Remote Sensing Data Analysis for the Ecological Stability Purposes

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Abstract. The remote sensing offers the opportunity of miscellaneous data acquisition with various ways of their consequent analysis and application. The processed remote sensing data in the form of georeferenced orthophotoimages or orthophotomaps enable the study of the examined locality from the chosen observed feature point of view. According to periodical data acquisition, it is possible to monitor the ongoing and emerging actions in time and then prevent and predict the upcoming actions. With the increasing interest in environmental issues and nature protection, the natural environment monitoring, preservation, protection and remediation present the number one priority. From the ecological point of view, the analysis of orthophotos/orthophotomaps present the up-to-date way of ecological stability calculation and monitoring.

1. Introduction
The remote sensing data availability has rapidly changed during the last years and the satellite images with high and medium resolution have become accessible. With the advent of data acquisition by the UAV method, many companies perform their own measurements and mapping for their research area and provide the orthophotoimages at the different level of resolution. The current effort on balanced environment preservation and creation places an importance on ecological stability monitoring.

For the demonstration of one of many applications following cases can be stated. Remote sensing technologies can be applied for continuous monitoring of earth structures stability, providing early warnings in the case of any natural or man-made hazard [1], secondly, large amounts of by-products or just mineral waste from mining and smelting industry (deposits and tailing dams) may be efficiently measured and controlled by means of remote sensing [2].

The ecological stability may be expressed in a numerical way according to the ecological stability coefficient (CES) calculations. The calculated values classify the examined locality into ecological
stable class, unstable class or partly stable/unstable class closer to natural or disturbed environment. The calculation itself is based on the different landscape features’ areas and the mutual ratio between these areas using the various formulas, defined independent of each other by more authors, with different consequent interpretations.

2. Data acquisition and calculation principle
The input data for the CES calculation represent the areas of landscape features, which occur in the examined locality. It is important to differentiate and define the landscape features’ boundaries with the highest possible accuracy. This condition guarantees the precise area calculations. The input data acquisition for analysis and calculations may be performed by various methods. These methods differ in the way of measurement process, necessary instrumentation, time factor, post-processing and last but not least precision.

The classic geodetic method of data collection is represented by terrestrial measurements. From the time point of view, this method is appropriate when a smaller locality is the subject of research. When the ecological stability of larger territory is about to be studied, the data acquired by the remote sensing enable the faster way of data collection. According to orthophotoimages of the examined locality obtained from post-processed remote sensing or UAV data, it is possible to get a sufficient overview and information about the subject of study [3]. The boundaries of the landscape features may be clearly and precisely determined on the orthophotoimages during the data processing and analysis.

Each author’s methodology dealing with the ecological stability and its coefficient calculation is based on the different approaches with different pre-set conditions and priorities, which consequently lead to a different interpretation of the examined locality. According to one approach, the locality may be determined as ecologically balanced territory with the prevailing natural features, but according to another approach, the locality may be defined as a locality with low ecological stability. [4-7]

The CES calculation according to Michal is based on the relative stable and unstable areas comparison and their mutual relation. The stable areas ($S$ in formula (1)) are represented by forests, low vegetation, gardens, vineyards, streams, meadows and pastures and the unstable areas ($L$) are presented by housing objects, industrial areas, transport and communication lines and arable lands [6].

$$CES_1 = \frac{S}{L}$$ (1)

The interpretation of the CES calculation (Table 1) according to Michal is:

| CES$_1$ value | Interpretation                                      |
|--------------|-----------------------------------------------------|
| $CES_1 < 0.10$ | maximal natural structures disruption               |
| 0.10 – 0.30  | above average used land with significant disruption |
| 0.31 – 1.00  | ecologically unstable and intensively used land (agriculture) |
| 1.01 – 3.00  | mostly balanced land                                |

Authors Liebel and Oberholzer [5] offer a different CES calculation approach based on the coefficient addition to every utility area of the landscape feature. The coefficients used in the calculation using the formula (2) are displayed in Table 2 and the CES$_2$ interpretation in Table 3.

$$CES_2 = \sum_{i=1}^{n} B_i P_i$$ (2)
In formula (2), $B_i$ represents the added coefficients for each utility area, $P_i$ represents the area of utility area and $P$ represents the total examined area.

Table 2. Coefficients of utility areas

| $B_i$ value | Utility area description                  |
|-------------|------------------------------------------|
| 9           | built-up areas                           |
| 12          | arable lands                             |
| 20          | grasslands and parks                     |
| 25          | special cultures and gardens             |
| 27.5        | meadows                                  |
| 31.2        | pastures                                 |
| 34.5        | coniferous forest                        |
| 50.7        | deciduous forest                         |
| 54.5        | dense planted forests                    |
| 65.1        | dense low vegetation                     |
| 75          | naturally dense forests                  |
| 80          | water areas and marshes                  |

Table 3. CES2 interpretation

| CES2 value | Interpretation                        |
|------------|---------------------------------------|
| 0          | Pointless                             |
| 1          | Very low ecological stability         |
| 2          | Low ecological stability              |
| 3          | Medium ecological stability           |
| 4          | High ecological stability             |
| 5          | Very high ecological stability        |

The CES calculation principle according to Low [4] (formula (3)) is based on the percentage representation of a landscape feature multiplied by the numerical coefficient value according to the class of the landscape feature and the mutual relation between the existing landscape features in the examined locality.

$$CES_3 = \frac{1.5A + B + 0.5C}{0.2D + 0.8E}$$

The percentage ratio of examined locality landscape features, represented by classes A – E, and their definition, are stated in Table 4, and CES3 interpretation in Table 5.

Table 4. A-E landscape classes definition

| Class | Definition                                                                 |
|-------|---------------------------------------------------------------------------|
| A     | Percentage of the areas with ecological quality of 5. level (forests, water areas) |
| B     | Percentage of the areas with ecological quality of 4. level (riparian vegetation) |
| C     | Percentage of the areas with ecological quality of 3. level (meadows and pastures) |
| D     | Percentage of the areas with ecological quality of 2. level (arable land) |
| E     | Percentage of the areas with ecological quality of 1. level (built-up areas) |
Table 5. CES$_3$ interpretation

| CES$_3$ value | Interpretation             |
|--------------|---------------------------|
| CES$_3$ > 10 | natural land close to nature |
| 10 - 1       | land with dominant natural features |
| 1            | stable                     |
| CES$_3$ < 1  | degraded                   |

For the research purposes, the cadastral district Jasenové, in the southern part of region Žilina, was chosen.

The Geographical Information System under the operation of GKÚ called ZBGIS [8] provides the orthophotomosaic of Slovakia capturing also the territory of cadastral district Jasenové (Figure 1). This service enables to download orthophotos of selected areas. The full coverage of the examined area required 4 orthophotomages at the scale of 1:5000.

![Figure 1. Orthophotoimage coverage](image)

3. Input data processing and calculations

In order to calculate and determine the ecological stability situation in the examined area, it was necessary to divide the examined area into basic landscape features, which differ in their utilization, ecological level and importance in the field of environmental issues [9]. The mentioned landscape features’ determination was performed by vectorisation of the landscape features’ boundaries.

A number of land characters were defined, especially, the forests, built-up areas, meadows, arable lands and transport network.

After the vectorization, it was necessary to calculate the total landscape features’ areas, which were crucial for the following calculations [10]. Calculation results may represent the ecological stability coefficient as a complex number. This number was compared by pre-defined requirements. (Figure 2)
Figure 2. Landscape features’ vectorisation: (a) forests, (b) meadows, (c) arable lands, (d) transport network, (e) built-up areas

4. Conclusions
Orthophotos may be used for the calculation of the ecological stability coefficient. For these purposes, the remote sensing simplified the process of data collection and definition of the ecological stability ratio. The coefficient may be calculated for the whole pre-defined area in this paper, for cadastral district Jasenové. The final results show that the CES1 acquired value was 2.43 (mostly balanced land), the CES2 acquired value was 3.18 (Medium ecological stability) and the CES3 acquired value was 8.25 (land with dominant natural features).

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References
[1] J. Bac-Bronowicz, P. Kowalczyk, and M. Bartlewska-Urban. Risk Reduction of a Terrorist Attack on a Critical Infrastructure Facility of LGOM Based on the Example of the Zelazny Most Tailings Storage Facility (OUOW Zelazny Most). Studia Geotech. Mech., 42, 376–
387, 2020.

[2] J. Rybak, S.M. Gorbatyuk, K.C. Bujanovna-Syuryun, A.M. Khairutdinov, Y.S. Tyulyaeva, and P.S. Makarov. Utilization of Mineral Waste: A Method for Expanding the Mineral Resource Base of a Mining and Smelting Company, Metallurgist, 64(9-10), pp. 851–861, 2021.

[3] J. Persson, K. Blennow, L. Gonçalves, A. Borys, I. Dutcă, J. Hynynen, E. Janeczko, M. Lyubenova, S. Martel, J. Merganic, K. Merganičová, M. Peltoniemi, M. Petr, F.H. Reboredo, G. Vacchiano, and C.P. Reyer. No polarization—Expected Values of Climate Change Impacts among European Forest Professionals and Scientists. Sustainability, 12, 2659, 2020.

[4] J. Löw et al.; Designer handbook of the local territorial system of ecological stability, Brno: Complement, 12 pp. + attachments, 1995 (in Czech).

[5] T. Reháčková, and E. Paudíšová. Methodical procedure for determining the coefficient of ecological stability of the country, In Acta environmentalica universitatis comenianae (Bratislava). Vol. 15, no. 1., 2007 (in Slovak).

[6] P. Lauko. et al. General principles of the functional arrangement of the territory in the district of the landscaping project, Nitra: GEOMETRA Levice, 79 pp., 2009 (in Slovak).

[7] Z. Muchová, et al.; Methodical standards of landscaping design. 1. ed. Nitra: SPU in Nitra in cooperation with Ministry of Agriculture and Rural Development of the Slovak Republik, 2009 (in Slovak).

[8] Y. Chen, B. Zheng, and Y. Hu. Mapping Local Climate Zones Using ArcGIS-Based Method and Exploring Land Surface Temperature Characteristics in Chenzhou, China. Sustainability, 12, 2974, 2020.

[9] J. Rüdisser, G. Leitinger, and U. Schirpke. Application of the Ecosystem Service Concept in Social—Ecological Systems—from Theory to Practice. Sustainability, 12, 2960, 2020.

[10] Geodetic and Cartographic Institute, National Forest Centre, © GKÚ, NLC; r. 2017.