Using vegetation indices to identify high chlorophyll tree cover in floodplains for carbon sequestration

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Abstract. The dynamics of changes of Chlorophyll vegetation index (CVI) and Red-edge chlorophyll index (CI_{RE}) for plant cover during the spring-summer period on river floodplains has been studied. Landscape sections with high photosynthetic activity were identified through GIS analysis. Various types of plant communities that accumulated chlorophyll during certain time periods, have been determined, as well as the areas of these types. A list of measures was proposed for plots of vegetation with an active accumulation of chlorophyll, and for plots where it is observed decreasing of its level, as well as for plots with an absence of considerable change of the content of chlorophyll level.

1 Introduction

Nowadays activity devoted to the theme of the international carbon tax and aimed at reducing of carbon dioxide emissions has been immensely developed. The Paris Agreement aimed at establishing of a new regime of international climate policy since 2020 [1], in frames of which there will be a gradual transition of the economy to low-carbon development, has an important organizing importance. It, in particular, determines the growing role of technologies and results of carbon balance monitoring. So, sharing of spatial data from remote sensing and data obtained as the result of ground-based (sub-satellite) surveys is necessary. At that, a topical task is the detection of landscape sections with plant cover having a high ecological potential (plots with high photosynthetic activity). It is possible to determine in the capacity of such plots coastal and water protection zones in river floodplains, because hydromorphic landscapes and wetland ecosystems provide an optimal natural environment for sequestration and long-term binding of atmospheric carbon dioxide [2]. Thus, in order to detect landscape sections with a high ecological potential, the monitoring of the state of vegetation in river floodplains is necessary. It is the most expedient to do this using remote sensing tools.

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For monitoring of the state of vegetation in river floodplains vegetation indices are used, with the help of which a wide range of problems is solved. For example, they allow to determine the reaction of vegetation to the impact of floods [3], they are used in creating of maps of chlorophyll fluorescence [4] and etc. To calculate vegetation indices, satellite photographs are used, for example, Sentinel-2 [5]. In our investigation for identification of plots with photosynthetic activity within river floodplains we chose: the Chlorophyll vegetation index (CVI), which can be used as a leaf chlorophyll estimator at the canopy scale for all classes of leaf inclination [6, 7], and Red-edge chlorophyll index (CI_{RE}) [8, 9], which is particularly suitable for estimating of canopy chlorophyll and nitrogen content.

2 Study area and dataset

2.1 Study area

The territory of the study area (Figure 1) is situated in the Shebekino district, in the valley of the Seversky Donets River, where 97 km from its source there is the mouth of its tributary, the Nezhegol River (with a length of 75 km).

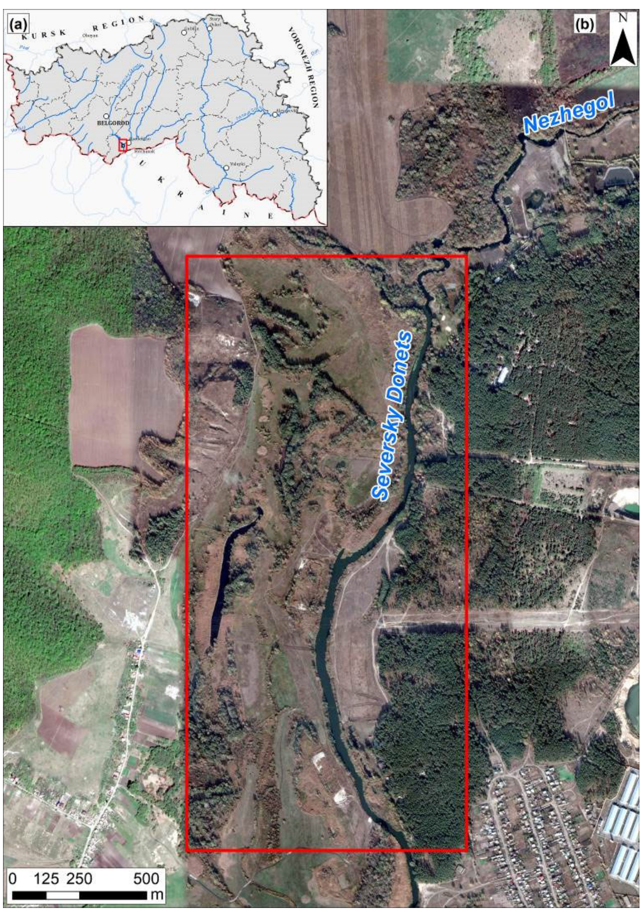

Fig. 1. Belgorod region (a) and study area (b) (the background is Google maps satellite imagery).

Most of the key territory (with a total area of 232 ha) belongs to the valley of the Seversky Donets River, and in the northern part of the key territory there is the mouth of the Nezhegol River. The landscapes of the study area belong to the class of floodplain and above-floodplain-terrace landscapes with sandy and sandy-loamy lithogenic base. The territory is a part of the Oskol and Donetsk physical-geographical region of the typical forest-steppe subzone (precipitation is 600 mm per year, average annual temperature is 7.7 °C). The investigation was carried out in the frames of the "Our Rivers" large-scale regional programme, which being based on the regional concept of the soil and water protection organization of watersheds [10] includes projects for clearing water objects, assessment of the risk of flooding of settlements, as well as developing of water protection zones [11].

2.2 Dataset

The initial data for the investigation included Sentinel-2 satellite photographs taken during the spring-summer period of 2021 with cloud coverage of no more than 10%. The results of the interpretation of space photographs, data of field observations, the results of the analysis of forest management maps, geobotanical and landscape maps were used to determine the types of vegetation.

3 Methods

The CVI index rasters were obtained in the ArcGIS 10.5 programme with the help of the "Raster calculator" tool for the following dates: 23.05.2021, 25.06.2021, 30.07.2021, 24.08.2021 using the formula (1):

$$CVI = (Band8/Band3)\cdot(Band4/Band3). \quad (1)$$

To obtain CI_{RE} index rasters for the same dates the formula (2) was used:

$$CI_{RE} = Band7/Band5-1. \quad (2)$$

For identification of plots where there is an increase or decrease of the level of chlorophyll in the vegetation cover during the spring-summer period, a subtraction from the CVI index raster for a later date of the CVI index raster for an earlier date was carried out. The same was done concerning the CI_{RE} index. A comparison of the vector layer containing information about vegetation types with vector layers which show the values of the difference between CVI rasters was carried out with the help of "Intersect" tool.

4 Results and discussion

To solve the problem for identification of plots with high photosynthetic activity we obtained 4 rasters of the CVI index and 3 rasters showing the difference between the rasters (Figure 2). Also, 4 rasters of CI_{RE} index were obtained, as well as 3 rasters showing the difference between the rasters (Figure 3).

By analyzing rasters which show the difference between rasters of CVI index and rasters mirroring the difference between rasters of CI_{RE} index, important regularities can be identified. The change in the CVI index is characterized by the prevalence of chlorophyll accumulation over its decrease during the period from 23.05.2021 to 25.06.2021, then the decrease of the chlorophyll level prevails over its accumulation during the period from 25.06.2021 to 24.08.2021, while on a significant part of the territory the level of chlorophyll content does not fluctuate immensely.

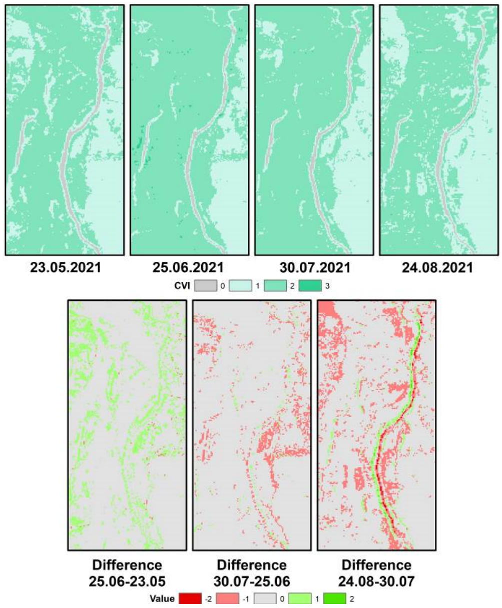

Fig. 2. Change in the CVI index for the period from 23.05.2021 to 24.08.2021 and the magnitude of the difference between the rasters.

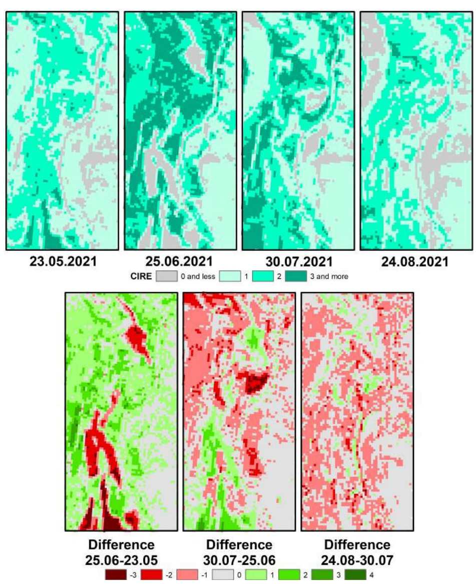

Fig. 3. Change in the CI_{RE} index for the period from 23.05.2021 to 24.08.2021 and the magnitude of the difference between the rasters.

It should be noted that during the period from 30.07.2021 to 24.08.2021, an increase of the level of chlorophyll content is typical for vegetation plots situated along the right bank of the Seversky Donets River in a zone about 30 m wide which is adjacent to the bank (it's located within the riverside protective zone). In general, it can be noted that an increase of the values of the CVI index is typical for these plots during the spring-summer period, and in the period 25.06.2021-30.07.2021 it is typical only for a little amount of plots in the riverside zone. As for the change of the CI_{RE} index, it should be noted that during the period from 23.05.2021 to 25.06.2021 a considerable decrease of the level of chlorophyll content was detected on a part of the key plot (the minimum value reaches -3), which is explained by the low density of vegetation cover according to the satellite photograph dated by 25.06.2021. At that, during the period from 25.06.2021 to 30.07.2021, on the plots, where a decrease of the CI_{RE} index was observed earlier, the chlorophyll content increased, while on the rest territory of the key plot it decreased or did not change. Thus, the analysis of changes of the CVI and CI_{RE} indices during the spring-summer period shows that these indices detect in different ways the peculiarities of changes of the chlorophyll content in the vegetation of river floodplains, and the changes detected with the help of one index may remain "unnoticed" when another index is used. Therefore, for a complex assessment of changes of the chlorophyll content for vegetation plots situated within river floodplains, it is expedient to use a wider set of vegetation indices, then it is necessary to verify these plots on the locality and to carry out more detailed observations on them.

To understand in which namely plant communities chlorophyll accumulates during certain durations of the spring-summer period, GIS analysis was carried out, in the course of which, first of all, through the interpretation of satellite photographs, field observations and analysis of cartographic sources the vegetation types were determined. Then the vegetation types were mapped digitally, particularly as a vector layer of polygon type of a geodatabase. The types of plant communities which accumulated chlorophyll in certain periods of time were identified (based on the analysis of changes of the CVI index), and the sizes of the plots of these types of vegetation were determined. The results of this analysis are presented in table 1.

Table 1. Types of plant communities for which the value of CVI increased and their area.

Raster name	Vegetation types corresponding to positive values	Area, ha
Difference 25.06-23.05	marsh-grass-sedge meadow	3.15
	grass-forb meadow	9.39
	artificial pine forests	3.33
	sedge-reed marshy meadows and swamps	4.24
	floodplain forests dominated by willow and black alder	12.43
Difference 30.07-25.06	marsh-grass-sedge meadow	0.25
	grass-forb meadow	0.35
	artificial pine forests	0.20
	sedge-reed marshy meadows and swamps	0.47
	floodplain forests dominated by willow and black alder	1.07
Difference 24.08-30.07	marsh-grass-sedge meadow	0.63
	grass-forb meadow	0.47
	artificial pine forests	0.79
	sedge-reed marshy meadows and swamps	1.31
	floodplain forests dominated by willow and black alder	1.37

Analysis of the data presented in table 1 allows to conclude that the total area of plots where chlorophyll accumulated during the period from 23.05.2021 till 30.07.2021 decreased from 32.54 ha to 2.34 ha, and then it increased to 4.57 ha by 24.08.2021, which is about 2% of the total area of the key plot (232 ha).

For plant communities, depending on their ability to accumulate chlorophyll, a number of measures are offered. In plots where the content of chlorophyll gradually decreases during the vegetation period, it is necessary to carry out actions for planting of trees with high reserves of chlorophyll in the leaves, and cleaning up old, withered trees. It is also possible to create combinations of trees of such species, which are similar by composition to the species of plots where the chlorophyll content has not decreased by August, if the landscape conditions are similar (steep slope and exposure of inclinations, conditions of moistening, soils, soil-forming rocks). Landscape sections, where the chlorophyll content remained constant, should be taken under a special control, considering them as model communities with stable biophysical parameters. While determining their species composition and structure, recommendations can be elaborated for biotechnical measures in concrete soil and climatic conditions. Also, such areas should be under control for monitoring of the carbon dioxide absorption and can be defined as research testing areas which provide perfecting of technologies for optimal efficiency in carbon sequestration.

5 Conclusion

The results of the investigation showed that using various vegetation indices showing the content of chlorophyll in the vegetation cover, it is possible to solve the problem of identification of landscape sections with a high reserve of chlorophyll and high photosynthetic activity, or, on the contrary, with chlorophyll deficiency and low photosynthetic activity, in relation to floodplains of flat rivers, where there are forests, meadows, swamps, i.e. different types of plant communities with different reserves of chlorophyll in the overground layer of ecosystems. For a more detailed study of the dynamics of changes in the chlorophyll content in the vegetation cover, it is expedient both to increase the number and frequency of observations during one year and conducting of additional analysis of data for previous years, at that it is preferable to use a wider set of vegetation indices along with field observations. By such way it is possible to detect the potential and contribution of the overground layer of valley-river landscapes in carbon sequestration.

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