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Quantitative - Spatial Analysis of Soil Loss by Laminar Erosion and Comparison with NDVI Method of the Municipalities of Mandaguaçu and Presidente Castelo Branco / PR

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ABSTRACT
Environmental monitoring is essential for society to maintain balance with the environment, given this fact, several methods from the science of geoprocessing and remote sensing were created to assist in the task. The present work used the Universal Soil Loss Equation to verify the spatiality of laminar erosions in the municipalities of Mandaguaçu and Presidente Castelo Branco, both in Paraná, in addition to comparing their results with data from the Digital Vegetation Index (NDVI) to obtain relationships between the loss of soils and the development or lack of vegetation. The results identified several foci of laminar erosion in the study area, as a possible cause, soils from the highly erodible Caiuá Sandstone can be considered, as well as topographic factors of the EUPS LS factor. It should be noted that the use of digital tools, satellite images and map algebra is not essential for environmental monitoring studies.

KEYWORDS: EUPS. NDVI. Loss of Soil.

1 INTRODUCTION

Geotechnologies are fundamental for spatial assessments, as they allow users to promote area recognition, quantification, qualification remotely, or even joint studies between field and laboratory analysis.

Remote Sensing for Saldanha, Cardias and Werlang (2021, p. 89) is described in the following light: “Geography understands remote sensing as a technology that allows the development of more careful and detailed studies on the earth's surface”.

Florenzano (2005, p. 24) comments that: “geotechnologies related to Remote Sensing and Geographic Information Systems (GIS) are increasingly interconnected. Its applications in different fields of knowledge have increased. At first, in Geography, these technologies have a wide application”. Dambrós (2020), based on Gustavo Daniel Buzai, shows that studies using geotechnologies continue to rise; the author also states that geotechnologies allow for multiple and complex analysis of geographic space.

On the other hand, the Normalized Difference Vegetation Index (NDVI) consists of being an index of easy calculation and robust results, with wide employability in forestry (FERNANDES; VICENS; FURTADO, 2018; BRITO et al., 2021), in Units of Conservation (MELO et al., 2019; EDUVIRGEM; PAROLIN; VILLWOCK, 2020), in Permanent Preservation Areas - PPAs (VENTURA; MIRANDA; SILVA, 2019), in temporary agriculture (CASA et al., 2018), in deforestation (VIEIRA; CARVALHO, 2017), and hydrographic basins (SOUZA et al., 2018; OLIVEIRA; AQUINO, 2020). This index – the NDVI – is also among the most used for monitoring vegetation (CORDEIRO et al., 2017; LEITE et al., 2017; ABOUD NETA et al., 2018).

NDVI values can range between -1 and +1, with negative values for water bodies and close to 0 for exposed soil (ALMEIDA et al., 2018); It is common to find in the literature that values close to 1 positive indicate arboreal vegetation (BARROS; FARIAS; MARINHO, 2020) – which is correct and makes perfect sense in areas with PPA, forest fragments, linear corridors, Conservation Units, among other examples environmental (LEITE et al., 2017; FERNANDES; VICENS; FURTADO, 2018; SILVA JUNIOR et al., 2021).

Nevertheless, one must be careful and pay attention to these values, since in specific situations, such as temporary crops, values may be higher than 0.90 (CARNEIRO, 2018; HU et al., 2018), whose values are also found in forest vegetation (DAULAT; PRANOWO; AMRI, 2018; FERNANDES; VICENS; FURTADO, 2018) – as an example in Atlantic Forest remnants (COSTA; GUASSELLI, 2017). In forestry areas, values ranging from 0.67 to 0.95 are found; in pastures, it can also be found from low (0.35) to high values (0.7 to 0.8) (FERNANDES; VICENS; FURTADO, 2018).

Thus, inferring targets from the values generated by the NDVI can increase interpretation errors. Thus, knowledge about land use becomes necessary, the period being analyzed, among other variables. Studies on a municipal and hydrographic basin scale need careful analysis, as they can have many targets – in land use and occupation.

The NDVI, in addition to being an index for monitoring vegetation and crops, is often used to compose other equations, such as the Universal Soil Loss Equation (USLE), for calculating the C factor (SILVA et al., 2017; UEMA; GASPARETTO, 2020).

USLE composes the system for the use of mathematical modeling constituted by indirect methods, in order to quantify laminar erosion (SOARES et al., 2017; SOUZA; GALVANI, 2017).

The results provided by USLE are extremely important and employable for planning, incorporating various natural and anthropogenic factors such as land use and occupation, conservation practices, topography, erosivity and erodibility, in addition to, indirectly, precipitation and soil classes, the proportion and spatial distribution of soil loss in ton per year helps to protect agricultural crops and natural areas, enabling managers to conserve the soil.

In this study, the focus of the USLE is related to soil loss in the municipalities of Presidente Castelo Branco and Mandaguaçu, in northwestern Paraná, in areas with higher slopes and with medium textured soils and use of pasture in the soil. Differentiation of precipitation influenced the NDVI values which, in turn, subtly changed the results of the April and December USLE, however, not expressing significant changes in localities with forest fragments, forestry and PPAs.

2 OBJECTIVES

The objective of this paper is to quantify and spatialize the laminar erosion existing in 2020 in the municipalities of Mandaguaçu and Presidente Castelo Branco, both in northwestern Paraná, and to verify a possible correlation with the vegetation stages, in two distinct scenarios: rainy month (December) and the month of April, which can cause the development of vegetation. To achieve the main objective of this paper, methods such as the Universal Soil Loss Equation (USLE) were carried out, which helps in the quantification and spatialization of soil loss and the Normalized Difference Vegetation Index (NDVI) to compare the vegetation cover in the required points with high values of laminar erosion.

The research hypothesis is verified by the fact that, if an USLE indicates a loss of soils by laminar erosion and the NDVI indicates how possible combinations between the vegetation cover areas can be, a combination of both variables will help in the spatial analysis of these variations, as the difference between the factors in the dry and rainy seasons show the relationship and dependence of the spatial correlation between soil loss and vegetation cover.

3 METHODS

The Universal Soil Loss Equation (USLE) was developed by WISCHMEIER and SMITH (1978) with the purpose of simulating and predicting soil loss exclusively by laminar erosion of small farms in the United States, which used other studies, including: ZINGG (1940)), SMITH (1941) and BROWNING, PARISH and GLASS (1947). In addition, post-USLE researchers have developed and used new methods and variations of the technique, improving it in relation to the use of new technological resources, including: UEMA (2018), PETSCH and SANTOS (2015) and SOUZA (2010). Thus, it is possible to use the USLE to simulate the loss of soil for entire cities, depending on the details of the data.

USLE can be represented by equation (01):

$$A = R \; x \; K \; x \; L \; x \; S \; x \; C \; x \; P \qquad (01)$$

Where: “A” represents the loss of soil by laminar erosion of the area per ton. ha. Year; the “R” variable represents the erosivity of the study area; the “K” represents the soil type erodibility; the “LS” factor is the topographic factor, the junction between the slope factor and the length of the slope; the “C” factor is the use and occupation of the land and the “P” factor represents the conservation practices used to manage the area.

To obtain the R factor values, the methodology of RUFINO, BISCAIA and MERTEN (1993) was used, which obtained values for isoerosive areas in Paraná, and has been used since then for erosivity calculations in the State, and the precipitation values were taken from the website of the National Institute of Meteorology (INMET), equation (02) is represented by:

$$EI=6,886 \, (r2P)0,85 \qquad (02)$$

Where: “A” represents the loss of soil by laminar erosion of the area per ton. ha. Year; the “R” variable represents the erosivity of the study area; the “K” represents the soil type erodibility; the “LS” factor is the topographic factor, the junction between the slope factor and the length of the slope; the “C” factor is the use and occupation of the land and the “P” factor represents the conservation practices used to manage the area.

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Table 1: K factor values (erodibility)

Soil	K factor
Red Latosol (Oxisol) with clay texture	0,0285
Red Latosol (Oxisol) with medium texture	0,0036
Red Argisol with sand texture	0,1007
Regolith Neosol with clay texture	0,0178
Red Nitosol with clay texture	0,018
Urban area	0,8

To obtain the LS factor, the image Shuttle Radar Topography Mission - SRTM from NASA (National Aeronautics and Space Administration, of the United States) was used, which was additional to the Gisus-M plugin from ArcGIS, in which the USLE process was accomplished.

For factor C, the NDVI (SILVA et al., 2017; UEMA; GASPARETTO, 2020) was used for the dates of 04/27/2020 and 12/26/2020, with equation (03) (ROUSE et al., 1974):

$$\text{NIR-RED}(\text{NIR}+\text{RED}) \qquad (3)$$

Where: NIR is the reflectance of the near infrared band, and RED is the reflectance of the red (visible) band. It is noteworthy that the images underwent conversion of the values of digital numbers (DN) to spectral radiance and, subsequently, to reflectance; being sequenced by atmospheric correction by the Dark Object Subtraction (DOS) method, available in Qgis 3.10 by the Semi-Automatic Classification Plugin. For descriptive statistics of NDVI values, n = 107 was used randomly.

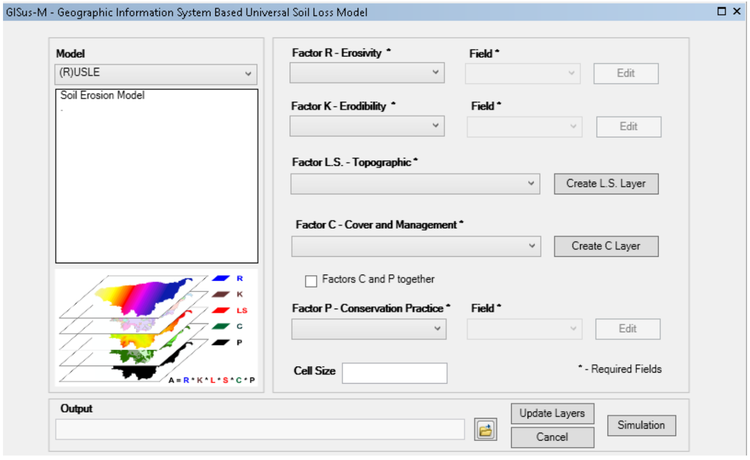
And finally, for the P factor, the ITCG shapefile for land use at 1:250,000 was used as a basis, and the bibliography values of FUJIHARA (2002), BERTONI and LOMBARDI NETO (1985) and SOUZA (2010). Table 2 shows the values adopted for fact P.

Table 2: P factor values (conservation practices)

Conservation practices	P factor
Natural forest vegetation	0,2
Contour planting	0,5
Permanent Vegetation Cords	0,2
Natural grassland vegetation	0,2
Pasture	0,5
Lakes	1,0

The GIS ArcGis was used to calculate the USLE, and the GISUS-m plugin, created by OLIVEIRA et al., (2015), the add-in layout is represented in Figure (01).

Figure 1: Layout do Gisus-M, add-in do ArcGis.



GISus-M - Geographic Information System Based Universal Soil Loss Model

Model: (R)USLE

Soil Erosion Model

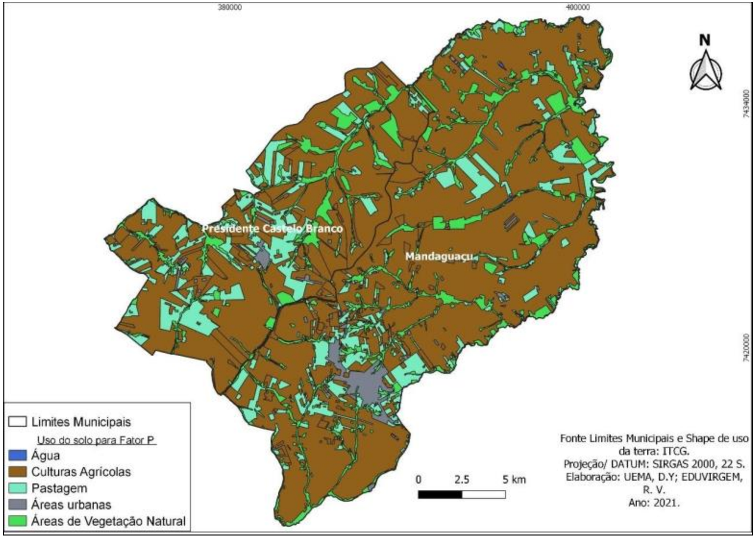
4 RESULTS

4.1 USLE factors

Obtaining the USLE results requires each map, or geospatial information, of the factors R, K, LS, P and C. For each vector map (R, K and P factors) an attribute table was generated with a column containing the factor values for each type of class in the image.

Figure 2 (1:25,000) constitutes land uses in classes such as water, agricultural crops, pasture, urban areas and areas of natural vegetation, in the vector image attribute table there are definitions that were related to Table 2 generating the base of the P factor.

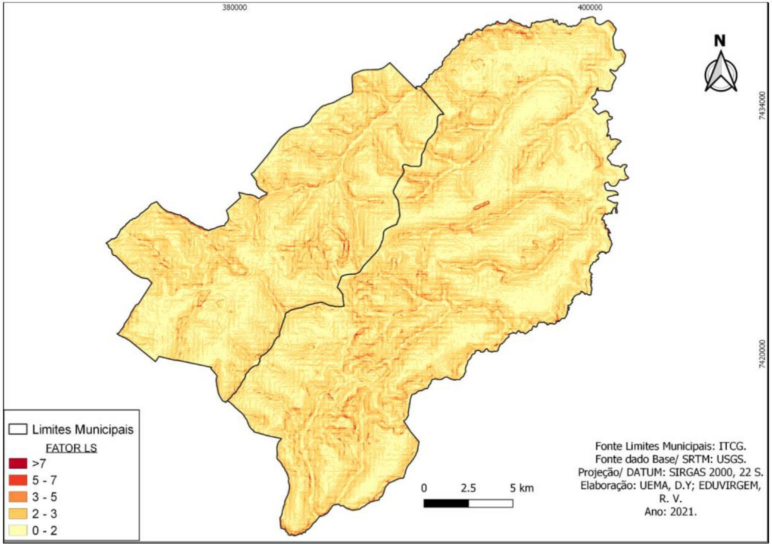
Figure 2: P Factor Map



Fonte Limites Municipais e Shape de uso da terra: ITCG.
Projeção/ DATUM: SIRGAS 2000, 22 S.
Elaboração: UEMA, D.Y; EDUVIRGEM, R. V.
Ano: 2021.

For the slope length-gradient factor (LS), generated from the SRTM image, represented in Figure 3, classes 0 – 2, 2 – 3, 3 – 5, 5 – 7 and >7 (dimensionless) were defined. The classes with the lowest LS value were identified as the areas of lesser slope, flatter and mostly on top of the slopes, whereas the classes with the highest LS value are concentrated in the areas of greater slope and low areas.

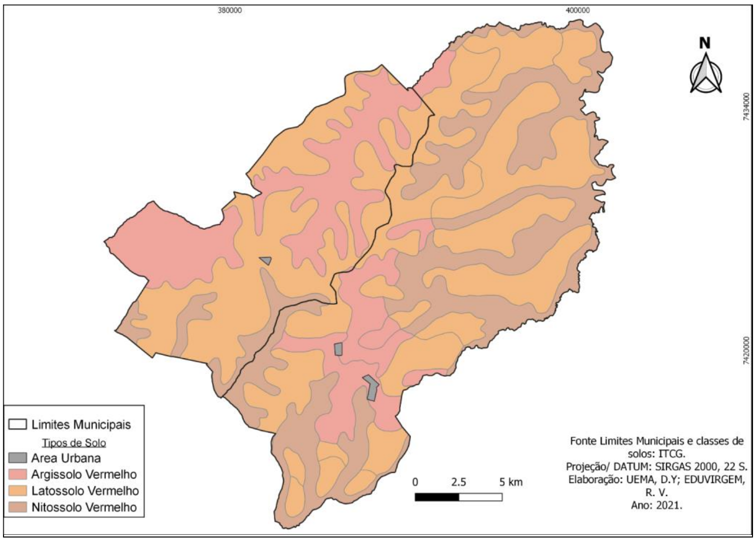
Figure 3: LS Factor Map



Fonte Limites Municipais: ITCG.
Fonte dado Base/ SRTM: USGS.
Projeção/ DATUM: SIRGAS 2000, 22 S.
Elaboração: UEMA, D.Y; EDUVIRGEM, R. V.
Ano: 2021.

Figure 4 is composed of the existing soil classes in the studied cities, according to the ITCG vector file on a scale of 1:250,000. The values assigned to the soil classes are identified in Table 1.

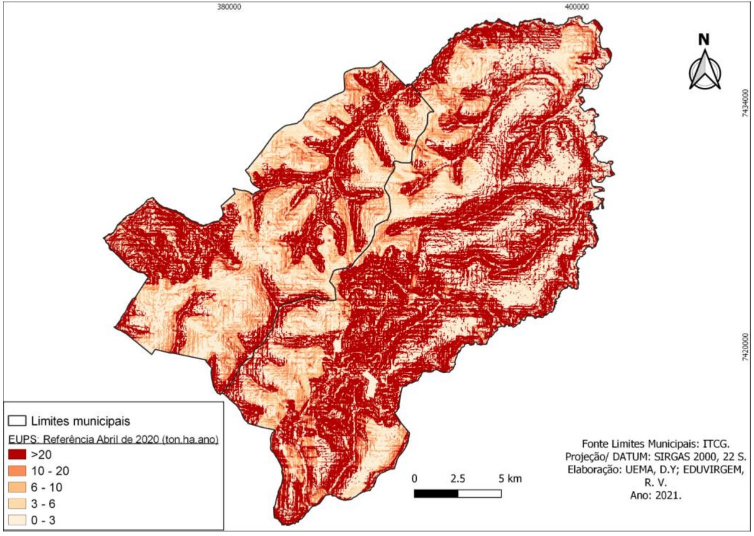
Figure 4:K Factor (erodibility)



4.2 2020 annual USLE with dry period NDVI (April)

As an annual result of the USLE for the year of 2020, using the reference NDVI for April (Figure 5), the driest month recorded by INMET, with 0 mm, classes of 0 - 3, 3 - 6, 6 - were obtained 10, 10 – 20 and >20 ton/ha/year. A large part of the 10-20 and >20 ton/ha/year soil loss classes are found in the areas with the highest slope and the highest LS factor, but a greater focus of soil loss is identified in the red Argissoil and Red Nitosol classes , showing more erosive classes than the red oxisol. Classes 0-3, 3-6 and 6-10, on the other hand, have greater spatial representation in flat and high areas, it can be seen that the municipality of Presidente Castelo Branco has a lower percentage of classes with greater soil loss, whereas Mandaguaçu had large part of the area with large soil loss per ton/ha/year. These facts can be linked by the fact that the land has a greater slope and the municipality is very exposed to pasture.

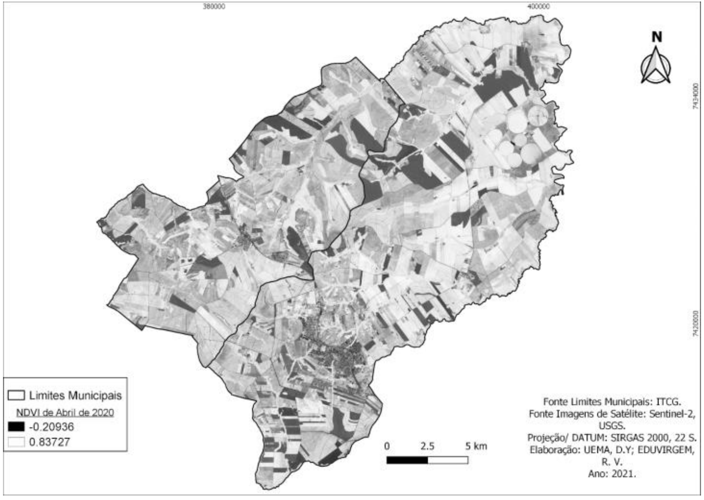
Figure 5: 2020 annual USLE/April reference



For April 2020 (Figure 6), the NDVI values had a maximum value of 0.84, a median of 0.61 and a standard deviation of 0.21; for December 2020 (Figure 7) the maximum value was 0.05 higher (0.89), as well as the median 0.03 (0.64) and the standard deviation 0.02 (0.23). Thus, it was determined that, in addition to the December values being higher, they showed greater variation, based on the dispersion measure – s = standard deviation. The increase in NDVI values can be attributed to the water in the system, as April is a dry month and December is rainy for 2020.

The highest NDVI values for April 2020 were determined for temporary crops (soybeans), sugarcane, forest fragments, headwater drainage and forestry. Values ≥ 0.80 for these targets were also identified by Carneiro (2018); Daulat, Pranowo and Amri (2018); Fernandes, Vicens and Furtado (2018); Teramoto et al. (2018).

Figure 6: NDVI April 2020

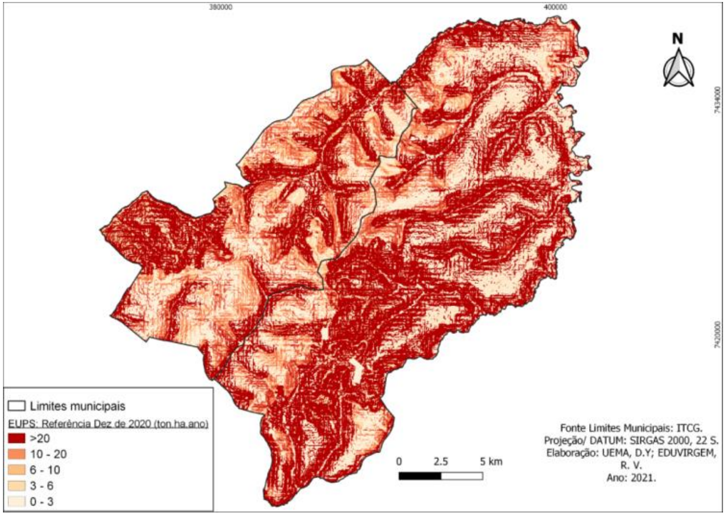


Spatial analysis (with composition of 4,3,2 colored bands), NDVI and USLE were used, and it was observed that classes 10-20 and >20 are found in permanent crops, sugarcane, forest fragments, temporary culture, PPA river and pasture. The other USLE classes (0-3, 3-6 and 6-10) were determined by land use and occupation: sugarcane, pasture, temporary culture, forest fragments, floodplain and forestry.

4.3 2020 annual USLE with rainy period NDVI (December)

The 2020 annual EUPS result (figure 7) NDVI benchmark for December, the wettest month of the year (181.6 mm), is also ranked between 0 – 3, 3 – 6, 6 – 10, 10 – 20 and >20 ton/ha/year for comparison purposes. The differences are found in the middle classes 6 – 10 and 10 – 20 ton/ha/year, and it is possible to find them more frequently in places that previously had low classes 0 – 3 and 3 – 6 ton/ha/year, evidencing the influence of precipitation and erosivity factor. The >20 ton/ha/year grade was little changed compared to the April benchmark USLE.

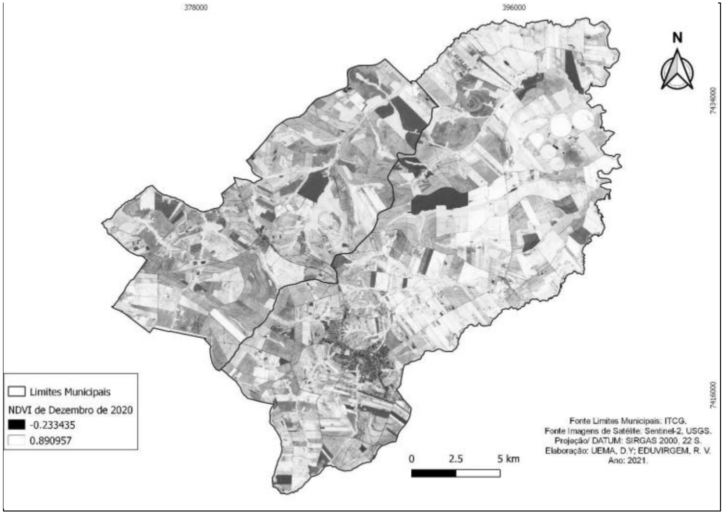
Figure 7: USLE 2020/December reference



The NDVI for April (Figure 6) differed from the month of December (Figure 8), mainly in temporary agriculture, including sugarcane which was determined exposed soil (positive NDVI values close to 0) – and consists of a momentary condition of the landscape – since for the next planting the soil needs rest or rotation with another crop; bare soil enhances laminar erosion (CAMPOS, 2018). This fact was observed in the southwestern area, where USLE prevailed with the class >20 ton/ha/year.

In the (temporary) soybean crop, the changes were noticeable mainly in the central north and southeast sectors, with plots of bare soil - due to soil preparation for planting, and the NDVI variation due to the plant development phase - due to the planting phases, development, harvesting and water in the system. Due to this situation, the USLE 6 – 10 and 10 – 20 ton/ha/year classes increased, thus causing a decrease in the 0 – 3 and 3 – 6 ton/ha/year classes. This situation – inversely proportional – highlights the influence of precipitation on the potentialization of laminar erosion. The areas with forestry, forest fragments, PPA river and drainage headwater continued with the prevalence of the class >20 ton/ha/year. Figure 7 illustrates the variation in vegetation cover for the rainy month.

Figure 8: NDVI December 2020



The “natural” cover (vegetation – whether native or secondary forest) consists of protection for the soil, thus decreasing the intensity of laminar erosion (SILVA; LUCHIARI, 2016). Nevertheless, those areas with high NDVI predominated in the USLE >20 ton/ha/year class. This combination became important in the USLE equation. This situation also occurred in an area studied by Corrêa (2011), and the opposite situation, by Moraes (2018).

Uema and Gasparetto (2020) carried out a multi-temporal analysis of the USLE – observing the differences during the seasons of the year (July 2016 to June 2017) and the annual values with covered and bare soil – determining high soil loss due to laminar erosion in fluvial PPA, only in stretches of the lower course of the Zauna stream HB (in two models: spring and bare ground), with values between 10-20 to >50 ton/ha/year; as regards the USLE values in forest fragments, the rates determined were between 0 – 3 to 10 – 20 ton/ha/year in the most catastrophic scenario because in the other scenarios the areas with arboreal vegetation presented a low rate of soil loss, being predominant class 0-3 ton/ha/year, thus configuring vegetation as an important factor for mitigating soil loss.

In view of the important results of Uema and Gasparetto (2020), it should be noted that the area under study has a smaller size than this study, as well as the absence of an argisol – which consists of a soil with greater susceptibility to laminar erosion; and predominance of soybean and corn crops, with no sugar cane, which is a crop that favors soil loss, especially in fallow; in addition to subtle differences in the other factors employed in the USLE. Thus, it is denoted that each area in which USLE is applied may have differences both in physical attributes and in the weights attributed to the variables, which is the primary result for planning conservation practices.

5 CONCLUSION

It can be concluded that the USLE methods used are influenced by all the proposed factors (R, K, LS, C and P), but in the studies the K and LS factors are the ones that most influenced the final USLE result.

The cities studied, in comparison with other studies in Paraná, suffer from greater laminar erosion, as a result of the soils being more sandy and medium, suffering more erodibility, coming from Caiuá sandstone.

The factor of high percentage of pasture and agricultural crops in the area also influenced the results.

The NDVI was effective in differentiating the land use targets, aiding in the distinction, requiring careful and thorough assessment of the targets, since high NDVI values may not only be forest fragments and forestry, but also other targets.

When comparing the USLE with the NDVI, it was spatially identified that the areas with forest fragments occurred mostly in areas with high soil loss, which is explained by other USLE factors such as LS factor and (k) soil (argisol) more susceptible to erosion, since clay soils in areas with high declivity are favorable to abundant soil loss by laminar erosion. For this reason, the importance of continuing to preserve these forest fragments is expressed, as, without tree cover, the laminar erosion process can be intensified. Finally, it is noted that this was a condition according to the municipalities under study, which is also identified in other areas of Brazil. However, as discussed, the opposite situation is possible and frequent, due to the conjunction of natural and anthropogenic environmental elements.

The results indicate that the research hypothesis can be proven, since the studied methodologies present data consistent with the laminar erosion systematic, for future research, it is possible to perform several algebras of temporal maps in different watersheds to result in raw data correlating still plus laminar erosion and vegetation cover.

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