Use of multispectral satellite imagery to monitor erosion on the Volyn Upland

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SUMMARY

The paper presents an overview of how dynamics changes of erosive landforms of the Volyn Upland (North-Western Ukraine) can be evaluated. For this, the satellite imagery by Google Earth, EOS Landviewer, and Sentinel-2 is used. The research provides examples of how ravines are represented on images with different spectral ranges. There are significant differences in remote identification of erosion forms for forested areas, cultivated and uncultivated lands. For each of these types, the images from different spectral channels during both growing and non-growing periods are analyzed. The results are presented in a table: it shows informative and practical value of different channels and indexes to detect and evaluate the dynamics of erosion landforms. Visible and near-infrared channels are found to be the most informative. Combining vegetation index, moisture index, and thermal infrared channel proved to be less informative. It is possible to extract some additional information through them though. The paper also provides suggestions on the use of remote sensing for erosion monitoring.

Introduction

The monitoring of erosion dynamics and the landforms is an important task for geological, geomorphological, and agroecological studies.
The Volyn Upland is characterized by a significant degree of erosion (around 27%). In some administrative districts, the loss of soil reaches 400,000 tons per year, while the average yearly rates of water based erosion range between 17 and 23 tons per hectare (Korol et al., 2012). The developmental dynamics of different erosion landforms varies: from intensive growth and deepening, to stabilizing and extinction. This is predetermined by differences in rock composition and thickness, slop steepness, humidity range, local erosion depth, developmental history of a particular object, and the way the land is being used.
To assess the scale and possible development of these processes and change of landforms, one needs to monitor them at regular intervals and at multiple levels (Kovalchuk, 2016; Protsyk, 2012). In 2000-2012, monitoring of the Volyn Upland was carried out by (Brovko, 2003; Zhdaniuk and Mykhnovych, 2012; Zhdaniuk et al., 2015) and others.
Nowadays, in addition to traditional field research and cartometric measurements, it is plausible to use vast data sets of remote sensing of the Earth.

Method and Theory

A database of space images was used to evaluate remote sensing for identifying erosion landforms and analyzing their dynamics within the Volyn Upland. Google Earth's Historical Imagery contains yearly dated layers of satellite low-resolution images starting with 1984. They are a part of the Landsat Program, managed by U.S. Geological Survey. Historical Imagery also includes some high-resolution images starting from 2003 (CNES, Airbus, Maxar Techologies, etc.).
For some areas, consecutively taken images were mapped spatially, and later morphometric parameters of ravine landforms were studied.
Analysis of satellite images (Landsat-8 from 2013 and Sentinel-2 from 2015) constitutes a separate research stage. Sentinel-HUB (apps.sentinel-hub.com) and EOS LandViewer (eos.com/lv) are the key services here.

Results

In the course of erosion assessment, high-resolution optical images helped identify more than a hundred ravines of considerable length (more than 100 m) in Lutsk, Lokachyn, Volodymyr-Volynsky, Ivanychi, Horokhiv, Mlyniv, Demydiv, and Dubno districts.
We tried to observe the developmental dynamics of certain erosion landforms by selecting and comparing images within a certain time range. Unfortunately, there are only few available images for this area – each has around 2-4 photographs with 3-7 years intervals. Therefore, it is difficult to make any claims about the intensity of erosion processes. The images were taken at different times of a year: there are photographs taken in winter, spring, summer, and autumn. This brings more difficulty for researchers. Usually, during the growing season, there are some limitations as grass and growing crops make it harder to notice any changes in landforms.
Nevertheless, on some images, one can trace some landform changes within relatively short time periods (Figure 1).
Figure 1a proves that half a year is enough for the relief to change noticeably in certain areas.
Having the images compared, we can see that the ravines on the uncultivated land between the villages become wider and more visible. The bottoms of the ravines widened. The slopes acquired white color – probably resulting from water based soil erosion and bedrock exposures.

a)

b)

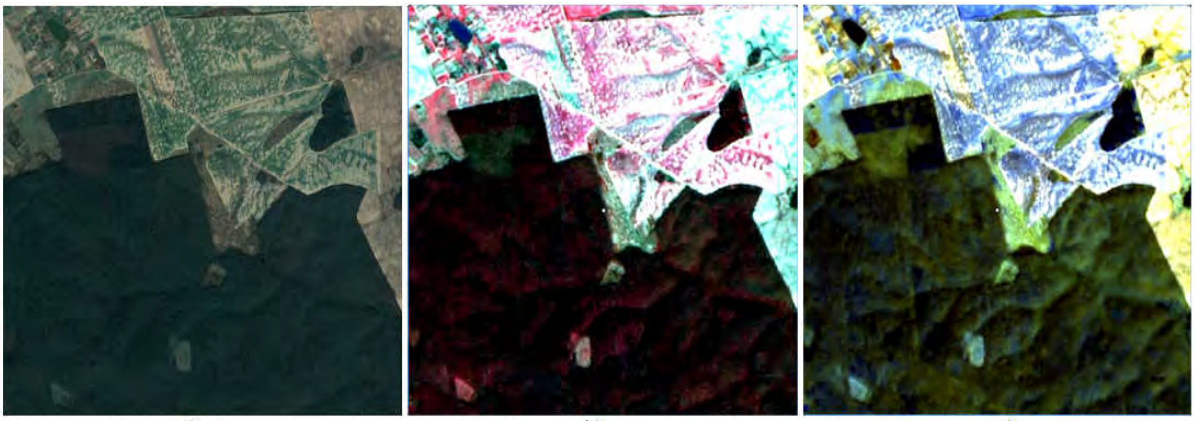
Figure 1 *Ravine development: a) Bobychi village, September 2011 –April 2012; b) Rachyn village, September 2012-April 2018*

We have analyzed the erosion development for 15 selected areas within several years (mostly from 2011 to 2018; for some areas, there is available data from 2003 or 2007). Two thirds of the ravines have no significant length changes within that time period. Three ravines grew longer (the ones near St. Zagoriv, Ratniv, Rachyn). Only two ravines grew smaller (Antonivka, Tseperiv). At the same time, in most areas (except for three of them), slope denudation was observed.

This way of monitoring helps see the development of erosion landforms in separate areas. It has a range of limitations though. First, the image database is relatively small and the variety of the photographs is limited. Therefore, there is a need to compare images taken in different conditions, full-color and panchromatic images, winter and summer images, etc.

Multispectral photographs by Landsat-8 and Sentinel-2 satellites can partially solve this problem. Since their launch (2013 and 2015 accordingly), there is a database with several hundred images for the areas under our consideration. Thus, it is possible to select a range of pictures within a specific time range (for example, early spring only) or within specific agrometeorological parameters (for example, taken after heavy rains only).

Despite the low spatial resolution (from 15 to 100 m / pixel in different ranges), due to having different bands and combining them, there is a chance to obtain much additional information about the landscapes.
For the selected eroded areas, we have compared the images combining different channels.
We discovered that the sharpness of ravine landforms depends on the type of land use.
They can be roughly divided into three categories: erosion forms on cultivated lands, on uncultivated lands, on forested lands. Apparently, it is more difficult to identify ravines on forested areas. Mixing various bands allows visualizing them more clearly (Figure 2).



a) b) c)

Figure 2 *Images of the ravine system (Sadivski Dubyny) from different sources: a) high-resolution optical image (Google Earth), b) "color-infrared" by Landsat-8, c) "atmospheric penetration" by Landsat-8*

For each of the three types of land, more than 10 spectral channels and their combinations were analyzed. To detect erosion forms, the well-known vegetation indexes (NDVI, SAVI, ARVI, etc.) appeared to be the least informative, unlike the GCI index, which relatively could clearly identify ravines in most areas during the growing season. At the same time, the combination of "color infrared (vegetation)", which combines red, green and near-infrared bands, in most cases gives a clear view of the ravine system.
It was not possible to visually outline the erosion forms using "moisture index" combination bands by SentinelHub. However, there are combinations for water bodies / land identification and for indirect soil moisture measurement. They worked well in our case. These are the following combinations: "Agriculture", "Land/Water", "Atmospheric removal", "Atmospheric penetration".

The Normalized Difference Water Index (NDWI) was not helpful in detecting erosion forms. Nevertheless, it works better when running an automatic pattern recognition on a small area. The mentioned above vegetation index (NDVI) has similar issues. However, this pattern recognition can detect ravines only on limited territories and only in some specific cases.
The Landsat-8 satellite also provides data via a separate thermal infrared channel. However, due to the low resolution (100 m / pixel), the microtemperature differences in predominantly narrow ravines of the Volyn Upland are practically invisible.
Only when using Pansharpening with these images, the quality of the pictures improves, and some erosive forms can be detected afterwards.

The following table gives an overview on how effective is it to use multispectral images to monitor the erosion processes on the Volyn Upland.

Table 1 *Remote sensing effectiveness in tracing the developmental dynamics of the Volyn Upland erosion landforms**

	Cultivated lands		Uncultivated lands		Forested lands	
Band/mix of bands	Growing season	Non-growing season	Growing season	Non-growing season	Growing season	Non-growing season
Optical	+ –	++	+	++	+ –	+
NDVI	–	–	+ –	–	–	–
NDVI+classification	–	+ –	+	–	+ –	+
GCI	+ –	–	+	–	+ –	+
NDWI	–	–	–	–	–	–
NDWI+ classification	–	+ –	+	+ –	+ –	+
"Agriculture"	++	+	++	+	++	++
"Land/Water"	++	+	++	+	++	++
"Atmospheric penetration"	+	+	++	++	+	+
Thermal (Landsat-8)	+ –	+ –	+ –	+ –	–	–
Moisture index	–	+ –	+ –	+ –	–	–

**this table uses the following denotations: – (impossible to detect), +– (possible to detect on certain areas), + (possible to detect), ++ (possible to detect and measure)*

Conclusions

Remote sensing allows extracting a lot of information about the development of erosion landforms on the Volyn Upland. Combining high-resolution optical images with the multispectral pictures covering near-infrared and visible channels ("Land/Water", "Atmospheric penetration") by Landsat-8 and Sentinel-2 appeared to be the most effective method. Ordinary combinations of vegetation indexes, NDWI, moisture index do not provide the desired information (work only for limited areas). When planning remote monitoring of eroded areas, it is recommended to get annual images for at least two identical periods (before and after growing season) and add some pictures in the time of heavy rains. Further monitoring should be backed up by field research of the observed territories.

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