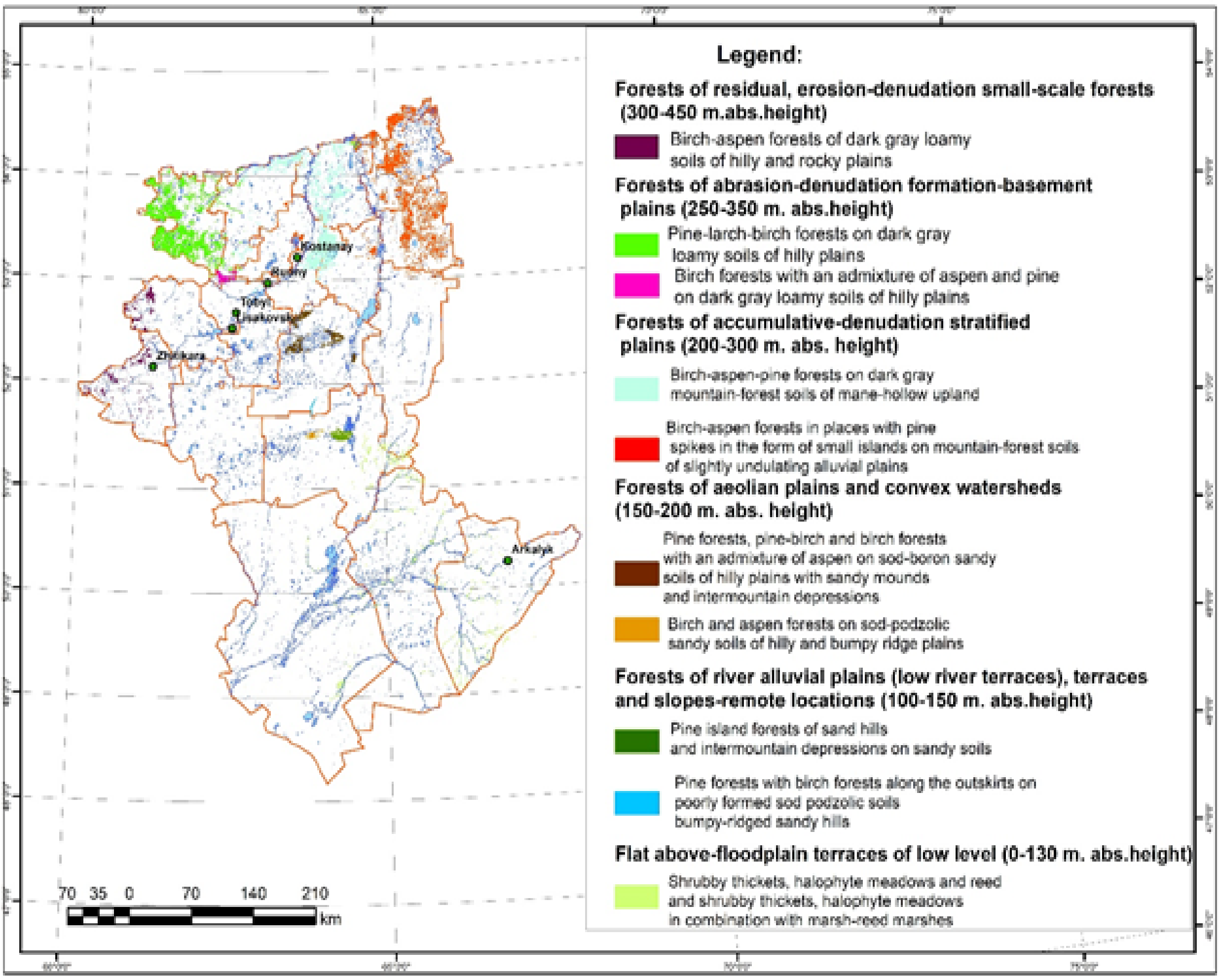


Fig. 3. *Map of tree species of forest vegetation in the Kostanay region based on the materials of the Landsat 9 satellite imagery as of July 15, 2023*

4) Forests of aeolian plains and convex watersheds (150...200 meters above sea level); 5) Forests of river alluvial plains (low river terraces), terraces, and slope-valley locations (100...150 meters above sea level); 6) Flat floodplain terraces of low level (0...130 meters above sea level).

CONCLUSION

Analyzing the Forest Tree Species Map of the Kostanay Region compiled during the study, obtained through Landsat 9 satellite imagery, it can be noted that areas with birch vegetation have a higher vegetation index compared to pine forest areas. Assessing the applicability of this methodological approach, which involves the use of an algorithm for forest mapping, it is necessary to emphasize that the accuracy of the generated maps depends on the quality and quantity of the training dataset. In images with a resolution of 10 meters, the spectral information of one pixel is a complex combination of radiation reflected from several trees, possibly of different species, and the underlying surface.

The results obtained by us provide grounds to conclude that by applying this methodological approach to higher spatial resolution satellite imagery, a more reliable classification of tree species can be achieved.

Thus, the methods we employed for identifying tree species in the forest vegetation of the Kostanay Region allowed for the differentiation of classes of forest-forming tree species in the region through the processing and analysis of remote sensing data, field research data (July 2023), and specialized literature. The synthesis method of simultaneous index and multispectral images proposed in the study enables the identification of tree species and their qualitative condition.

As a result of the conducted research in the Kostanay Region, we identified coniferous and deciduous forest-forming tree species in the studied region, such as pine, birch, aspen, larch, shrub thickets, and meadow vegetation. Further differentiation of forest stands based on physiogeographical features (landscape characteristics) allowed us to categorize them into 6 classes of forest stands and conduct their mapping.

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ҚОСТАНАЙ ОБЛЫСЫНЫҢ ОРМАНДАРЫНДАҒЫ ОРМАНТҮЗУШІ ТҰҚЫМДАР ҚҰРАМЫН ЖЕРДІ ҚАШЫҚТЫҚТАН ЗОНДТАУ ДЕРЕКТЕРІ АРҚЫЛЫ АНЫҚТАУ

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Ғылыми зерттеу барысында Қостанай облысының орман өсімдіктерінің ағаш түрлері анықталды және орман өсімдіктерінің картасы құрастырылды әр түрлі деректер бойынша: далалық материалдар, Жерді қашықтықтан зондтау мәліметтері және ArcGIS10.9 бағдарламалық құралын пайдалану арқылы және арнайы әдебиеттер материалдары негізінде. Жоғары кеңістіктік ажыратылымдықпен сипатталынатын Landsat 9 спутниктік суреттері негізінде орман ағаштарының түрлерін анықтау бойынша әрекеттер алгоритмі жасалды. Орман құраушы негізгі ағаш түрлерін анықтау Landsat 9 спектрлі каналдарының комбинациясы негізінде, жылдың әртүрлі маусымындағы өсімдіктердің индекстерін (NDVI, EVI) зерттеу және бақыланатын жергілікті бейімделу классификациясы негізінде жүзеге асырылды. Алынған деректер далалық зерттеулердің (2023 жылғы тамыз-қыркүйек) және орман шаруашылығының материалдарымен тексерілді.Таңдалған әрекеттер алгоритмі Жерді қашықтықтан зондтау арқылы алынған ғарыштық суреттерінің деректерінен қажетті материалды алу және өңдеудің ең өзекті тәсілдерін жүзеге асырады. Қостанай облысының орман өсімдіктерінің картасын одан әрі саралау және құрастыру орман өсімдіктерінің ағаш түрлері картасы, цифрлық рельеф үлгісінің деректері, зерттелетін аймақтың геологиялық және геоморфологиялық ерекшеліктері, жүргізілген далалық зерттеулер , тақырыптық карталардың материалдары және зерттелетін аймақтың физикалық географиясы негізінде жүзеге асырылды. Зерттеу нәтижесінде Қостанай облысының аумағында орман алқаптарының 6 класын анықталып сонымен қатар аймақта ақшылқылқанды, жапырақты орман құраушы түрлері анықталды, оның ішінде қарағай, қайың, көктерек, қарағай, бұта және шалғынды өсімдіктер. Бұл зерттеу алгоритмін басқа зерттеу объектілеріне қолдануға болады және практикалық маңызы бар.

Түйін сөздер: орман өсімдіктері, ағаш түрлері, Қостанай облысы, спектрлік арналар, дешифрлеу, геоақпараттық жүйелер.

ОПРЕДЕЛЕНИЕ ПОРОДНОГО СОСТАВА ЛЕСНОЙ РАСТИТЕЛЬНОСТИ КОСТАНАЙСКОЙ ОБЛАСТИ ПО ДАННЫМ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ

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В процессе научного исследования были определены древесные породы и создана карта лесной растительности Костанайской области на основе различных данных: полевых материалов, данных дистанционного зондирования Земли и с использованием программного средства ArcGIS10.9, материалов специальной литературы. Создан алгоритм действий для выявления древесных пород лесов по материалам космических снимков Landsat 9, характеризующихся высоким пространственным разрешением. Распознавание преобладающих древесных пород лесообразующих пород выполнялось на основе различных комбинации спектральных каналов снимка Landsat 9, исследованию вегетационных индексов (NDVI, EVI) в различные сезоны года и контролируемой локально-адаптивной классификации с обучением. Полученные данные были верифицированы с материалами полевых исследований (август-сентябрь 2023) и лесоустройства. Выбранный алгоритм действий реализует наиболее актуальные подходы к получению и обработке необходимого материала из данных космических снимков дистанционного зондирования Земли. Дальнейшая дифференциация и создание карты лесной растительности Костанайской области осуществлялось на основе созданной карте древесных пород лесной растительности, данным цифровой модели рельефа, геолого-геоморфологическим особенностям региона исследования, проведенным полевым исследованиям, материалам тематических карт и физической географии исследуемого региона. В результате проведенных исследований на территории Костанайской области было выделено 6 классов лесных массивов и были выделены светлохвойные, лиственные лесообразующие породы, такие как сосны, березы, осины, лиственница, кустарниковые заросли и луговая растительность. Данный алгоритм проведенных исследований могут быть применен на других объектах исследования и имеет практическое значение.

Ключевые слова: лесная растительность, древесные породы, Костанайская область, спектральные каналы, дешифрирование, геоинформационные системы.

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