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RESEARCH ARTICLE

Implementation of agroecological zoning index to map the suitability of agricultural lands of the Steppe zone of Ukraine for the cultivation of major crops

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Abstract

Current climate change requires revision of agroecological zones in terms of their suitability for crops cultivation. The main goal of this study was to perform comprehensive agroecological zoning based on complex Agroecological Zoning Index (AEZI) for major crops of the South of Ukraine. The AEZI values are calculated based on the values of NDVI, NDWI, and NRI spatial indices, providing a complex assessment of the croplands in terms of their general suitability, water and nutrition supply. The results of the agroecological zoning of the steppe zone of Ukraine by AEZI values, screened for the 2018-2019 season, testified that the zone is unfavourable for late spring crop cultivation under rainfed conditions, while cereals and rapeseed could be cultivated in the zone even without irrigation. As for the irrigated croplands of the zone, they are conditionally suitable or absolutely suitable for all the major crops. The results of the estimation were mapped and included in the database 'Agroecological Zoning of the Steppe Zone of Ukraine v.1.00' to ease the use of the methodology by scientists and practitioners. Further extension of the agroecological zoning scale and updates to the database will be conducted in future research work.

Keywords: Climate change, Database, Mapping, Plant ecology, Remote sensing

Introduction

The current climate change is one of the greatest challenges facing mankind. Meteorological shifts result in dramatic changes in environmental conditions, which in their turn, create preconditions for changes in natural biodiversity, as well as suitability of ecosystems as a habitat for species, the most susceptible of which are under the threat of extinction (Bellard et al., 2012). Global warming results in malfunction of natural regulatory mechanisms in biosystems, creating place for the occurrence of sustainability violation on almost all the levels of biosphere, including not only natural, but also artificial agroecosystems. The latter is the main cause of the aggravation of the current food security crisis, which is becoming even more severe under the circumstances of the military conflict in Ukraine (Gregory et al., 2005; Pushak et al., 2022; Wheeler & Von Braun, 2013).

It is a well-established fact that climate change greatly impacts agricultural industry because it is strongly dependent on the environmental conditions and natural resources. This is especially true for the sector of crop production. Climate change, mainly manifested in temperature and evapotranspiration increase, decrease and/or uneven distribution of rainfall, soil quality and fertility changes, increased number of adverse meteorological events (hailstorms, sandstorms, prolonged drought, etc.), has changed the conditions of vegetation cover health, as well as productivity of major crops (Lykhovyd, 2021b). In some cases, climate change resulted in the impossibility of further crop cultivation in its usual areal because of lack of natural humidification and/or adverse effects of extreme temperatures. For example, current climate change has dramatically changed the volumes of irrigation water, required for sustainable crop production in Ukraine, as most territory of the country is in the semi-arid or dry subhumid conditions (Lykhovyd, 2021a). Furthermore, climate change has resulted in the aggravation of some extremely harmful and dangerous phytopathogens and insects, which become very difficult to control. Meteorological shifts require revision of cultivation technologies in terms of sowing dates, phenological development, harvesting time, etc. (Gregory & Ingram, 2009). In addition, climate change results in changes in the distribution of optimal ecological zones for wild and cultivated plant species. Therefore, it is evident that current agroecological zoning, which was developed in the XX century, requires revision with accordance to modern agrometeorological, soil, and agrotechnological conditions of crop production. This thesis has been proved by numerous studies conducted in different places of the world, which are subjected to strong changes in climate (Kala et al., 2012; Lin et al., 2013).

There are numerous methodological approaches to agroecological and agroclimatic zoning of agricultural lands. Conventional methodology is usually based on agrometeorological observations, soil surveys, relief estimation, direct measurements of plant parameters, etc. Then the parameters and productivity of the plant, expressed in different ways, are connected to the observed meteorological and soil conditions, and a decision on agroclimatic zoning is made (Lyaschenko, 2013). Although such an approach is a standard one and provides the best accuracy, it is laborious, and requires high inputs of material and time resources. Besides, it is inappropriate for operational dynamical monitoring of agroecological conditions. In this regard, remote sensing-based methods have their advantages, mainly because of relative simplicity, accessibility, lower labor, time, and financial resources expenditures.

Considering the relevance of remote sensing applications for agroecological zoning, different approaches and methods were developed to fulfil this task. One of the pioneer publications on successful agroecological zoning using remote sensing data, namely, time series of NDVI and Fourier analysis, provided evidence for the prospects of such an approach in ecological studies (Menenti et al., 1993). (Patel 2007) used the integrative approach to create a fusion of remote sensing data (mainly NDVI) and GIS technologies to create an agroecological zoning of the Kumaon Himalayas region of India. In recent decades, the FAO proposed the Agricultural Stress Index, based on remote sensing data, to assess the levels of water stress in croplands (Vozhehova et al., 2023). However, all the mentioned methods are somewhat unilateral, as they apply a single vegetation index (mostly NDVI) to decide. Therefore, the need for more comprehensive and robust method is relevant, and this question is not still properly solved in scientific community. Recently, we have developed and proposed a new approach to agroecological zoning based on remote sensing data, which utilises three vegetation indices, such as NDVI, NDWI (Smith et al., 2021), and NRI (Diker & Bausch, 2003) to characterise general vegetation conditions, water supply level, and nitrogen supply level of croplands. The complex Agroecological Zoning Index (AEZI) is calculated based on three vegetation indices, providing more comprehensive assessment of ecological conditions suitability for certain crops production.

The main purpose of this study was to provide a novel agroecological zoning of the steppe zone of Ukraine based on the AEZI values for the main crops, grown under irrigated and non-irrigated conditions, and present the database 'Agroecological zoning of the steppe zone of Ukraine v.1.00' for agricultural scientific, students, and practitioners.

Materials and Methods

The agroecological zoning of the steppe zone of Ukraine (partially, as Kharkiv, Donetsk and Luhansk regions were not encountered in the study, as presented in Fig. 1) was carried out based on the proposed methodology of the AEZI calculations with further gradation and mapping of the areas (Lykhovyd, 2024).

Figure 1. Steppe zone of Ukraine: the total area and the studied area

The values of primary spatial indices used in the AEZI calculations, namely, NDVI, NDWI, and NRI, were estimated using combined imagery from the satellites Sentinel-2 and Landsat-8 (resolution 250 m, cloudless images, AgroMonitoring API service). The estimation of the spatial indices was performed for six randomly selected and fixed fields of each crop studied, namely, grain corn, sunflower, soybeans, rapeseed, wheat, barley, alfalfa, sugar beets and rice. In total, 594 fields in 7 regions of the steppe zone (the Crimea, Kherson, Mykolaiv, Zaporizhzhia, Dnipro, Kropyvnytskyi, Odesa) were subjected to analysis and AEZI computation. It should be noted that sugar beets are not represented in Crimea, and rice is represented only in the Kherson and Odesa regions. The data set was created for the 2018-2019 season. The database 'Agroecological zoning of the steppe zone of Ukraine v.1.00' was created based on the results of the AEZI calculations using MS Access software. Agroecological mapping was performed using Adobe Illustrator software.

Results and Discussion

The results of the calculation of the AEZI for the steppe zone of Ukraine testified about unfavorable conditions for late spring crops, while early spring and winter cereals, as well as rapeseed, could be cultivated in the area even in the non-irrigated conditions in case of rational agrotechnology. The best correspondence of environmental conditions in the rainfed steppe zone was found for rapeseed and wheat, while the worst – for grain corn (Tab. 1).

Table 1. The results of the AEZI estimation in the steppe zone of Ukraine for the major cultivated crops (rainfed conditions)

Region	AEZI					
	grain corn	soybeans	sunflower	wheat	barley	rapeseed
Crimea	21.00%	22.80%	25.10%	36.30%	35.50%	39.30%
Kherson	21.50%	22.00%	26.00%	40.10%	38.90%	46.20%
Mykolaiv	24.30%	23.00%	26.60%	39.70%	36.50%	42.10%
Odesa	24.50%	24.30%	30.00%	37.20%	38.30%	41.60%
Zaporizhzhia	22.00%	21.00%	27.40%	34.10%	34.50%	44.10%
Dnipro	25.10%	25.10%	27.40%	36.60%	37.70%	40.20%
Kropyvnytskyi	24.30%	27.40%	25.00%	38.50%	38.50%	39.60%
Average for zone	**23.20%**	**23.70%**	**26.80%**	**37.50%**	**37.10%**	**41.90%**

To facilitate the comprehension of the results, agroecological crop mapping was performed and is presented in (Fig. 2). The coastal areas of the steppe zone are the best districts for rainfed rapeseed cultivation.

Figure 2. Mapping of the suitability of the non-irrigated agricultural lands in the Steppe zone of Ukraine for the cultivation of major crops (color scheme: yellow – unfavourable; light green – conditionally suitable; green – suitable)

Regarding irrigated agricultural land, the situation has changed dramatically, mainly due to the better moisture supply for the crops, which provided for much higher NDWI values and, as a result, much higher AEZI. There are no unfavourable regions for any of the crops studied in irrigation conditions. The irrigated steppe zone environment fits best for the cultivation of wheat, barley, and rapeseed, while less favourable is for sunflower and grain corn (Tab. 2). As for rice, this crop is cultivated in Kherson and Odesa regions only, and the AEZI for the studied period was 47.3% and 50.5%, respectively.

Table 2. The results of the AEZI estimation in the steppe zone of Ukraine for the major cultivated crops (irrigated conditions)

Region	AEZI							
	grain corn	soybeans	sunflower	wheat	barley	rapeseed	alfalfa	sugar beets
Crimea	36.70%	48.10%	32.50%	50.60%	47.60%	51.60%	43.60%	N/A
Kherson	41.30%	41.00%	41.00%	51.00%	43.90%	50.80%	45.30%	44.40%
Mykolaiv	33.20%	39.00%	41.90%	41.70%	44.50%	47.20%	41.00%	48.30%
Odesa	40.00%	37.10%	36.10%	52.00%	55.20%	47.80%	46.60%	41.50%
Zaporizhzhia	39.00%	40.80%	41.30%	50.70%	56.10%	47.70%	45.80%	41.40%
Dnipro	46.80%	42.90%	40.10%	47.70%	44.20%	44.40%	41.00%	44.30%
Kropyvnytskyi	50.70%	46.80%	42.30%	47.40%	46.30%	45.90%	43.30%	44.00%
Average for zone	**41.10%**	**42.20%**	**39.30%**	**48.70%**	**48.30%**	**47.90%**	**43.80%**	**44.00%**

To facilitate the comprehension of the results, agroecological crop mapping was also performed for the irrigated steppe zone, and it is presented in (Fig. 3). It is evident that the best conditions for the cultivation of the crops studied were formed in the Kherson and Kropyvnytskyi regions.

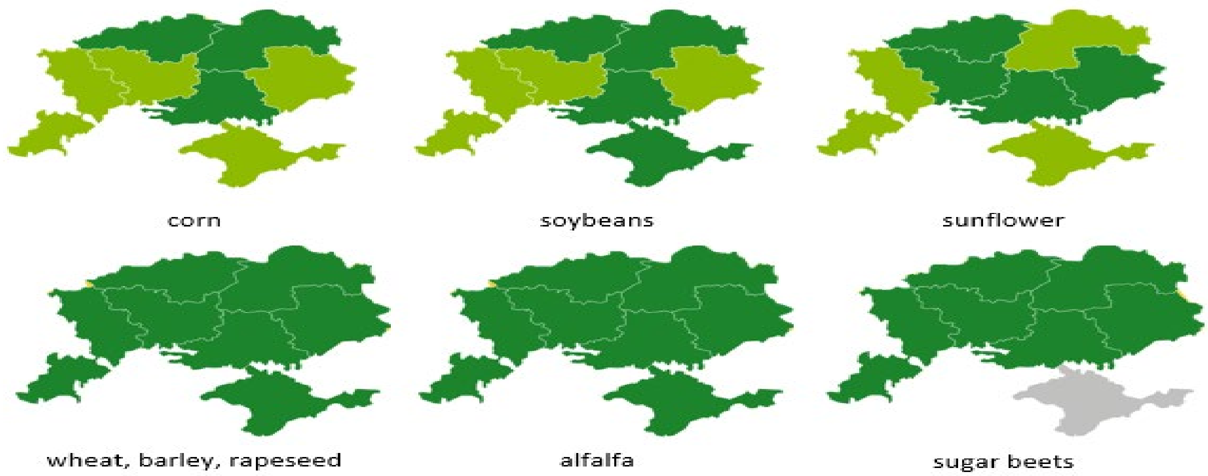

Figure 3. Mapping of the suitability of the irrigated agricultural lands in the Steppe zone of Ukraine for the cultivation of major crops (color scheme: light green – conditionally suitable; green – suitable; grey – no data available for the region)

The results of the agroecological zoning of the Steppe zone of Ukraine, based on the AEZI calculation, were presented to scientists and practitioners in a convenient form of the database – Agroecological Zoning of the Steppe Zone of Ukraine v.1.00. The database provides a simple interface to access information on the current agroecological zoning of the steppe of Ukraine for major crops depending on the conditions of moisture supply. In addition, it provides a short explanation on the AEZI calculation and implementation, as well as references for the quotation of the methodology and/or the database (Fig. 4).

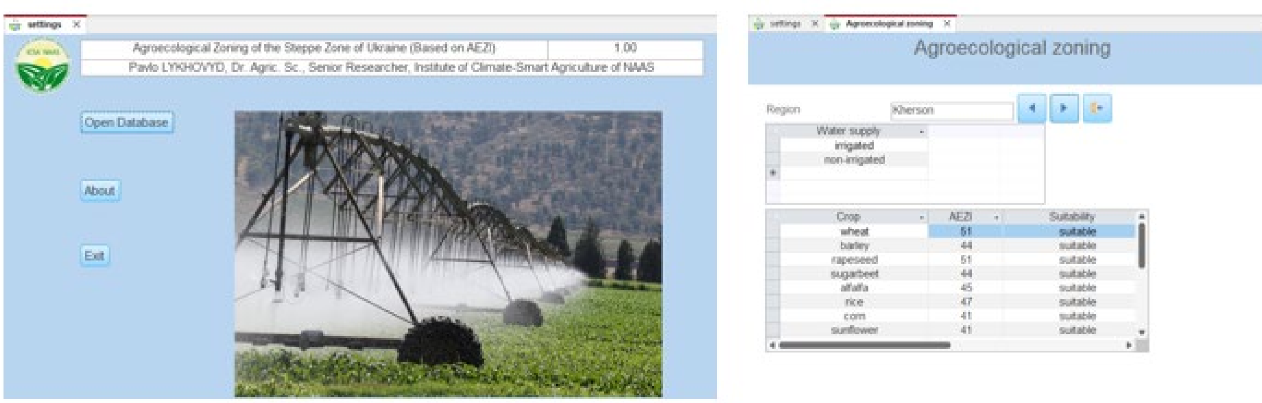

Figure 4. The interface and contents of the database 'Agroecological Zoning of the Steppe Zone of Ukraine v.1.00'

The database will be updated with further research, and it is going to include more regions and additional crops, **e.**g., grapes, dry beans, fruits and vegetables, etc.

The proposed methodology for agroecological zoning has no analogues in Ukraine or the world. It is the first time complex remote sensing data are applied to estimate the suitability of croplands for the cultivation of peculiar crops. Most previous approaches are based on statistical processing of time series data on NDVI, VCI (vegetation condition index) or VHI (vegetation health index) are unilateral, and mainly determine drought conditions and general productivity of crops, while the proposed approach is found on the complex assessment of three vegetation indices to estimate not only vegetation health conditions, but also water and nitrogen supply of crops (Gidey et al., 2018). The only database of more comprehensive agroecological assessment now is GAEZ v4 (Global Agroecological Zones), which provides global zoning based on the number of biological characteristics of agriculture, soil quality, land use, and crops (Fischer et al., 2021). The database 'Agroecological Zoning of the Steppe Zone of Ukraine v.1.00' is of local importance; however, it could be extended further for the entire territory of the steppe zone of Ukraine and expanded to embrace longer period.

Conclusions

The Agroecological Zoning Index (AEZI) is a convenient and simple way to estimate the suitability of any agricultural land for the cultivation of any crop using the values of remote sensing indices such as NDVI, NDWI, and NRI. Complex approach to the evaluation of the correspondence of environmental conditions for the cultivation of a particular crop, embracing general vegetation health (described by NDVI), water supply (assessed by NDWI), and nitrogen availability (estimated by the NRI value), provides robust insight on the suitability of the area, making it easier to take rational decisions on agricultural land use policy, cropland and crop rotations structure, etc. In addition, AEZI could be easily assessed in dynamics and requires little amount of time to determine the suitability of a particular area; thus, it is a prospective tool for continuous and operational monitoring of croplands. The developed database 'Agroecological Zoning of the Steppe Zone of Ukraine v.1.00' database makes the AEZI-based agroecological zoning approach closer to common agricultural practitioners, students, and beginning scientists.

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