PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

ALTERAÇÕES SAZONAIS E A LONGO PRAZO DO ÍNDICE DE VEGETAÇÃO DE TERRAS ARÁVEIS DA REGIÃO DE BRYANSK (RÚSSIA CENTRAL): REGULARIDADES E FATORES DINÂMICOS

SEASONAL AND LONG-TERM CHANGES OF VEGETATION INDEX OF ARABLE LANDS OF BRYANSK REGION (CENTRAL RUSSIA): REGULARITIES AND DYNAMICS FACTORS

СЕЗОННЫЕ И МНОГОЛЕТНИЕ ИЗМЕНЕНИЯ ВЕГЕТАЦИОННОГО ИНДЕКСА ПАХОТНЫХ ЗЕМЕЛЬ БРЯНСКОЙ ОБЛАСТИ (ЦЕНТРАЛЬНАЯ РОССИЯ): ЗАКОНОМЕРНОСТИ И ФАКТОРЫ ДИНАМИКИ

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Received 16 January 2020; received in revised form 16 March 2020; accepted 26 March 2020

RESUMO

Existem vários fatores diferentes que afetam o desenvolvimento sustentável da agricultura. Uso eficiente dos recursos terrestres e hídricos, levando em consideração as ameaças que podem surgir como resultado das mudanças climáticas, bem como a dinâmica do crescimento e desenvolvimento das plantas. Os índices de vegetação desempenham um papel importante no monitoramento das variações da vegetação. Este artigo fornece informações sobre as mudanças sazonais e de longo prazo no EVI (índice de vegetação expandida) de terras aráveis em Bryanskaya Óblast. O objetivo do artigo é identificar a dinâmica sazonal do indicador, os intervalos de sua variabilidade, as prováveis causas das diferenças entre anos 2000-2018. Neste artigo, os métodos de pesquisa físicos e químicos foram usados para calcular o conteúdo de húmus, as características da topografia da superfície e as características do uso agrícola com base nos materiais cartográficos e de origem; a composição e densidade do solo foram determinadas usando trabalho de campo. Apresenta-se o material resumido sobre as alterações nos valores de EVI para o período sem neve como um todo e para os intervalos individuais da pesquisa (18 por ano) em 2000-2018. É descrito o mecanismo da influência de várias condições da vegetação edáfica sobre as diferenças de suavização no EVI ao longo de vários anos com diferentes condições meteorológicas. São apresentados os resultados da análise de fatores da dinâmica de longo prazo, o papel das flutuações climáticas de curto prazo, a diminuição progressiva das chuvas e mudanças na composição de espécies de culturas na dinâmica de longo prazo. EVI é demonstrado.

Palavras-chave: *índice vegetativo expandido, terras aráveis, dinâmica sazonal das condições da vegetação, dinâmica de longo prazo dos fatores da vegetação, agrocenose.*

ABSTRACT

There are a number of different factors that affect the sustainable development of agriculture. Efficient use of land and water resources, taking into account the threats that may arise due to climate change, as well as the dynamics of plant growth and development. Vegetation indices play an important role in monitoring vegetation variations. This article provides information on seasonal and long-term changes in the EVI (Enhanced Vegetation Index) of arable land in the Bryansk region. The purpose of the article is to discern the course of the seasonal dynamics of the index, the ranges of its variability, probable causes of differences between 2000-2018. In this article, physicochemical research methods were used to calculate the humus content, surface topography characteristics, and agricultural use features based on cartographic and stock materials, and the soil composition and density were determined through fieldwork. Summarized material on changes in EVI values for a snowless period as a whole and for individual filming intervals (18 per year) in 2000-2018 is presented. The mechanism of the influence of a variety of edaphic vegetation conditions on smoothing the differences in EVI over a series of

DOI: 10.52571/PTQ.v17.n34.2020.769_P34_pgs_745_755.pdf

years with different meteorological conditions has been described. The results of the analysis of the factors of the long-term dynamics are presented, the role of short-term climatic fluctuations, a progressive decrease in the amount of precipitation, and changes in the species composition of grain crops in the long-term dynamics of EVI are demonstrated.

Keywords: *enhanced vegetation index, seasonal dynamics, conditions, factors, agrocenosis*.

АННОТАЦИЯ

Существует ряд различных факторов, которые влияют на устойчивое развитие сельского хозяйства. Эффективное использование земельных и водных ресурсов с учетом угроз, которые могут возникнуть в результате изменения климата, а также динамики роста и развития растений. Индексы растительности играют важную роль в мониторинге вариаций растительности. В данной статье представлена информация о сезонных и долгосрочных изменениях EVI (расширенного индекса растительности) пахотных земель в Брянской области. Целью статьи является выявление динамики сезонной динамики показателя, диапазонов его изменчивости, вероятных причин различий между 2000-2018 гг. В этой статье физико-химические методы исследования использовались для расчета содержания гумуса, характеристик топографии поверхности и особенностей сельскохозяйственного использования на основе картографических и исходных материалов, а состав и плотность почвы определялись с помощью полевых работ. Представлен обобщенный материал об изменениях значений EVI для бесснежного периода в целом и для отдельных интервалов съемок (18 в год) в 2000-2018 гг. Описан механизм влияния различных условий эдафической растительности на сглаживание различий в EVI в течение ряда лет с различными метеорологическими условиями. Представлены результаты анализа факторов многолетней динамики, роли кратковременных климатических колебаний, прогрессивного уменьшения количества осадков и изменения видового состава зерновых культур в многолетней динамике. EVI демонстрируется.

Ключевые слова: *расширенный вегетативный индекс, пахотные угодья, сезонная динамика условий вегетации, многолетняя динамика факторов вегетации, агроценоз.*

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1. INTRODUCTION

Sustainable agricultural development is recognized as one of the main conditions for the practical implementation of the goals outlined in the Millennium Declaration (Resolution adopted by the General Assembly..., 2015). The principles of such development, in particular, are the efficient use of land and water resources of agriculture; climate change-related threats are based on up-to-date information on the dynamics of farmland productivity (Bobylev and Grigoryev, 2016; Liu *et al.,* 2014; Trushkov *et al.,* 2019). On their basis, ideas about the significance of individual factors of vegetation are formed; the conformity of management decisions to changes in environmental conditions is assessed; the dynamics of the state of agro-landscapes is forecasted. An important source of information on farmland productivity comes from multi-zone satellite filming (Ambika and Mishra, 2019; Jaafar and Ahmad, 2015; Reyes-Díez *et al.,* 2015; Rokni and Musa, 2019). The "specialization" of satellite images as a source of information is associated with wide possibilities for analyzing the state and dynamics of agrocenoses of large regions with an area of tens of thousands of square kilometers, with a distraction from local variability of vegetation factors. The experience of satellite filming for sustainable agriculture in Central Russia is relatively small, but at the same time, it is interesting for the wide variety of edaphic conditions and the instability of weather conditions both within the growing season and in a number of years (Biewer *et al.,* 2009; Grzegozewski *et al.,* 2017; Sarmah *et al.,* 2018; Sobhani *et al.,* 2018).

The primary material for the analysis of long-term changes in the productivity of arable land by remote methods is data on the geographical distribution of vegetation indices (VI). Vegetation indices are a family of indicators that express the ratio of the spectral brightness of the surface in the red and near-infrared range. The indicative properties of the indices are theoretically justified by the dependence of the surface absorption intensity in the red spectrum on the concentration of chlorophyll molecules. The content of chlorophyll characterizes the physiological state of plants, and through it – the primary productivity of the vegetation cover. The value of productivity, in turn, characterizes the intensity and direction of the processes occurring in the landscape. The distribution of vegetation indices in space reflects differences in factors affecting the growth and development of plants (edaphic, climatic). Based on theoretical ideas about the nature of vegetation indices, their dynamics over time follow seasonal and long-term changes in the state of landscapes. The integrated nature of vegetation indices determines interest to apply them in remote monitoring of natural landscapes and agricultural land (Wardlow *et al.,* 2007; Cherepanov, 2011; Terekhin and Posternak, 2019; Panigrahi *et al.,* 2019).

Over the decades of operation of remote monitoring programs, a lot of factual material has been collected on the distribution of vegetation indices. Based on the interpretation of their differences in time and space, models are constructed that explain the differences in the VI in space and time within the boundaries of one region or type of landscape. The spatial resolution of surveys in satellite monitoring programs allows tracking the dynamics of VI at the level of a large region, agricultural land, or individual arable land. Studies of indicator properties, patterns of VI distribution in space and time are at an empirical level. For some types of natural and cultural communities, relationships between the distribution of VI in space with the species composition, age structure, and direction of changes in productivity have been established and justified (Tsalyuk *et al*., 2017; Zewdie *et al*., 2017; Cho *et al.,* 2014). At a qualitative and quantitative level, relationships have been established between individual spectral and other topographic, physical, physicochemical surface characteristics that affect the distribution of vegetation indices (Cabello *et al*., 2012a). Methods are being developed for applying information on vegetation indices to agricultural management (Sakharova *et al*., 2015; Kern *et al*., 2018; Nagy *et al*., 2018).

At the same time, modern models of the distribution of index values are distinguished by a low level of generalization, “tied” to the features of the structure and dynamics of the landscapes of the model territory. The possibilities of transferring methods and approaches from other objects of study are limited, first of all, in explaining the reasons for the differences in vegetation indices of surface areas in space and time. A low level of theoretical generalizations retains the relevance of studying the factors of the distribution of VI of objects at the regional and local levels or their types. Information on the geographical distribution and dynamics of indexes of individual territories form the basis for evaluating higher-level processes. In particular, the study of the dynamics of VI contributes to the creation of a general picture of changes in the productivity of landscapes of large regions under conditions of modern climate warming (Dubovyk *et al*., 2015; Gopp *et al.,* 2018; Phompila *et al.,* 2015; Zhao *et al.,* 2020).

Changes in the productivity of arable land agrocenoses are revealed in the differences in the distribution of VI in a series of satellite images of the territory taken at the same time intervals. Distributions are compared according to the average values of the index, the variation range, and the statistical characteristics of the deviation. Seasonal changes in the distribution can be seen in the pictures, repeated after a few days or one or two weeks (depending on the phase of vegetation). Long-term changes in vegetation indexes are manifested in two aspects: features of seasonal dynamics in years with different vegetation conditions and differences in distribution characteristics in images repeated after a year. The seasonal dynamics of vegetation indexes reflect a regular change in the state of agrocenoses, which is interpreted unambiguously – as a change in the physiological state of plants in development phases. The interpretation of long-term dynamics is a much more difficult task for territories with a wide variety of vegetation conditions and different specialization of agricultural enterprises (Cabello *et al.,* 2012b).

A comparison of the dynamics of the VI of the surface of the plots with different types of plants, natural conditions of vegetation, and land use features allows highlighting the changes determined by local causes and processes of regional and (or) global rank. The influence of the latter is manifested in similar changes in the productivity of sites with unequal vegetation conditions and species composition of plants (Piedallu *et al*., 2018; Chen *et al.,* 2015; Mengue *et al.,* 2019). The causes of differences in dynamics are rarely detected by statistical methods due to the wide variety of vegetation conditions and the weak connection between the productivity dynamics and the factors determining it. To explain the local features of seasonal and long-term dynamics of vegetation, one has to resort to a detailed study of the conditions of heat and moisture supply. Along with natural factors, the state of cultivated vegetation is determined by the features of the farming system, which is understood as technical, technological, and organizational decisions in the use of arable land affecting their productivity. Natural factors act on the dynamics of productivity through short-period fluctuations in meteorological conditions of vegetation and long-term steady changes in the climate system. The fluctuations in heat and moisture supply are consistent with alternating periods of high and low VI values in a number of years (Lobanov *et al*., 2018; Lobanov *et al*., 2019). The directed long-term changes are manifested in productivity shifts, which are explained by steady shifts in the heat and moisture supply of cultivated plants. Changes in the agricultural system affect the distribution of VI through the development of agricultural machinery, crop cultivation technologies, and especially the demand for agricultural products. At the level of individual farms, changes are manifested in a change in land structure, crop rotation, intensity, and direction of land reclamation. Changes determine rapid changes in the value of the state of agrocenoses; therefore, vegetation indexes of arable land plots can vary greatly from year to year. The separation of the contribution of natural and technical and economic factors to the dynamics of productivity is revealed by involving materials on the state of agricultural production of the model territory. Therefore, the aim of this study was to identify the dynamics of the seasonal dynamics of the indicator, the ranges of its variability, and the probable causes of differences between 2000-2018.

2. MATERIALS AND METHODS

The patterns of changes in vegetation indexes over time are considered for arable land in the Bryansk region – a region with an area of 34.5 thousand square km located in the southwestern part of Russia, in the northern part of the river Dnieper basin. The territory of the Bryansk region is stretched for 250 km from west to east, 150 km from north to south. The relief is flat, with heights of watershed surfaces from 240-260 m in the north and east, to 140-160 m in the southwest (Rybalsky *et al.,* 2007) (Figure 1). The average temperature at the beginning of the 21st century is 7.1°C, and the minimum temperature is – 28.4°C, the maximum +38.3°C, 630 mm of precipitation falls annually, mainly in the form of rain. Snow cover is usually set in September, destroyed in March. The nature of the relief determines small differences in the main climatic within the region, but long-term climate variability is very high. Quasi-rhythmic fluctuations of the main climatic characteristics are characteristic with a frequency of several years (Climatic Data, 2019). A slight growth trend is expressed in temperature changes from the beginning of the century, on the contrary, the amount of precipitation decreased by 25%. A significant part of the watersheds is occupied by arable land. Many lands are ploughed up from the Middle Ages (10-13 centuries) so that the natural low-fertile soils of the southern part of the forest zone are significantly transformed.

The primary research material was the data of the MOD13 product – data of multi-stage automatic processing of medium resolution satellite images obtained by the MODIS spectroradiometer (Earth Explorer, 2019). The product provides information on the distribution of the maximum values of Enhanced vegetation index (EVI) for intervals of 16 days with a spatial resolution of 250 m, after geometric and atmospheric correction and linkage of the satellite image to the coordinate system. The index value (EVI) is determined through the ratio of the spectral brightness of the surface in the near-infrared, red, and blue range with correction factors (Equation 1):

$$EVI = G \times \frac{NIR-Red}{NIR+C_1 \times Red-C_2 \times Blue+L} \qquad \text{(Eq. 1)}$$

Where NIR, Red, Blue – the spectral brightness coefficients in the near-infrared region, the red, blue region of the spectrum; G, C1, C2, L empirical coefficients equal respectively to 2.5; 6.0; 7.5 and 1.0, respectively (Huete *et al*., 1999; Huete *et al*., 2002; Justice *et al*., 2002).

The use of MOD13 as a source of primary research material corresponds to the level of diversity of natural and economic conditions for the growth and development of plants. The average resolution of the images allows for tracking the main patterns of changes in the index values in time and space for arable land; Moreover, local differences in the spectral characteristics of the surface, which greatly complicate the distribution pattern, are not specifically considered. The study uses satellite images of the surface in the time interval from the second decade of February to early December. From mid-December to early March, the surface is usually covered with snow, although the timing of snow cover may vary from year to year by several weeks.

A correct interpretation of the differences in the index in time and space on the terrain is provided by information on vegetation conditions on 255 key plots of arable land with an area of 150 hectares each. For the plots, the mechanical composition and density of soil compaction (fieldwork), the content of humus (by physicochemical methods), the characteristics of the surface topography, and the features of agricultural use (from cartographic and stock materials) are determined. The selection of key objects reflects the diversity of combinations of natural and economic factors of vegetation.

The relief of the territory occupied by arable land is mostly homogeneous. Arable lands occupy flat or slightly inclined (up to 2°) watershed surfaces in the southern part of the forest zone. The lithological composition of parent rocks and the mechanical composition of soils are much more diverse. Fine-grained sands, sandy loams, and light loams are typical, soils on heavy mechanical composition and large sands are rarely ploughed. The prevalence of loamy and sandy loamy arable soils is explained by the history of the development of the territory. For arable land, first of all, elevated, well-drained areas with a flushing water regime were used, such a direction of the use of the territory has been preserved to this day. The average humus content varies from 0.8 to 4.5%, depending on a combination of natural and anthropogenic factors.

The natural fertility of soils on the watersheds generally decreases from convex, elevated areas, composed of loessoid loams and sandy loams, to flat, relatively low, folded water-ice sands. The characteristics of arable soils in the region are strongly altered by long-term agricultural development. The most significant effect on the soil occurs in the second half of the 20th century in connection with the targeted improvement of agrochemical characteristics by the introduction of fertilizers and a decrease in acidity. Despite the decrease in the activity of regulating the properties of soils in the 90s of the 20th century, the humus content on many arable lands exceeds the average value for natural soils. At the same time, there are plots of arable land with a low humus content and a dense surface horizon that have lost fertility due to surface erosion and the removal of nutrients from the crop (Mameev *et al.*, 2016).

The sown area is occupied by crops – winter and spring wheat, spring barley, oats, corn for grain; buckwheat, oilseed crops are less common. The ratio of grain areas has changed from the beginning of the century – the proportion of crops of spring crops and corn has increased. At the beginning of the first decade of the 21st century, the areas under crops of winter rye and wheat were correlated as 5 to 3; in the second one, as 1 to 2. The rational selection of crops partially compensates for the adverse changes in vegetation conditions due to climate fluctuations. Differences in vegetation conditions are manifested in fluctuations in the yield of grain crops, which varies significantly over the years and seasons.

3. RESULTS AND DISCUSSION:

The EVI values of key areas vary in the shooting interval by a value from a few to the first hundred percent. The differences are explained by the unequal species composition of crops, the geographical features of the thermal and water regimes of soils, and the technology of agricultural work. The composition of crops affects the distribution of EVI through physiological differences in the growth and development of varieties and species of agricultural plants – the rate of biomass accumulation, changes in the projective cover over time, and photosynthesis rate. Differences in the thermal and water regimes determine the favorable conditions for the growth and development of plants, and through them, the timing of the onset of vegetation stages in crops of different species composition. The composition of technological methods (selection of crops, terms of tillage, use of fertilizers, plant protection products) sets the timing of vegetation and the state of vegetation, as well as natural factors – over a wide range. A wide variety of options for combining natural and economic conditions is consistent with the “colorful” picture of the distribution of EVI values in space, the explanation of which is not limited to one- or two-factor models. At the same time, the absolute value of the index and its position in the ranked series of values are in good agreement with information on the differences in arable land.

The distribution of the average long-term values of the VI by the intervals is presented in Figure 2. The direction and magnitude of changes in the index are in good agreement with ideas about physical processes in agro-landscapes.

In late winter and early spring, the average EVI value is explained by the ratio of the areas of plots still covered with snow and freed from it. The surface of the latter can be open (under “steam”) or occupied by winter crops. The values of EVIs of surfaces of different types are usually significantly different: with a snow cover close to zero with open soil under the steam of less than 0.2, under winter crops about 0.2. At this time, the projective cover under crops is small. Therefore, the average spectral characteristics are close to those for open soil. EVI growth is driven by the gradual, uneven destruction of snow cover. The difference between the dates of snow cover melting in the southwest (the warmest part of the region) and the north (the coldest part) is two weeks. First, elevated, well-heated sections of the southern exposure are freed from snow, then – flat surfaces, the last –

lowering and flat watershed surfaces with weak drainage.

The snow melting provides an increase in the index values usually until mid-April; depending on weather conditions – until early April – early May. With the growth of winter crops and the beginning of vegetation of spring crops, EVI values grow rapidly over 3–4 weeks and reach 0.40–0.45 in mid-May. The index growth is provided by an increase in the area of cereal leaves and projective cover. In late May - early June, index growth slows. The EVI values reach a maximum (0.5-0.6), change little overtime for some time, and gradually decrease at the end of summer and autumn with a decrease in vegetation activity. The decline in EVI values begins in the second half of summer, due to a decrease in the leaf (photosynthetic) surface as the grains ripen, and decreases to values characteristic of the open soil surface by early November due to a decrease in the photosynthetic activity of winter crops. A critical factor in the rate of decline of EVI values is moisture availability.

The values of VI in years with a drought in the second half of summer (2010) decrease after the maximum faster than the average for a long period and then reach a plateau. In late summer and early fall, the rate of decrease in EVI is affected by grain harvesting and soil preparation for sowing winter crops. Treated open soil areas with a low EVI value reduce the average index values. At the end of the calendar autumn – the beginning of the calendar winter, the average EVI values decrease to 0.2-0.1. The spectral properties of the surface are determined by the ratio of the areas with the open surface of the soil, crop residues, and crops of winter cereals. With the establishment of snow cover, EVI values tend to zero 0, and sometimes they become negative – with high water content in the snow. The seasonal dynamics of EVI differ in a number of years in the amplitude of values, the duration of periods of growth, decline and relative stability, and the rate of change of vegetation.

The average EVI values for the entire shooting period (from February to December) slightly increase in a number of years – from 0.30 to 0.32 (Figure 3).

A small increase is formed by the small amplitude of fluctuations in the index values in the intervals near the maximum vegetation (the first half of the calendar summer). The EVI values in the intervals near the borders of the vegetation period (beginning of spring and late autumn) vary quite noticeably in a number of years – by several tens of percent, but their contribution to the general trend is small due to small absolute values. The distribution of EVI values relative to the long-term average is unstable in a series of years in two aspects. The first is the inconstancy of periods of high and low index values in a certain interval, the duration of which is from one to four years. The second is the unequal position of the index values relative to the annual average for the year as a whole and for individual intervals of the growing season. In years with high (or low) average EVI values, intervals of the growing season with the opposite position of the index values are distinguished (Table 1).

The amplitude of average EVI values in 2000-2018 varies widely – from 0.39 to 0.58, depending on the time of destruction (less often – formation) of the snow cover and favorable weather conditions for vegetation in spring. The lower limit of EVI values determines the duration of snow cover. The index value for the open soil surface is significantly higher than for areas covered with snow; therefore, their ratio of areas determines the EVI value in early spring or late autumn.

The upper limit of EVI is determined by the meteorological conditions of spring. The maximum values of the index correspond to the winter ripening phase, which usually occurs in mid-June (12 years out of 19). Less often, the maximum occurs in early June or early July, and the values change in a series of years no more than 10%. Minor differences are probably due to two reasons. The first is uneven, and in some cases, multidirectional, the influence of weather on vegetation conditions over time intervals of different durations (from several days to the phenological season). In wet years, the best conditions for plant growth and development are characteristic of well-drained areas; in dry, on the contrary, for arable land covered with poorly permeable soils and muds; soils that retain moisture. The second reason is the great variability of the weather at the beginning of the growing season. Seasonal spring warming occurs unevenly, gives way to severe cold, which dramatically slows down the vegetation. Typically, the maximum values of vegetation are less in years with long and strong cooling in April and May.

EVI values are steadily increasing until the time of the beginning of active vegetation (mid-April), with the maximum growth rate occurring in late February – early March. The direction of the dynamics of the index at the end of winter is in good agreement with the increase in average temperature and, accordingly, the early periods of snow cover destruction. The large variability of the snow cover melting dates determines the largest (in the period from February to December) amplitude of the EVI values. The percentage deviation of the VI from the mean annual values exceeds 150%.

In the middle of spring (April), the dynamics of EVI values and temperatures are multidirectional: an increase in the index occurs against a background of lower air temperatures. The increase in EVI in this period is due to the long "protracted" spring, which is typical for Central Russia in the second decade of the 21st century. The middle of spring at the end of the 2nd decade is colder than at the beginning of the century, but as a rule, active vegetation is already going on in arable lands in April. The values of the index in late spring (late April – mid-May) as a whole increase in agreement with the trend of temperature growth, which provides more favorable vegetation conditions. However, the growth rate of EVI values directly depends on the amount of precipitation. A significant increase is noted in April (temperature and precipitation increase) and insignificant in May (temperature rises, but precipitation decreases). The dynamics of the index is in good agreement with the well-known regularity of functioning of the agro-landscapes of Central Russia – the amount of water in the soil in spring acts as a critical factor at the beginning of the growing season in the south of the forest and north of the forest-steppe zone. In recent decades, the amount of moisture in the soil has been decreasing due to frequent thaws and small reserves of water in the snow by the beginning of melting.

Near the vegetation maximum (June-July), the EVI values change little in a number of years. The difference between maximums and long-term average values does not exceed 5.5% – the smallest deviation in comparison with other shooting periods. In general, the index values slightly decrease from the beginning of the century to the present. Quasi-rhythmic oscillations with a frequency of 2-3 years overlap the trend. Fluctuations are caused by a rhythmic change in humidification conditions (a combination of temperature and precipitation). According to the dynamics of weather conditions, rhythm is better expressed in the first half of June and mid-July, worse at the border of the months. In June, the dynamics of EVI values are associated mainly with meteorological conditions of previous weeks. Low index values in June are preceded by periods of dry and (or) cold weather. In July, low index values are typical for shooting intervals with low rainfall and high temperatures. The lack of moisture in combination with high temperatures creates the least favorable conditions for vegetation, and therefore, in dry and hot years, the index values tend to a minimum. Rare years with exceptionally high rainfall in early summer (more than 200 mm in late June – early July 2011) also have low index values.

The vegetation recession period (late July – late August) is also characterized by the constancy of EVI values. The average deviation from perennial values does not exceed 6%. The rhythm of fluctuations is less pronounced than during the maximum of vegetation. Several isolated minima and maxima of EVI values alternate with periods of weak index changes lasting several years. The change in the index, as well as in the previous phase of the growing season, is determined by humidification conditions and agrotechnical measures. The periods of dry and hot weather coincide in time with the lows of vegetation or precede them.

In late August – mid-September, the pattern of the distribution of the vegetation index is affected by soil preparation for winter crops. The timing of the start of soil cultivation and sowing strongly depends on the moisture content of the last months of summer and weather forecasts for the beginning of autumn. Therefore, they differ in time by one to two weeks. Differences are reflected in the quasi-rhythmic distribution of index values over a series of years. The low values of the index most often correspond to the worst wetting conditions, sometimes in combination with low temperatures. In October, the long-term dynamics of the index is due to differences in winter vegetation conditions; the average deviation in a number of years is 12%. The general direction of changes is poorly expressed, however, the meteorological conditions of mid-autumn have noticeably changed since the beginning of the century – a steady decrease in temperature of 1-2°C is combined with a small amount of precipitation of 10-20 mm. Apparently, the conditions of autumn differences in heat and moisture do not fundamentally affect the speed of vegetation, therefore, the average value of the index varies slightly. Low values in a number of years are due to a sharp deterioration in the supply of crops with heat and vegetation conditions in September. The long-term dynamics of EVI in November is mainly due to the difference in the timing of snow cover. The spectral properties of the early albeit unstable snow cover reduce the average EVI to 0.1-0.0 (depending on the fraction of the area occupied by snow).

4. CONCLUSIONS:

The nature of the long-term dynamics of the index allows considering short-term fluctuations in meteorological conditions as an important factor in changing the primary productivity of arable lands agrocenoses. Changes in the heat and moisture supply of cultivated plants significantly affect the average value of the index, despite the wide variety of natural conditions of vegetation and local characteristics of the farming system. Differences in EVI values in the spring in a series of years are determined mainly by temperature fluctuations; in the middle and at the end of the growing season – humidification conditions. At the same time, the distribution of the average values of the index in a series of years – average for the year as a whole or part of the growing season – as a rule is not explained solely from the meteorological conditions of the growing season during the survey. The value of the index, and presumably, the primary productivity of the land is affected by the state of vegetation factors in the weeks preceding the filming interval. The influence can be traced mainly at a qualitative level, and it is difficult to formalize, but it is often a necessary component of a consistent model of EVI dynamics.

There is no pronounced trend in the change in average annual EVI values from the beginning of the 21st century. The index values fluctuate with a small amplitude relative to the long-term average with insignificant changes in heat supply and a steady decrease in rainfall. A steady decrease in moisture supply has a weak effect on the average values of EVI, probably due to changes in the composition of grain crops from the beginning of the century – the use of spring wheat and maize less demanding on moisture, as well as the growth of agricultural technology in general. The findings are consistent with statistics on increasing agricultural land productivity.

The idea of the scale, direction, and reasons for the long-term dynamics of the EVI of a large region (in this case, the Bryansk region) is a prerequisite for the development of a consistent model of the influence of natural and technological-economic factors of vegetation on the productivity of agrocenoses.

5. ACKNOWLEDGMENTS:

The study was performed as part of the work on the state task 5.8588.2017/БЧ – "Use of multi-zone satellite filming as a source of information about the structure, seasonal and long-term dynamics of landscapes in the upper Dnieper region".

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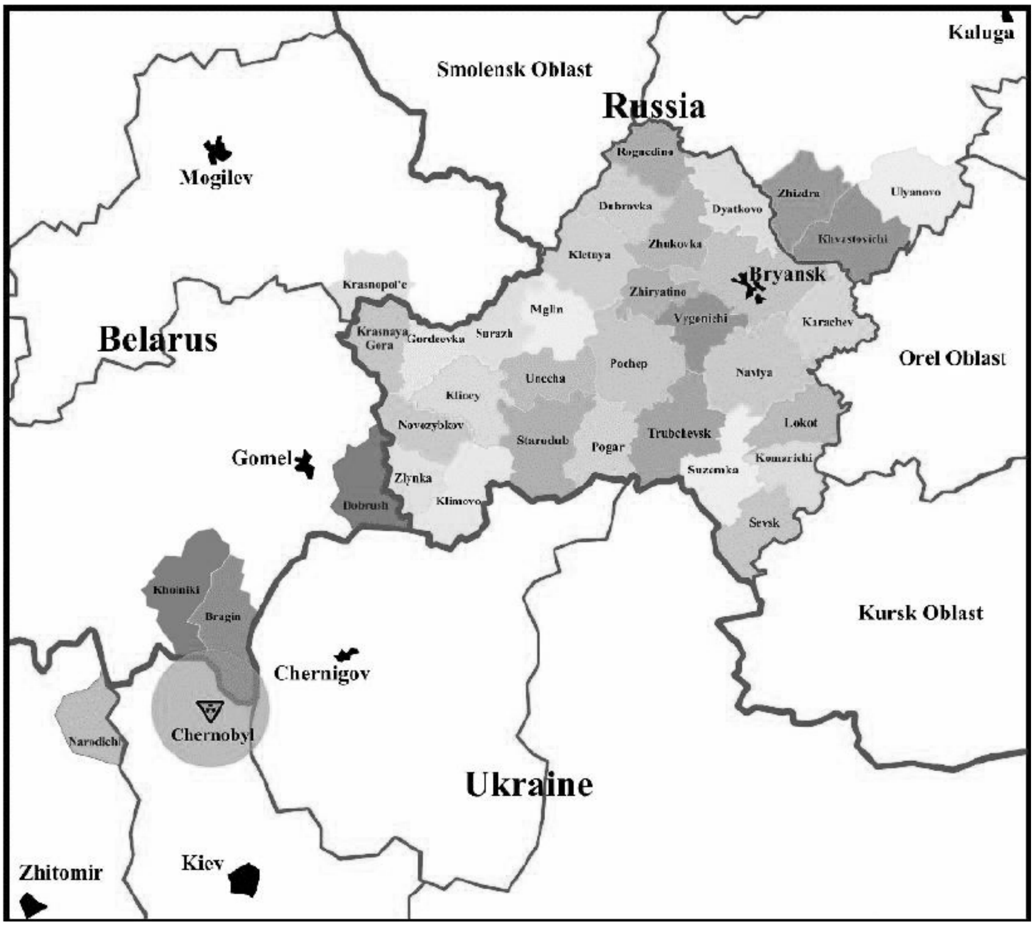

Figure 1. *Map of the districts of the Bryansk region of the Russian Federation*

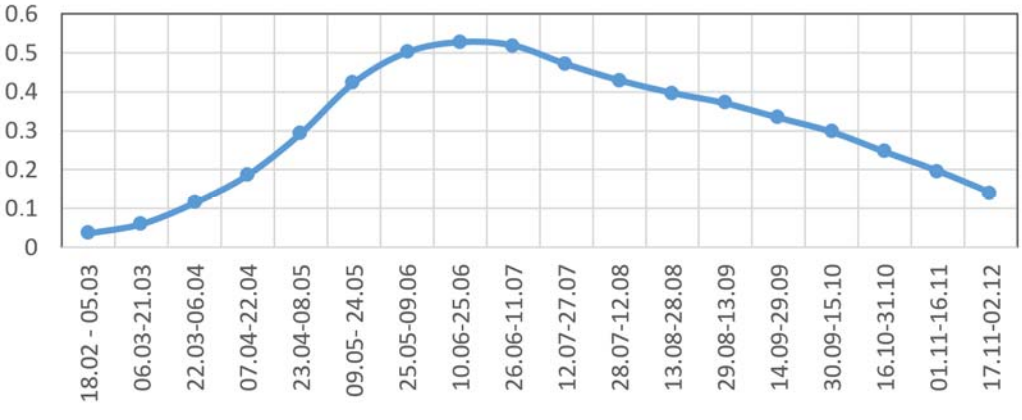

Figure 2. *Seasonal dynamics of EVI values*

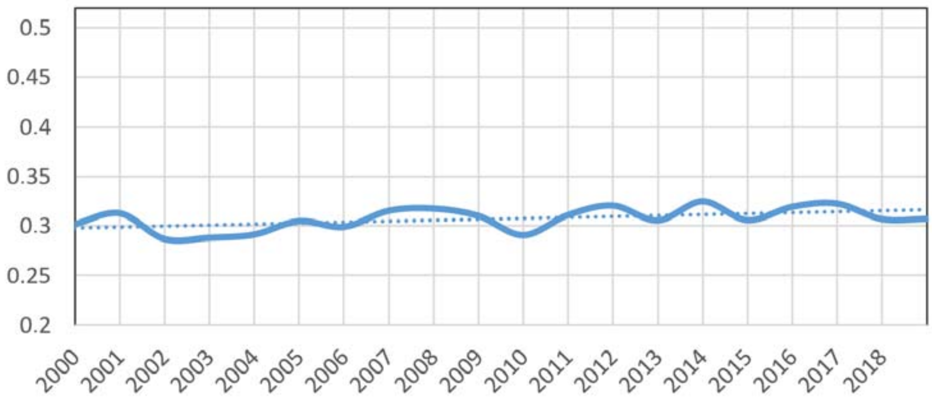

Figure 3. *Long-term changes in the average EVI. Dotted line – linear trend.*

Table 1. *The ratio of EVI values for filming intervals to long-term trends*

Years	Filming intervals																	
	I	**II**	**II**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**	**XV**	**XVI**	**XVII**	**XVIII**
2000	l	l	l	h	h	l	l	l	l	h	h	h	h	h	h	h	l	h
2001	l	l	h	h	h	h	h	l	h	h	h	h	h	h	h	h	h	l
2002	h	h	h	h	h	h	h	l	l	l	l	l	l	l	l	l	l	h
2003	l	l	l	l	l	l	l	h	l	h	h	h	h	h	h	h	h	l
2004	l	l	l	l	l	l	s	h	h	h	h	l	l	l	l	l	h	l
2005	l	l	h	l	l	h	l	h	h	h	h	h	h	l	l	l	h	l
2006	l	l	h	l	l	l	l	h	h	h	h	h	h	h	h	h	l	h
2007	l	h	h	h	h	h	h	h	h	l	s	h	h	h	h	h	l	l
2008	h	h	h	h	h	h	h	s	h	l	l	l	l	l	l	h	h	l
2009	l	l	h	s	l	l	l	h	h	h	h	h	h	h	h	h	h	l
2010	l	l	l	l	l	h	h	l	l	l	l	l	l	s	h	h	l	h
2011	l	l	l	l	l	l	s	l	l	h	h	h	h	h	h	h	h	h
2012	l	l	h	l	h	h	h	l	h	l	l	h	h	h	h	l	h	h
2013	l	l	l	l	l	h	h	h	h	l	h	s	l	l	l	s	h	h
2014	h	h	h	h	h	h	h	h	h	l	l	l	l	l	l	l	h	h
2015	h	h	h	l	l	l	l	l	l	h	l	l	s	l	h	h	l	h
2016	h	h	h	h	h	l	l	l	h	h	l	l	h	h	h	l	l	l
2017	h	h	h	h	h	l	l	l	l	h	h	h	h	h	l	h	l	l
2018	l	l	l	l	h	h	h	l	s	h	h	h	s	l	h	l	h	L

*Filming intervals: I – 18.02 – 05.03; II- 06.03-21.03; III- 22.03-06.04: IV- 07.04-22.04; V- 23.04-08.05; VI – 09.05- 24.05; VII – 25.05-09.06; VIII – 10.06-25.06; IX – 26.06-11.07; X- 12.07-27.07: XI – 28.07-12.08; XII- 13.08-28.08: XIII – 29.08 – 13.09; XIV – 14.09-29.09; XV – 30.09-15.10; XVI – 16.10-31.10; XVII – 01.11-16.11 XVIII – 17.11-02.12

** Deviation of EVI values from a long-term trend: h – upward; l – downwards; s – corrsponds to a long-term trend.