Cover Management Soil Erosion Factor Using Multispectral Vegetation Indices: An Example of the River Sarayardere Watershed (Eastern Rhodopes, Bulgaria)

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http://doi.org/10.29227/IM-2024-01-66

Submission date: *13.4.2023* | Review date: *10.5.2023*

Abstract

Land cover/land use is one of the main factors influencing the development of soil erosion. It has been included in the calculation and modelling of erosion and sediment transport in many studies. In the current research NDVI (normalized difference vegetation index) and NDRE (normalized difference red edge index) are used for quantifying the cover management factor (C-factor). They are calculated on the base of Sentinel 2 multispectral images. Taking into account the vegetation phenology two time points were analyzed: end of May - June – active vegetation and September (beginning of October) – late vegetation. The changes in the values of the indices were considered for 2018, 2021 and 2022. The study area is the watershed of the river Sarayardere, located in the southern part of Bulgaria. This is a hilly to low-mountain area, prone to erosion due to rare vegetation, high slope gradients and a relatively long dry period followed by intensive rainfall. The calculated values of the C-factor are indicators for higher susceptibility to erosion in September than it is in June. The spatial distribution of the C-factor shows different patterns. The results, received on the base of the image of September 2021, show increasing the areas with C-factor < 0.1 and these ones > 0.5, in comparison with the results of September 2018. C-factor values calculated on the image of October 2022 indicate the highest susceptibility to erosion. Using NDRE instead NDVI results in slightly higher values of the C-factor. The advantage of the NDRE index is that it provides information on the content of chlorophyll in the vegetation during the end of the vegetation period and allows a more accurate assessment of the state of the separate plants, regarding the determination of diseased or damaged plants. In addition to the vegetation indices, an expert evaluation of the state of vegetation was done. The results of the current study show that the watershed of the river Sarayardere is in a relatively good condition regarding the development of erosion processes. The attention should be directed to the possible increase of erosion on deforested slopes and the availability of loose materials, in case of intense rainfall.

Keywords: land cover, land use, soil erosion factor, multispectral vegetation indices, river sarayardere watershed, Bulgaria

Introduction

Water erosion is an adverse geomorphological process that can be considered mainly in two aspects – slope wash (splash and sheet erosion) and linear erosion (rill, gully and channel erosion). Erosion processes not only destroy agricultural land and reduce agricultural productivity, but they also have a negative impact on water, vegetation and ecosystems in general. If long-term mitigation measures are not taken, the process can lead to changes in the topographic surface, reduce the slope stability, and this increases the susceptibility to the occurrence and propagation of geological-geomorphological hazards, for instance, landslides and debris flows. Intensive rainfall and snowmelt are the main triggering factors of erosion and slope processes but the movement of slope material can be influenced by the character of the topographic surface, the properties of rocks and soils, and also land use and vegetation. The most dynamic of these conditioning factors are vegetation and land use. Only for the period 2001-2012, soil erosion increased by 2.5%, the main reason being assumed to be human activity [1], and more precisely intensive land use with continuous mechanical processing of agricultural lands and deforestation [2]. The role of vegetation as an erosion retention factor is considered in many publications. Special attention is given to the impact of forests on decreasing surface runoff and soil erosion. On the other side, the efficiency of vegetation in erosion retention is analysed as a function of vegetation quality, topography, slope, hydrology, geology, and soils. In general, vegetation impacts the limitation of erosion in three main directions: reducing the kinetic energy of raindrops; retaining part of the precipitation by the above-ground parts of the plants; and improving the state of the soil. Zakov [3] stated that forest vegetation reduces the kinetic energy of raindrops up to 1000 times, and grasslands - up to 25 times.

Vegetation is one of the main factors that was considered in the equations for the evaluation of soil erosion. One of the most widely used approaches for the assessment of soil erosion is empirical modelling, based on the application of the universal soil loss equation (USLE), [4], and taking into account rainfall, slope gradient and slope length, soil properties, land cover and land use practice. Some modifications have been developed in the revised soil loss equation (RUSLE) where the cover management factor (C-factor) is usually calculated on the basis of normalized difference vegetation index (NDVI), [5, 6, 7]. The analysis of publications shows two main approaches to calculating the C-factor. The first one is based on field research and empirical modelling or on the basis of land use/land cover map [4, 8], and the second one is on the basis of NDVI, using regression relations [5, 7]. Using multispectral vegetation indices for the calculation of the C-factor allows rapid evaluation of land cover and the susceptibility to erosion [9, 10, 11]. The higher C-factor, the more susceptible to erosion lands. Vegetation indices, and mainly NDVI, are used in many studies for monitoring vegetation, evaluation of drought effect and also for land cover classification [10, 12, 13].

In the current study, the C-factor was calculated using NDVI and NDRE (Normalized Difference Red Edge). Using the RE band, NDRE gives better insight into the state of the crops in the late vegetation, due to the ability to measure down into the canopy and obtain more accurate data [14, 15]. The results for remote sensing-based C-factor are compared to the erosions susceptibility evaluation determined by an expert assessment of land cover based on the data given in the forestry plan of the studied watershed.

Study Area

The watershed of the river Sarayardere is located in the Eastern Rhodopes mountains, the southern part of Bulgaria (Figure 1) and covers an area of 44.30 km2. The terrain is hilly to low-mountainous, where the elevation varies from 298 m to the east to 1016 m to the west. The rivers in the considered watershed have an irregular river flow and almost dry up in the summer. This river regime is characteristic of most rivers in the Eastern Rhodopes. The studied watershed is located in the continental-Mediterranean climate area, where precipitation is mainly concentrated in the autumn-winter season. In the period 2000 – 2020, the minimal amount of precipitation fell in August (average monthly precipitation 28 mm) and maximal precipitation - in December (average monthly precipitation 103 mm), data was provided by the National Institute of Meteorology and Hydrology (Bulgaria). The alternation of the dry period with a period of intensive rainfall is a prerequisite for the occurrence of intensive erosion. The disintegration of soil particles is facilitated during a dry period, and the occurrence of intensive precipitation after a relatively long dry period is a prerequisite for more intense erosion.

The watershed of the river Sarayardere has a relatively high horizontal division of the relief, which is an indicator of the development of erosion processes. The average density of the river/stream network is 1.85 km/km2. The specificity of the relief in this part of the Eastern Rhodopes is determined by the wide presence of Paleogene volcanic rocks. In the Sarayardere watershed, the petrographic composition is represented mainly by sandstones, breccia conglomerates, limestones, tuffs, andesites, rhyolites, and amphibolites [16, 17]. The cover of unconsolidated diluvial and diluvial-proluvial deposits on the deforested slopes, as well as the highly prone to weathering sandstones (Dzhebelska Formation) and tuffs are a prerequisite for the development of erosion processes, and in some cases, during intense rainfall, for the occurrence of debris flows.

According to the phytogeographical zoning of Bulgaria [18, 19], the studied area falls into the European broad-leaved forest region, Macedonian-Thracian floristic province, Eastern Rhodope district. This part of the country is characterized by xerophytic and mesoxerophytic vegetation of the oak belt. Another characteristic type of vegetation is mesophytic and xeromesophytic microthermal vegetation in the hornbeam-oak forest belt. There are also Scotch pine (Pinus sylvestris L.) and black pine (Pinus nigra Arnold) plantations in the area.

A predominant part of the study area is occupied by forest vegetation, in different conditions, but there are also significant areas with deforested slopes, rare shrub vegetation or pastures, where erosion processes of varying intensity are observed (Figure 2).

Regarding the economy, the regional development is focused on ecotourism, forestry and agriculture, mainly pasture livestock breeding, which also impact land cover changes.

Fig 1. Location of the study area

(a) (b)

Fig. 2. Landscapes of the river Sarayardere catchment area: a) lower part, near to the confluence of the river Sarayardere in the river Varbitsa; b) upper part

Data and Methodology

The land cover management factor (C-factor) is evaluated on the base basis of Sentinel 2 multispectral indices, Level 2A [20]. For this purpose, two time points (active vegetation and late vegetation) in three years (2018, 2021 and 2022) are considered. After analysis of the data, available for the watershed of the river Sarayardere, and taking into account the cloud cover, we choose the images of the following acquisition dates: for active vegetation – 31 May 2018, 24 June 2021 and 24 June 2022, and for late vegetation – 23 September 2018, 27 September 2021 and 02 October 2022. The C-factor was calculated using the exponential function of NDVI [5] using the formula:

$C = \exp[-2 * NDVI / (1 - NDVI)]$, where

$NDVI = (NIR – Red) / (NIR + Red)$

NDVI varies between -1 and 1, and gives information about the state of vegetation. High NDVI values suggest healthier vegetation. At low NDVI, vegetation is rare, absent, or in poor ecological condition. Values of 0 or negative are indicative of water bodies or bare rocks. NDVI above 0.5 is an indicator of the forest. This vegetation index can be used for the evaluation of susceptibility to erosion in relation to the influence of vegetation on the distribution of surface runoff. Usually, high values of NDVI are related to areas less prone to erosion.

Regarding the reflectance of the vegetation and the chlorophyll content, in the current study, NDRE is used for the assessment of the C-factor in the later stage of vegetation. It is calculated according to the formula:

NDRE = (NIR – RedEdge) / (NIR + RedEdge)
In this case,
C = exp [-2 * NDRE / (1 - NDRE)],

Low chlorophyll values indicate diseased or damaged plants, nutrient deficiencies, or plants that are infected with pests. These plants have a smaller erosion retention role and slope wash or rills can form.

Data from the forestry plan of Momchilgrad State Forestry (2017-2027) were used for the assessment of erosion susceptibility. Values from 1 to 5 were assigned to different areas according to the role of different types of vegetation in erosion retention. Vegetation, with the highest erosion retention role was evaluated with 1 and areas most prone to erosion were marked with 5. Taking into account the properties of the land cover, the erosion susceptibility indices were determined by expert evaluation, as follows:

- 1 was assigned to the vegetation that implies the least degree of erosion such as plantations with high coverage and seed stands. These are mainly forests that are mature, with a large projective coverage of the crowns, which reduces the kinetic energy of rainfall, the roots are well developed and help to retain the soil;
- with 2 the coppices, not very dense plantations with not very high coverage were evaluated. Some of them are low-stemmed and determined to be transformed, i.e., their structure is not good, the projective coverage of the crowns is lower, and they protect against erosion to a lesser extent;
- 3 is for meadows because the grass cover protects against erosion to a lesser extent than the forest;
- 4 was assigned to forest cut lines and unforested areas. They are deforested and the risk of erosion is high, but there may still be protection from trees, which distinguishes these areas from screes, clearings and bare rocks, where the susceptibility to erosion is higher;
- 5 is the evaluation for areas most prone to erosion, such as clearings, bare rocks, screes and truck roads, where the erosion hazard is highest, due to lack of grass, shrub or tree vegetation.

Results

The analysis of the calculated NDVI and NDRE, show similar values and territorial distribution for May 2018 and June 2021 (active vegetation), as well as for the considered data of late vegetation - September 2018 and 2021 (Table 1). The conditions for 2022 are different, when the areas with NDVI from 0.2 to 0.5 have the largest share in the river Sarayardere watershed, and those from 0.5 to 0.7 are in second place. Regarding the respective data of 2021 and 2018 (for active and late vegetation), the areas with NDVI > 0.7 are predominant which is an indicator of better vegetation conditions. This can be seen also considering the values of NDRE for the autumn months, where the largest areas have values in the intervals 0.2-0.5 and 0.5-0.7, while for October 2022, in a negligibly small part of the watershed, NDRE is greater than 0.5 and the share of the areas with NDRE from 0 to 0.2 increase.

Tab. 1. Distribution of NDVI and NDRE in the watershed of the river Sarayardere (%)

Classes / values	Classes of NDVI in % of the watershed area						Classes of NDRE in % of the watershed area		
	June'22	June'21	May'18	Oct.'22	Sept.'21	Sept.'18	Oct.'22	Sept.'21	Sept.'18
< 0	0.01	0.023	0.03	0.04	0.04	0.06	0.11	0.13	0.14
0−0.2	0.74	0.32	0.19	4.05	0.64	0.74	17.02	5.92	5.35
0.2−0.5	59.43	4.09	9.7	79.38	20.96	21.51	82.35	47.69	54.45
0.5−0.7	39.68	21.59	26.04	16.52	19.23	25.11	0.52	44.92	38.78
> 0.7	0.02	73.95	64.04	0.002	59.12	52.57	-	1.35	1.28

The analysis of the C-factor shows similar patterns for May 2018 and June 2021 (active vegetation), as well as for the considered data of late vegetation - September 2018 and 2021 (Figure 3, Table 2).

Significantly different conditions are shown by the values of the C-factor, calculated using the data of 2022, respectively June and October. The higher the C-factor values the higher the susceptibility to erosion. The results of both months indicate a worse vegetation state in 2022 and higher susceptibility to erosion. This can be related to less precipitation in 2022 and dryer conditions for vegetation. For example, the precipitation amount for September and October in the village of Ustren is respectively 33 mm and 5 mm (according to our measurements – automatic meteorological station) while for the same months in 2021 at the town of Dzhebel (10 km northeast of Ustren) the monthly precipitation is 49 mm (September) and 165 mm (October). The values of the C-factor vary mainly between 0 and 1 which corresponds to the results for other areas, presented in publications [10, 21]. In the current study, negligibly small parts of the Sarayardere watershed have C-factor values higher than 1 (Figure 3, Table 2), and this could be related to some gaps in the data. In the largest part of the watershed, the values of NDVI-based C-factor (for the considered dates of 2018, 2021) are less than 0.1, and in June and October, 2022 predominant areas (respectively 68 % and 79 %) have a C-factor between 0.1 and 0.5. NDRE-based C-factor for the months of late vegetation is characterized by the largest area share of the class from 0.1 to 0.5.

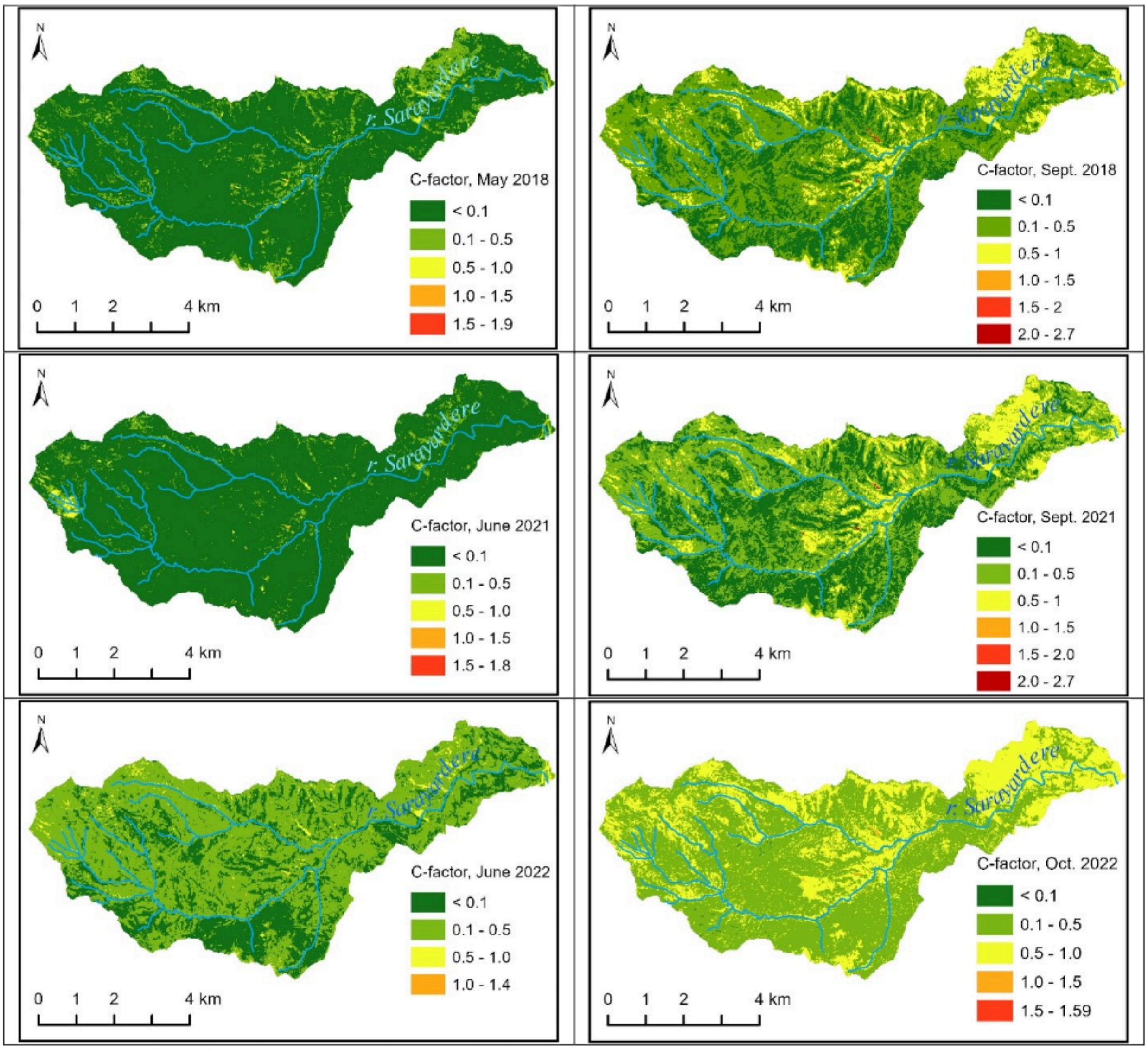

Fig. 3. C-factor for active vegetation (May, June) – based on NDVI and for late vegetation (September, October) – based on NDRE

Tab. 2. Distribution of NDVI and NDRE in the watershed of the river Sarayardere (%)

Classes / values	**Classes of C-factor, based on NDVI in % of the watershed area**						**Classes of C-factor, based on NDRE in % of the watershed area**		
	Jun-22	**Jun-21**	**May-18**	**Oct-22**	**Sep-21**	**Sep-18**	**Oct-22**	**Sep-21**	**Sep-18**
< 0.1	29.82	94.17	87.24	10.03	75.46	74.02	0.11	35.52	28.87
0.1−0.5	68.08	5.18	12.06	79.13	22.46	23.9	65.27	50.92	58.1
0.5−1.0	2.09	0.63	0.67	10.8	2.04	2	34.5	13.42	12.89
1.0−1.5	0.01	0.02	0.03	0.04	0.03	0.04	0.11	0.07	0.065
1.5−2.0		0.004	0.004		0.001	0.02	0.004	0.02	0.024
> 2.0								0.04	0.056

The susceptibility to erosion of the river Sarayardere watershed is rated from 1 to 5 on the base of the land cover, determined in the Momchilgrad State Forestry plan (2017-2027). The largest part of the territory of the Momchilgrad Forestry, on whose territory the research site is located, is occupied by coppice stands. The main tree species are Quercus frainetto Ten., Quercus petraea L., Pinus nigra Arnold, Pinus sylvestris L. and Robinia pseudoacacia L., and small areas are occupied by Carpinus orientalis Mill. and Quercus cerris L. Areas with a very low susceptibility to erosion, regarding the vegetation, take the largest part - 76% of the catchment, and those evaluated as low susceptible occupy about 12%. Areas with moderate susceptibility take 5%, and high and very high susceptibility each have 3% of the watershed (Figure 4).

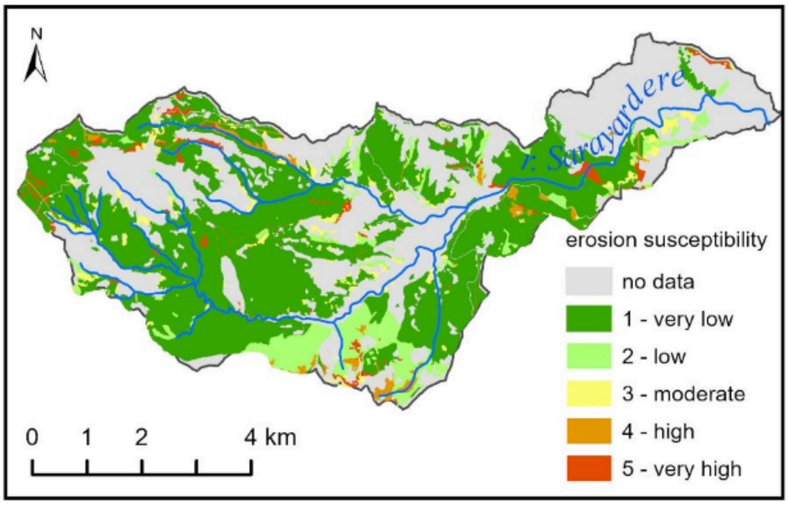

Fig. 3. Erosion susceptibility set on the land cover, based on the Momchilgrad Forestry plan (2017-2027)

High and very high erosion susceptibility rates are related to deforested areas and bare soils and rocks without any vegetation. Regarding vegetation, the watershed of the river Sarayardere is in a good condition. Generally, the results about erosion susceptibility, based on the data of Momchilgrad forestry plan correspond well to the results, based on vegetation indices, and particularly those determined by NDRE. An exception to this are the southern parts of the watershed with high and very high susceptibility to erosion.

Conclusion

The C-factor of soil erosion is evaluated using multispectral vegetation indices. NDVI was used for the calculation of the C-factor for the months of active vegetation (May, June) while on the basis of NDRE, values of C were calculated for the late vegetation (end of September and beginning of October). The results show logical regularity for higher erosion susceptibility in autumn months when vegetation (particularly grass) is mostly dry and with less retention capacity. For the most part of the studied watershed, the values of the C-factor vary between 0.1 and 0.5. The evaluation of erosion susceptibility using Momchilgrad State Forestry Plan (2017-2027) shows a very low susceptibility to erosion. The areas highly prone to erosion take a very small part.

Using NDRE instead of NDVI for the calculation of the C-factor for the months of late vegetation gives a bit higher values but for the particular study area, they correspond well to the land cover. At this stage, the research carried out is not sufficient to confirm that the use of NDRE for the phase of late vegetation is a more appropriate approach than NDVI. More analyses of multispectral images of different points in time and for different areas to evaluate the applicability of the applied approach. The current results are closely related to the atmospheric conditions and the landscape state at the particular moment of data acquisition as well as the image resolution. However, regarding the properties of vegetation reflection in the state of less chlorophyll content, the current study is a good base for further evaluation of erosion susceptibility using multispectral images.

Acknowledgments

This research has been carried out in the frame of the project "Application of geoinformation technologies in erosion research in mountain areas - Case studies of Eastern Rhodopes (Bulgaria)", funded by the National Science Fund, Ministry of Education and Science (Bulgaria), Competition for financial support for basic research projects - 2019 (Contract No КП-06-Н34/3, signed on 5.12.2019).

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