Analysis of the complex vegetation index considering greenness and shortwave infrared to determine anomalies in the vegetation spectral characteristics caused by hydrocarbon deposits

S.I. Golubov, A.I. Vorobyov, O.V. Sedlerova, M.S. Lubskyi, I.O. Piestova *(Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the NAS of Ukraine)*

SUMMARY

In this study, the authors analyzed the possibilities of using the standard Normalized Difference Vegetation Index (NDVI) and the finer Vegetation Index considering Greenness and Shortwave infrared (VIGS). Above hydrocarbon deposits, the vegetation state is affected by metal oxides and dioxides formed during the oxidation of soil trace elements. This fact allowed the authors to suggest the possibility of using the VIGS-to determine the anomalies of the vegetation spectral characteristics caused by hydrocarbon deposits. In the course of the work, the Landsat ETM + satellite data were sequentially processed in order to statistically calculate the probability of detecting anomalies in the vegetation spectral characteristics. Anomalies were identified based on the calculation of the values of the vegetation spectral indices (NDVI and VIGS) for 26 pairs of polygons built within the known deposits and beyond them for areas with homogeneous vegetation. The probability of recognizing anomalies for the NDVI is 66%, for the VIGS - 75%. There is a significant (85%) correlation between the NDVI and VIGS values for gas and oil and gas and 90% for oil fields. This approach can be used as a means of additional exploration of hydrocarbon deposits in areas with known explored deposits and as an auxiliary one when performing geological prospecting works in order to identify new deposits.

Introduction (problem statement)

The influence of hydrocarbon (HC) deposits on the vegetation spectral characteristics is considered in many works (*Lyalko et al., 2006, 2017, Kühn et al., 2004, Pererva et al., 2004*). Recording changes in the vegetation spectral characteristics and other landscape elements on satellite images form the basis of the methods for predicting oil and gas promising objects on land. To study the phenomenon, the methods for assessing the red edge shift (REP), using a variety of vegetation and adaptive indices for the statistical assessment of changes in plant behavior above and outside the fallow were used (*Jakimchuk et al., 2016, Golubov, Lubskyi, 2020*). In this study, the authors analyzed the possibilities of using such vegetation indexes as the standard NDVI and the finer VIGS. The VIGS was proposed by Japanese researchers to assess the vegetation state over metal ore deposits (*Hede et al., 2015*). Above hydrocarbon deposits, the state of plants is affected by metal oxides and dioxides formed during the oxidation of soil trace elements. This fact allowed the authors to suggest the possibility of using the VIGS to determine the anomalies of the vegetation spectral characteristics caused by hydrocarbon deposits.

The basis of study

The experience of previous works shows that the use of remote sensing methods in forecasting oil and gas promising objects requires integration, it is necessary to try to take into account all the factors affecting the formation of a useful signal on a satellite image. The use of adaptive and chlorophilic indices for detecting spectral anomalies over oil and gas fields in the Dnieper-Donetsk depression has already been described (*Golubov, Lubskyi, 2020*). The publication describes the results obtained in evaluating the anomaly using adaptive index (ASI), terrestrial chlorophyll index (MTCI) and normalized area vegetation index (NAVI). The authors concluded that ASI-did not show systematic differences when compared to its value in the range of hydrocarbon deposits and beyond. Chlorophilic indices MTCI and NAVI showed a 75% to 80% probability of recognizing anomalies within the test sites. When analyzing vegetation facies of the same name, a significant difference was noted in the coverage of vegetation cover; often the presence of open ground areas also had an effect on the formation of a useful signal in the image. This circumstance became the reason for using the VIGS to recognize anomalies over hydrocarbon deposits.

In works (*Hede et al., 2015, 2017*), the results of studies on the development and application of remote optical sensing technology in difficult geological conditions and dense vegetation (including forests) for identifying ore deposits are presented. For this purpose, a more advanced vegetation index (VIGS) has been proposed, which can also be used in conditions of identifying areas of oil and gas accumulation.

Satellite data and their processing

For our studies, Landsat ETM + images were selected for July 2016, August 2017, August 2018, 0% cloud cover.

During the research, Landsat ETM + satellite images were pre-processed for atmospheric correction using atmospheric analysis (FLAASH) using the specialized software module, and the C-correction method was used for topographic correction. The reflectance in each pixel is derived from pre-processed Landsat ETM + satellite images and used to calculate the two vegetation indices, VIGS and NDVI. The formula for calculating VIGS is as follows (*Hede et al., 2017*):

$$VIGS=w_1(G-R)/(G+R) +w_2(N-R)/(N+R) +w_3(N-S_1)/(N+S_1) +w_4(N-S_2)/(N+S_2) \qquad (1)$$

where G, R, N, S1 and S2 represent the surface reflectance in the visible green, and red, near infrared (NIR) and two short-wave infrareds (SWIR1 and SWIR2) wavelength ranges, respectively. For the Landsat satellite image ETM + G, R, N, S1 and S2 correspond to channels 2, 3, 4, 5 and 7. And the coefficients w1, w2, w3, and w4 are weighted, they are obtained empirically and equal, respectively: w1 = 1.0, w2 = 0.5, w3 = 1.5, and w4 = 1.5. The same coefficients were obtained on the basis of the research results presented in (Hede et al., 2015).

The equation for NDVI is as follows:

$$NDVI = (N-R)/(N+R), \qquad (2)$$

where N is near infrared, R is red wavelength range.

The VIGS ~~index~~ is complex and consists of three previously normalized spectral difference indices: a normalized green and red difference index (NDVI) and a normalized difference index based on shortwave infrared channels. The first two indices are used to identify the state of chlorophyll depending on the season. The third index is sensitive to the lack of water in vegetation and can also change depending on the stress caused by metal (*Hede et al., 2015*) as well as hydrocarbons.

The methodology of the work

The general set of works that must be performed to obtain a probabilistic assessment of the possibility of localizing spectral anomalies caused by the presence of hydrocarbon deposits includes the solution of the following series of problems. Landsat-8 images are downloaded from the Earth Explorer resource. For their further processing, the specialized software for Landsat-8 images is used. Next, a radiometric correction is performed, and the areas whose images will be used are determined. The next step is to carry out consistent atmospheric correction of the images.

All the obtained data on the distribution of spectral indices are superimposed on the map of the existing explored oil and gas fields, and a sample of pairs of test polygons is formed within the reservoir and outside of it on a homogeneous territory, a statistical comparison of the differences of these values for all parameters (spectral indices) is performed. Next, the probability of detecting the difference in parameters for each of the surface characteristics as such, caused by the presence of hydrocarbon deposits, is estimated. A block diagram of this process is shown in Fig. 1.

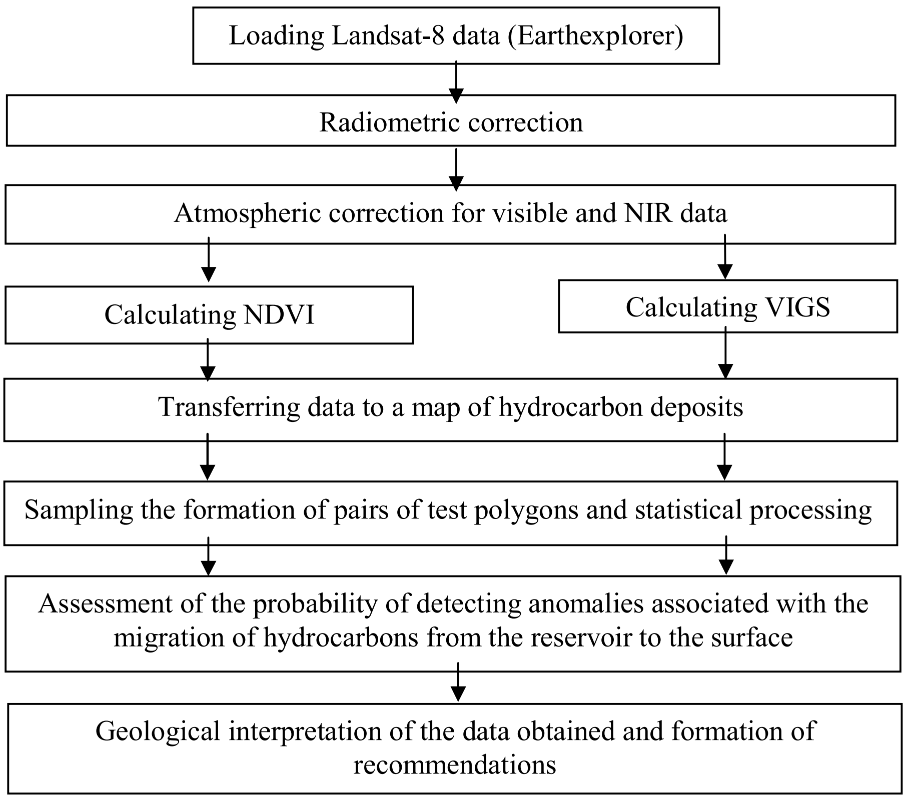

Figure 1 *Block diagram of the process of collecting, processing, statistical analysis and geological interpretation*

Landsat ETM+ software processing

Based on the processing of satellite data, a comparative statistical evaluation of the values is performed. Based on Landsat ETM + data, the NDVI and VIGS indices are calculated within and outside the hydrocarbon deposits. For this, the formation of test sites was carried out within the known deposits of gas, gas condensate and oil and beyond using the specialized software module for constructing regions of interest (ROI Tool) (Fig. 2).

The constructed polygons were compared within the area with homogeneous vegetation to reveal the difference between the mean values of the corresponding indices. As a result, tables of anomalous values were created. For the formation of sections of the boundaries of the deposits, maps of the spatial location of hydrocarbon deposits were used. For processing, a comparison of the average value of the distribution statistics of the studied characteristics was used. To assess the statistical probability of identifying abnormal deviations, the work was carried out on the basis of samples from 26 pairs of polygons. Pairs of polygons were formed on the basis of the map of the fields of the Dnieper-Donetsk depression, one of the polygons was created within the contour of the field, the second - outside. The sample was formed randomly, observing the rule of the ratio of a pair of polygons to one area with homogeneous vegetation.

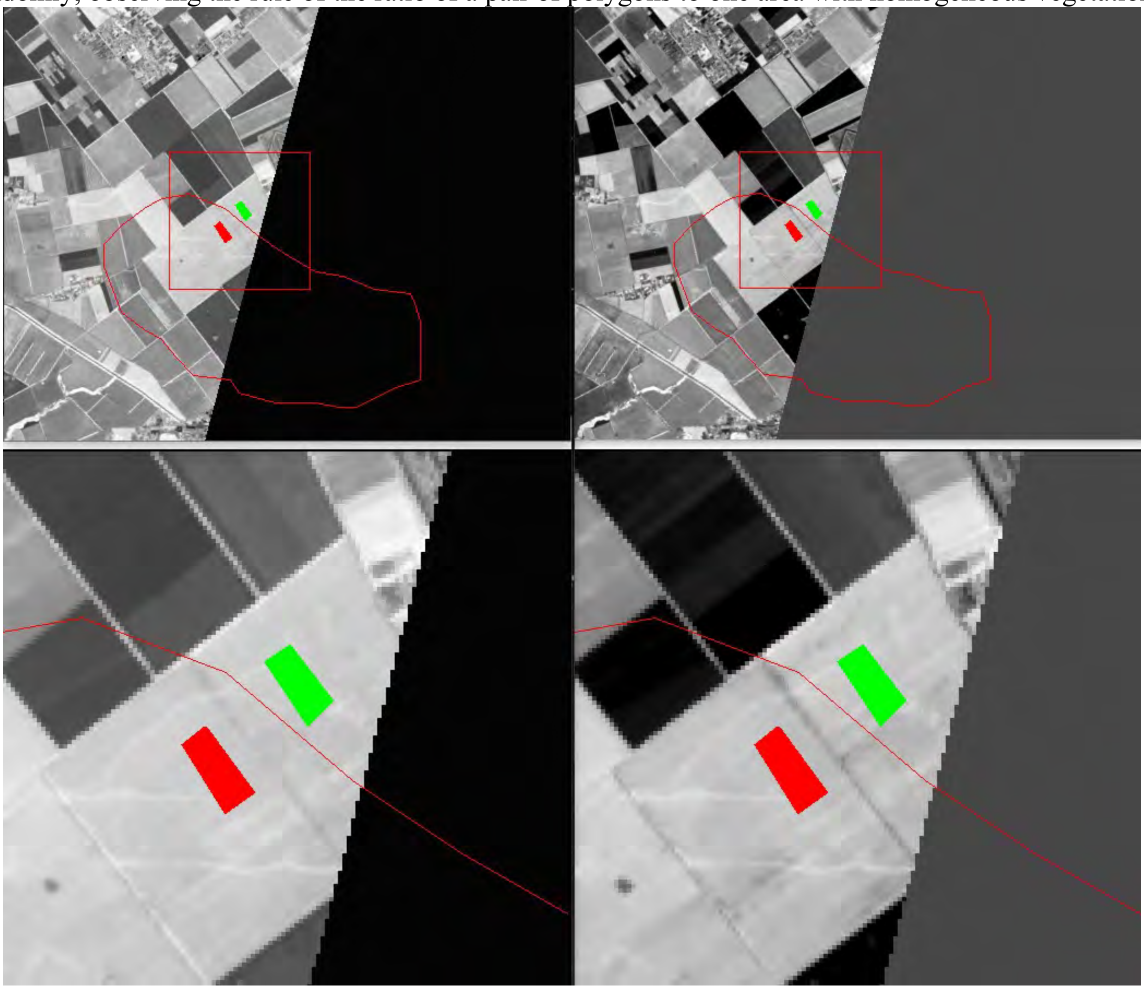

Figure 2 *An example of creating pairs of test polygons within and outside the deposits using the ROI Tool subroutine in the specialized software environment*

Conclusion

In the course of the work, the Landsat ETM + satellite data were sequentially processed in order to statistically calculate the probability of detecting anomalies in the vegetation spectral characteristics. These anomalies can be caused by the presence of hydrocarbon deposits, which is confirmed by previous studies. Anomalies were identified based on the calculation of the values of the spectral indices of vegetation NDVI and VIGS for 26 pairs of polygons built within the known deposits and beyond them for areas with homogeneous vegetation.

The probability of recognizing anomalies for the NDVI is 66%, for the VIGS - 75%. There is a significant (85%) correlation between the NDVI and VIGS values for gas and oil and gas and 90% for oil fields. For some oil and gas fields, inversion of values was observed. The anomaly was clearly defined, but with the opposite sign. This phenomenon requires further study.

In terms of spatial resolution, sensitivity and frequency of survey, Landsat ETM + satellite imagery data are effective for solving the problem of detecting anomalies in vegetation spectral characteristics associated with hydrocarbon deposits. This approach can be used as a means of additional exploration of hydrocarbon deposits in areas with known explored deposits and as an auxiliary one when performing geological prospecting works in order to identify new deposits.

Reference

Lyalko, V.I., Popov, M.O. (Eds.) (2006) Bahatospektralni metody dystantsiinoho zonduvannia Zemli v zadachakh pryrodokorystuvannia. K: Nauk. dumka, 360 p.

Kühn, F., Oppermann, K., Hörig, B. (2004) Hydrocarbon Index - an algorithm for hyperspectral detection of hydrocarbons. *Int. Jour. of Remote Sensing*, **25**, Issue 12 June 2004, 2467 – 2473.

Pererva, V. M., Tepliakov, M. O. Arkhipov, O. I. (2004). Multispectral structural-field method of oil and gas deposit forecasting. *Pat. UA 63073 A.* Publ. 15.01.2004. (in Ukrainian)

Lyalko, V.I., Popov, M.O. (Eds.) (2017) Novel remote sensing methods for minerals prospecting. ISBN 978-966-02-8295-7

Jakimchuk, V. G., Suhanov, K. Ju., Porushkevich, A. Ju. (2016). The use of the adaptive spectral indexes for the hydrocarbon deposits exploration using remotely sensed data and ground-based photometry. *Ukrainian journal remote sensing,* **8**, 24-28.

Golubov, S.I., Lubsky, M.S. (2020).Application of visible and long-wave infrared satellite data for hydrocarbon deposits prospecting. *International conference Geoinformatics: Theoretical and Applied Aspects,* 11-14 May 2020, Kyiv, Ukraine. https://doi.org/10.3997/2214-4609.2020geo102

Hawu, H., Koki, K., Katsuaki, K., Shige, S. (2015). A new vegetation index for detecting vegetation anomalies due to mineral deposits with application to a tropical forest area. *Remote Sensing of Environment,* **171**, 83-97. https://doi.org/10.1016/j.rse.2015.10.006

Hede, A.N.H.; Koike, K.; Kashiwaya, K.; Sakurai, S.; Yamada, R.; Singer, D.A. (2017) How can satellite imagery be used for mineral exploration in thick vegetation areas. *Geochem. Geophys. Geosyst.*, 18, 584–596. https://doi.org/10.1002/2016gc006501