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Sentinel-2 water indexes application for the underground water level analyses in Ovidiopol area of Odessa region

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Abstract

Studied area has a high level of agricultural development. There are different irrigation and drainage systems located there. Significant part of the supplied water losses from the irrigation network because of filtration and reaches the groundwater level, which begins to rise. Control and analyses of groundwater level changes with remote sensing methods for Ovidiopol area is the main goal of that work. The object of study is the groundwater level regime in the territory of Lower Dniester irrigation system in Ovidiopol district, Odessa region. The subject of research is water indexes application for analyses of groundwater level changes. The local system of groundwater observation includes 7 drillholes in Nadlimanskoe village and around. These drillholes located in different geomorphological, hydrogeological and technogenic conditions. The groundwater level was surveyed monthly in 2017. Sentinel-2 2A images for each month from March 2017 to December 2017 were used for studied area. All satellite images has atmospheric correction. Three water indexes NDWI, MNDWI, NDPI were calculated for drillhole points for each month in 2017 year. Significant correlation coefficients obtained in comparison between groundwater level changes and water indexes in

some drillholes points. The highest numbers of correlation connected with free of construction areas and for drillholes, which are located outside of villages.

Key words: underground water; Odessa region; Ovidiopil district; Black Sea region

Introduction

Irrigated agriculture in the steppe regions of southern Ukraine is naturally accompanied by negative phenomena, among the most dangerous of which should be included the flooding of agricultural lands due to the violation of the water balance of active water exchange zone as a result of irrigation. A significant part of supplied water losses from the irrigation network in the form of filtration and directly during irrigation, passes through the aeration zone and reaches the ground water level (GWL), which is beginning to rise. The amplitude of the GWL depends on the depth of the water table, the intensity of irrigation, the distance from the irrigation network channels, the method of irrigation and other factors. The rise of GWL can lead to soils overwetting, secondary salinization and, as a result, to a decrease in the yield of agricultural crops.

The most radical measure to improve or prevent deterioration of soil and hydrogeological conditions is the drainage construction. Drainage systems on the southwest of Odesa region irrigated lands were put into operation during 1970-1985. Within the territory of the Nizhne-Dniester irrigation system in the Ovidiopol district, monitoring of the water level is carried out on the network of observation wells, which are unique for that area [1, 2].

The combination of hydrogeological in-situ observations of the groundwater regime and remote methods, which are carried out from various aerial vehicles that record the state of the earth's surface and certain parameters of the natural environment, are becoming important and relevant. Recently, such observations have been actively used in various parts of the world, from deserts to tropical jungles [3, 5]. In this regard, proposed to test a new method of assessing the watered area, based on the remote satellite data.

The object of the study is the territory of the local sites of the Nizhny-Dniester irrigation system in the Ovidiopil district of the Odesa region. The subject of the study is the groundwater level regime of irrigated massifs.

Control and analyses of groundwater level changes with remote sensing methods for Ovidiopol area is the main goal of that work.

Materials and methods

ESA Sentinel-2 satellite images were used to analyze the flooding degree of the territory surface layers. The complex consists two satellites: Sentinel-2A, which launched on June 23, 2015, and Sentinel-2B, launched on March 7, 2017. The satellites belong to the European Space Agency (ESA) and were created as part of the Copernicus global environmental and security monitoring project. This satellite complex allows receiving multispectral images of the Earth's surface in 13 bands: from the visible, through the near-infrared, to the infrared short-wave spectrum. The resolution of different spectral bands varies from 10 to 60 meters.

The water amount determination in the surface layer performed by remote sensing methods, which based on the creation of specialized combinations of different spectral bands and the index images calculation. At this time, there is a certain number of different index values that are actively used, which allow us to estimate the level of ground water in soils [5]. This is primarily due to the fact that different authors compared the reflection spectrum of water and different soils in different environmental conditions and established certain patterns. This paper presents three water indices that are the most widely distributed among remote methods of assessing the irrigation of the territory.

The NDWI index - the normalized differentiated water index was proposed by Gao in 1996 [4]. This index calculated as the ratio of near-infrared and mid-infrared ranges according to the formula:

$$NDWI = \frac{nIR - mIR}{nIR + mIR}$$

Where *nIR* is the near-infrared range, which is correlated in Sentinel-2 images with band 8; *mIR* is the mid-infrared range that corresponds to band 12. The index allows to estimate the amount of water in the surface layer of the soil or in the vegetation cover. It is a dimensionless quantity that is in the range from -1 to 1. Values approaching 1 indicate increased waterlogging, even flooding. Values close to -1 determine the drainage of the territory. The peculiarity of this index image is that the vegetation cover condition of the territory has a significant influence for it.

The MNDWI index – a modified normalized differentiated water index proposed by Hee in 2006 [8]. The calculation of this index is primarily aimed to detecting and recording water signals in the surface layer, especially open water on the surface. It is calculated according to the following equation:

$$MNDWI = \frac{Green - mIR}{Green + mIR}$$

Where *Green* is the band that determines the reflectance intensity in the visible green spectrum and corresponds to channel 3 in Sentinel-2 imagery, and *mIR* is the mid-infrared band that corresponds to channel 12. This index also ranges from -1 to 1 Values close to 1 indicate a high level of moisture in the surface layer of soils. The open water surface has a value of 1. The more arid area has index values that approach -1.

The NDPI index - the normalized differentiated lake (pound) index calculated and proposed by J.P. Lecaux and others in 2007 [4]. This index aimed at identifying and mapping small water bodies, areas of waterlogging and flooding. The results of this index are significantly affected by the presence of specific vegetation that forms around small reservoirs and swamps. The index calculated according to the following equation:

$$NDPI = \frac{Green - mIR}{Green + mIR}$$

This equation has similarities with the modified normalized differentiated water index (MNDWI) values. The difference is that channel 3 of the Sentinel-2 satellite complex, as the visible green range, and channel 11, as the mid-infrared range, are used to determine the NDPI. This index also takes values from 1 to -1, where values approaching one occur when the area is waterlogged or flooded.

The indexes calculation was made for the of the Sentinel-2 satellite images, which recorded the territory of the Ovidiopil district of the Odesa region on the following dates: 31.03.2017; 04.13.2017; 10.05.2017; 12.06.2017; 12.07.2017; 11.08.2017; 30.09.2017; 10.17.2017; 26.12.2017. Thus, during the period from March to December 2017, remote monitoring of the territory carried out almost every month. All images used belong to the Level 2A processing level, i.e. classification and atmospheric correction procedures applied to the primary satellite images at the preprocessing stage. This level of pre-processing allows you to get a reflection that is characteristic of the lower part of the atmosphere and directly of the Earth's surface, so such pictures have the additional mark "BOA (Bottom of Atmosphere)". Also, all images cover a surface area of 100*100 km2 and have a coordinates in the UTM/WGS84 system.

Results

There are 7 observational hydrogeological wells selected in the Ovidiopil district of the Odesa region in the area of the Nadlymanske settlement. These wells studied for temporal changes in the groundwater level regime with measurements have made every month from 2007 to 2017 inclusive.

Groundwater lies in alluvial, alluvial-deluvial, eolian-deluvial deposits of the Neopleistocene. Water-bearing rocks are sandy loams, sands, loams.

OD-53 and OD-56 wells located to north of the Nadlymanske village, within the drainage area 10-GRD, which was put into operation in 1982. The drainage area is 41 hectares. The depth of the drainage network laying in this area is 4.85 meters. All other wells (OD-12a, OD-18a, OD-108, OD-110, OD-112) are located within the Nadlymanske village.

Thus, the slope drainage created within the Nadlymanske village prevents significant flooding of the territory. However, since the studyed area is located on the slope to the Dniester Estuary, in some places the groundwater level is less than 1 meter from the surface.

The assessment of the water level change in 2017, which is being studied, for all the selected wells shows certain patterns. Practically all wells have seen an increase in the water level rom the beginning of the year to March.

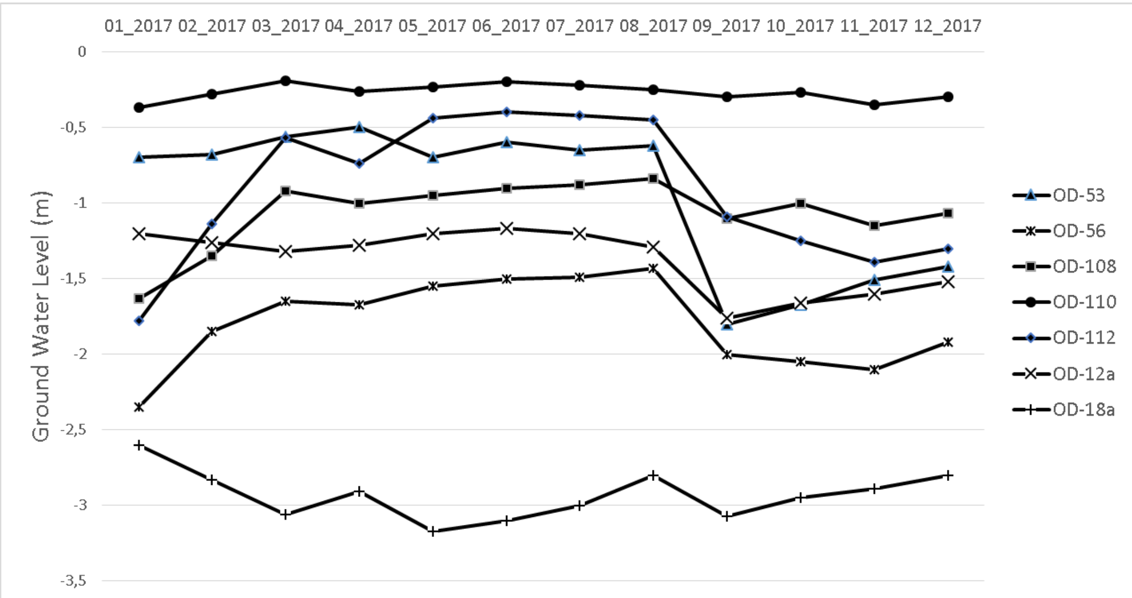

Fig. 1. Ground water level changes during 2017 year.

Then, stabilization of the level detected during March - August 2017, and from September, the level decreases to the values of the beginning of the year. The exceptions are wells OD-18a with an absolute head mark of 67.5 m, located on the outskirts of the village, and OD-110 with an absolute head mark of 54.26 m, in the central part of the village, where the lowest and highest of GWL were recorded, respectively. (fig 1)

Discussion

Correlation coefficients were calculated between the values of the groundwater level in the wells and the values of the remote sensing water indexes that were obtained for the same wells points and for the same dates during 2017.

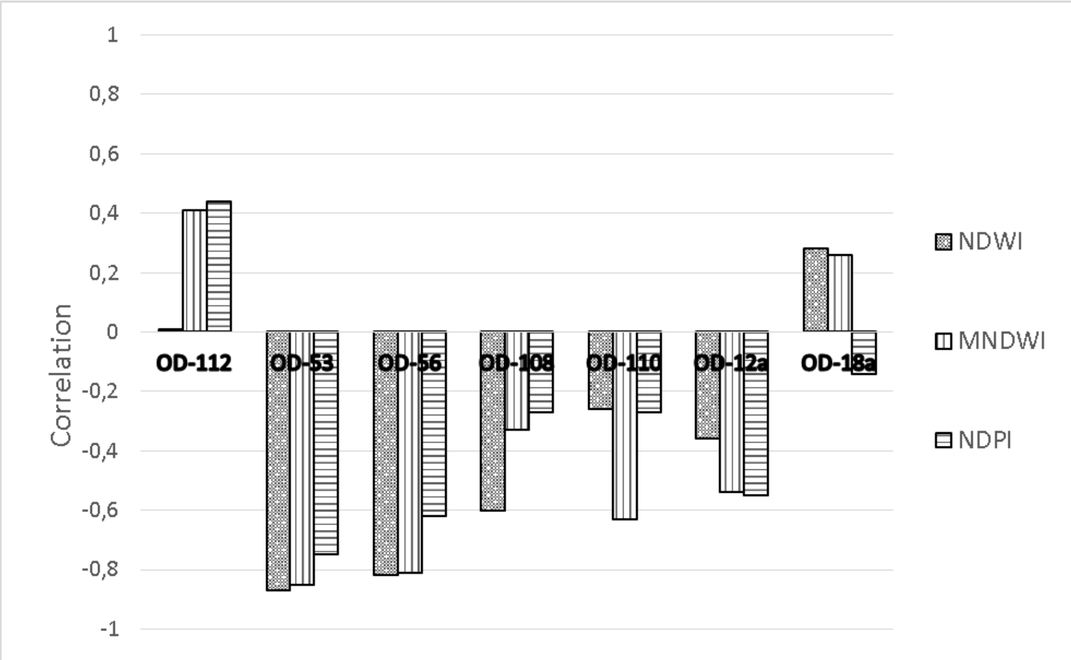

Fig 2. Correlation coefficients between ground water level changes and remote sensing indexes.

Negative correlation values indicate that groundwater is close to the surface, and the territory may be flooded. The most significant correlation coefficients between the remote sensing water indexes and the groundwater level depth found for wells OD-53 and OD-56, with has mouth absolute marks 63.47 m and 55.32 m, respectively. These wells are located within the drainage section 10-GRD, with a depth of 4.85 meters, and outside the Nadlimanske village, on the open surface of the land. All other wells are located within the territory of the village in the built-up area.

Conclusions

1. Based on the conducted research, the remote satellite observations method can be used to assess the state of flooding of the territory within the northern Black Sea region. However, it should be noted that the proposed methods have certain limitations in use.

2. First of all, such restrictions related to the fact that the atmospheric conditions must provide satellite images with minimal cloud cover, or, best of all, its absence, which is quite difficult to obtain during late autumn, winter and early spring for the territory of the northern Black Sea region.

3. The second limitation, which revealed during the research, related to the fact that the proposed and widely used index values of territory flooding and soil irrigation correlate well with indicators of the groundwater level depth only in open areas. Within the limits of any development or occupation of the territory by any technical facilities, the proposed index values do not demonstrate the real natural picture.

4. Other images and image calculation algorithms should be developed and used for man-made areas.

5. However, the proposed method of assessing the flooding of the territory has the right to be used and needs to expand the network of ground points and the observation time interval.

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