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ESTIMATION OF THE CHANGES IN THE RAINFALL EROSIVITY IN HUNGARY

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Abstract

According to the forecasts of numerous regional models (eg. REMO, ALADIN, PREGIS), the number of predicted rainfall events decreases, but they are not accompanied by considerably less precipitation. It represents an increase in rainfall intensity. It is logical to ask (if the limitations of the models make it possible) to what extent rainfall intensity is likely to change and where these changes are likely to occur in the long run. Rain intensity is considered to be one of the key causes of soil erosion. If we know which areas are affected by more intense rain erosion, we can identify the areas that are likely to be affected by stronger soil erosion, and we can also choose effective measures to reduce erosion. This information is necessary to achieve the neutral erosion effect as targeted by the EU. We collected the precipitation data of four stations every 30 minute between 2000 and 2013, and we calculated the estimated level of intensity characterizing the Carpathian Basin. Based on these data, we calculated the correlation of the measured data of intensity with the values of the MFI index (the correlation was 0.75). According to a combination of regional climate models, precipitation data could be estimated until 2100, and by calculating the statistical relationship between the previous correlation and this data sequence, we could estimate the spatial and temporal changes of rainfall intensity.

Keywords: rainfall intensity, regional differences of R, data of REMO and ALADIN models

INTRODUCTION

Soil erosion is one of the greatest environmental threats, which causes significant environmental damage in Hungary. Its extent has been estimated lots of times, and it affects about 2 million hectares (Stefanovics, 1992). In order to prepare long-time estimations concerning the regional change tendencies of soil erosion, we have to pre-estimate dynamic parameters and factors. (In 2015, the EU set an ambitious goal to reduce the extent of soil erosion to zero.) The aim of the present analysis is to pre-estimate the temporal changes of rainfall erosion potential of the dynamic parameters. By doing so, we will receive information about one of the most important factors of soil erosion. Even if it is all about tendencies, detecting temporal and spatial changes in rainfall intensity may serve as important information to take extended-range measures to reduce the effects of erosion. In addition to geomorphological and soil data, dynamic (land cover) as well as numerous static factors may also be required to estimate the extent of soil erosion. Our study aims at revealing major changes of the R value in the present study. There are lots of uncertainties that result from using the data of the applied regional climate models, and, besides these, we also have to take into account that such social and economic changes may happen in the next few decades that may also change climate and land cover data predicted earlier. Our results must be interpreted within these limitations.

Soil erosion processes are characterized by a lot of theoretical and empirical models. However, the parameters of the processes can be well-defined. For example, rainfall intensity and land cover (C) are dynamic parameters in the Universal Soil Loss Equation (USLE), while the others are static ones. It is a complex task to calculate rainfall intensity and the erosion potential associated with it. Rainfall erosivity factor (R) is expressed by summarizing the energy values of each rainfall event in a given period (Wischmeier - Smith, 1978, Wischmeier, 1959). The rainfall erosivity factor is calculated by multiplying the kinetic energy of precipitation (E) by the maximum rainfall intensity during a period of 30-minutes for each rainstorm (ExI30). Rainfall erosivity (R) expresses the collective erosivity value of locally occurring rainstorms (Table 1). The logic of the calculation dates back to the 1961s (Wischmeier, 1959), but it gained wide recognition when the Universal Soil Loss Equaiton became commonly used (1978) as it was one of its parameters.

Table 1 Calculating the rainfall erosivity factor

Rainfall erosivity factor (R) (MJ/ha.cm/h)	$R = E \times I_{30}/100$, where I_{30} – maximum rainfall intensity during a period of 30-minutes for each rainstorm (cm/h), E – total kinetic energy of precipitation (J/m^2)
Total kinetic energy of precipitation (E) (J/m^2)	$E = \sum_{i=1}^{n} E_i$, where E_i - the kinetic energy of the i segment of precipitation (n is the number of segments) $E_i = (206 + 87 \log I_{si}) \times H_{si}$, where I_{si} – the intensity of the i segment of precipitation (cm/h), H_{si} – the amount of the i segment of precipitation (cm)

In Hungary, R factor values vary between 360 and 1,000 (Panagos et al., 2015), and they are characterized by small-scale variance as a result of the homogeneous environmental features of the country. (The calculation is based on the ten-minute precipitation data of 30 rain gauges between 1998 and 2013.) It has an average value compared to other European data, and it is also far below the great, 4,000 to 6,000 MJ/ha rainfall intensivity values of the continent. Former Hungarian local test results usually recorded data in this interval (Kertész and Richter, 1997: 49-59 MJ/ha; Centeri, 2002: 76 MJ/ha; Jordán et al., 2004: 809 MJ/ha; Szűcs, 2012: 60-512 MJ/ha). Homogeneity is expressed in the elevation, the climate type, and the general water balance, although different soil conditions would require different land use in order to reduce soil erosion. Despite the relative homogeneity of the environmental factors, territorial differences are visible (if not otherwise, then their impact is). We also aimed at estimating this spatial difference concerning the future periods.

Rainfall intensity can be calculated by two different methods. One of them operates with great temporal resolution using a minimum of 30-minute precipitation data. The other one does not have such high temporal resolution data, it calculates intensity with more easily accessible precipitation data by employing parameters which are significantly correlated with R. The frequent use of the latter method also shows that there is no widely accepted and widely applied method for calculating rainfall intensity. The different precipitation data and their correlations can only be used with quantitative (eg. with <12.7 mm of rainfall - otherwise at EI default event) and qualitative (e.g. fixed drop size ratio) prerequisites, and they can be converted to $MJha^{-1}cmh^{-1}$ value. A weakness of the commonly used empirical formula is that it presupposes the existence of precipitation data series dating back to several decades, and the correlation was tested on plot-sized areas. The erosion factor (R) is usually the average value of the data collected during several years.

There are usually not any data (which would be detailed enough) available to calculate the rainfall erosivity factor, so a lot of alternative parameters were developed by using daily and annual precipitation data to substitute the value of the R factor. These parameters are typically such indices that are related to smaller areas, and they are used at the maximum of meso-level. They often show as good correlation with soil erosion as the R index (eg. Fournier p^2/P index, REM index Lal's Aim index, P/S_t universal index) (Fournier, 1960; Arnoldus, 1980; Daidato, 2007; Onchev, 1985; Sauerborn et al., 1999; Renard et al., 1994 - Table 2). These indices also show at least as strong a correlation with the rainfall erosivity index as the $E \times I_{30}$ calculated by Wischmeier. The rainfall erosivity factor (R) was also estimated by using other precipitation data, but they usually did not live up to the expectations (eg. Deumlich et al., 2006).

The result of the large number of measurements is that there is not a one and only sure method of calculating the rainfall erosivity factor due to the large number of active components and their plot-specific nature (although it would be important in order to estimate soil erosion, for example). Measuring soil

Table 2 A compilation of alternative methods of calculating rainfall erosivity

Authors	**Alternative methods of calculating rainfall erosivity**	**Remarks**
Fournier, 1960	$F = p^2/P$, where p is mean monthly precipitation, and P is mean annual precipitation	Fournier Index
Arnoldus, 1980	$MFI = \sum_{i=1}^{12} p_i^2/P$, where p_i is mean monthly precipitation, and P is mean annual precipitation	Modified Fournier Index
Onchev, 1985	$R = P/S_t$, where P is > 9.5 mm rainfall intensity, S_t is the time of a > 0.18mm/min rainstorm	Universal Precipitation Event Index / Universal Index for Calculating Rainfall Erosivity
Renard – Freimund, 1994	$R = 0.07397\ F^{1.847}$ $R = 95.77 - 6.08\ F + 0.477\ F^2$	F<55mm F>=55mm
Sauerborn et al., 1999	$R_s = -33.2 + 2 \times FIM_s$ ($r^2 = 0.64$)	Fournier Index with summer months
FAO – Colotti, 2004	$R = a \times MFI + b$	a and b are two regionally defined parameters
Deumlich et al., 2006	$R = -12.98 + 0.0783 \times P$, where P is annual precipitation	Mean annual precipitation
Diodato – Bellocchi, 2007	$R_m = b_0 \times [p_m (f(m) + f(E, L)]^{b1}$	R_m is based on monthly precipitation
Eltaif et al., 2010	$R = 4 \times 10^{-6} \times F^{3.5874}$	Monthly precipitation data
Hernando – Romana, 2015	R = 0.15 P, where P is annual precipitation data R = 2.51 F, where F is the Fournier Index R = 1.05 MFI, where MFI is the Modified Fournier Index	>5-year-long simulation > 10-year-long simulation >10-year-long simulation

erosion requires an extensive collection of both spatial and temporal data (eg. 10-to-30-minute precipitation data, and a sufficient number of rain gauges, or pluviographs). As they often were and/or are available, a lot of methods were developed to estimate this factor by employing easily obtainable data (Table 2). The R factor was often introduced as an index that significantly correlates to soil erosion (Wischmeier, 1959; Wischmeier and Smith, 1978; Lo et al., 1985). Several alternative indices were also connected to rainfall erosivity. Most of these indices had a strong correlation with the Fournier Index that uses monthly and annual mean precipitation data (1960), which index assesses the extent of erosion by using the p^2/P (average monthly/annual rainfall) correlation. The subsequent modification of the Fournier Index (MFI) defined an even stronger correlation, and it eventually showed its connection with soil erosion.

Preparing soil erosion models requires such precipitation information that is very time-consuming and cost-intensive to obtain, and it is often without measurable benefits. The R value often correlates well with other readily available rainfall data in the long run. Of course, the result is usually also true: high erosivity rainfalls result in high R values. From the alternative calculations, the readily available monthly/annual precipitation data were investigated, a lot of researchers also used these data for extreme values, e.g. for >100 mm precipitation. Other researches preferred to have a greater number of rain gauges (>100) or excluded extreme values (eg. >1,000 mm, exclusion of winter precipitation) in order to secure a strong correltaion between the MFI and the R index (typically 0.8) (Renard, 1997; van Dijk et al., 2002; Hernando 2015).

STUDY AREA AND METHODS

In our study the major changes of R were evaluated in Hungary, as study area. The method we applied consisted of the following steps:

Step 1: We calculated the R value on the basis of the 10-minute rainfall data of 4 meteorological stations in Hungary (Szeged, Agárd, Pécs, Debrecen) as shown in Table 1, and we used the available data series from 1999 to 2014. We calculated the Modified Fournier Index on the basis of mean monthly and mean annual precipitation data as shown in Table 2 for the same period. Then we calculated the correlation between the rainfall intensity (R) and the Modified Fournier Index (MFI) data series.

Step 2: We calculated monthly and annual precipitation data by averaging the daily data of this century on the basis of the REMO and ALADIN regional models (Mezősi et al., 2013). These models did not provide detailed data on rainfall events, which could have helped to estimate the spatial and temporal changes of rainfall intensity. These average values were the raw data of the MFI values concerning certain intervals of this century.

Step 3: We used the so-gained correlation between the R and the MFI to do the calculations for this century. By employing it as a linear relationship, we could estimate the R values as we also had knowledge of the MFI values of this century. In addition to the linear nature of the relationship calculated by FAO (which is also used in the study), other relationships can also be interpreted (Table 2).

Step 4: We calculated the R values for the periods of 2021-2050, and 2071-2100. For both the near and the distant future, we prepared the average results as the average of every five years, then we visualized these data on maps. We edited the maps by kriging which was based on the data relating to the given settlements. The small number of data limits the preparation of statistical maps. This disadvantage is reduced by the nature of the results which were created to raise awareness about both time periods. It could not be calculated for the target data model limited of uncertainty, respectively. We did not aim at preparing a more accurate spatial and temporal estimation of rainfall intensity as it was restricted by the limitations and uncertainty of the computed model data, and the limited possibilities of the applied calculation. Applying the Gaussian process regression slightly improved the geostatistical method that had been based on little data. Practically it meant that elevation (despite the study area having relatively small elevation differences) as a supportive parameter was included in generating the pattern of the R factor when the maps were being produced (Goovaerts, 1999).

RESULTS

We calculated the correlation of the R factor with the data measured for the 1999-2014 period by applying the Modified Fournier Index (MFI) for a linear relationship, (Figure 1). More than three dozens of such rainfall events occurred during that period which were characterized by >12.7 mm of rainfall. The correlation was 0.74 which indicates a significant relationship between the two parameters as the limit is 0.4 with a 1% probability. Hernando and Romana (2015) studied a smaller Spanish area with eight stations for a longer time period, and calculated a >0.8 correlation. It further strengthens the relationship between the R and the F/MFI/P that had already been proven by numerous researches earlier, however, it does not exclude further analyses.

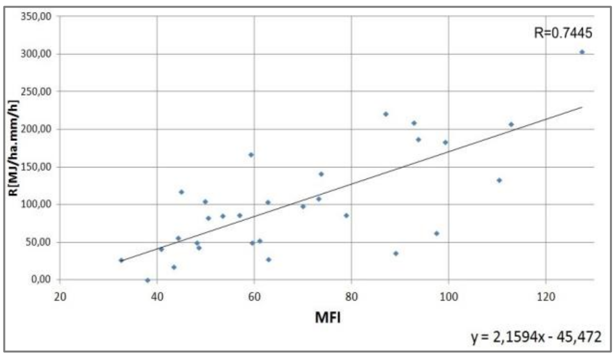

Fig. 1 The correlation between rainfall intensity (R) and the calculated MFI value on the basis of 10-minute data recorded from 1999 to 2014

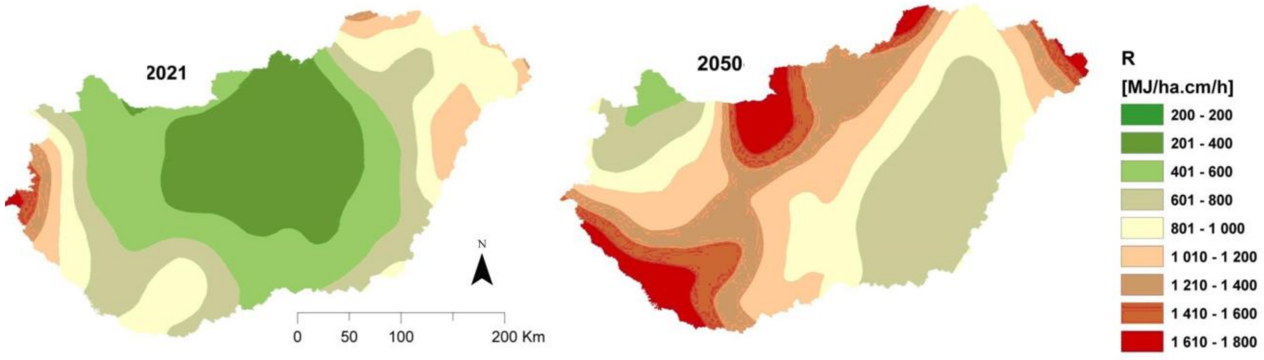

Fig. 2 Rain intensity values in two years of the modeled time period from 2021 to 2050

Changes in rainfall intensity can also be studied annually. The annual results of the R value using simulated data increase in the 30-year time period. We give two examples of our calculations calculated by the average values of the REMO and ALADIN models between 2021 and 2050. These results demonstrate that intensity varies both spatially and temporally (Fig. 2).

The initial values are characterized by 750 MJ/ha intensity, which is characteristic of the average values of the past 25 years (Panagos et al., 2014), and their increase is clearly observable from 2021 to 2050. Changes in the pattern of the R often follow the changes of relief (even if elevation differences are modest) and the changes in the amount of rainfall. The deviation of the R data shows a more significant change which is greater than the increase in the R values. Figure 2 represents the annual data displaying this change. The uncertain, simulated basic data can be evaluated on the basis of the average values of longer time periods.

Figure 3 displays the R values modeled for a nearer time period broken down by five years. The average figures for the short period support the fact that these data are not sufficient enough to reach an easily recognizable and well-established conclusion. However, when comparing to the average raw data of the 1961-1990 interval that served as the base of our study, we can see that the R value usually differs positively. The changes do not exhibit regional trends though. Therefore, the average data of longer periods provide more reliable information.

Changes in rainfall intensity can be obtained by using average model values. The comparison was related to the average value calculated for the years between 1961 and 1990 which served as raw data. The regional climate models used in our study do not give the same known results when calculating the quantity of rain. The results of the models are, therefore, separately included (Table 3), but regional conclusions were drawn on the basis of the average values. The rate of growth both in the proximal and distant intervals is significant, it is more than 50% of the current value.

Compared to the raw data, the R value can as well be doubled, but it is not extremely high concerning European data. Other European peak values of the R index exceed 4,000, while the maximum mean value is 1,500 in Hungary. In addition, the environmental features and economic conditions of the Carpathian Basin are also remarkably different. This increase is in line with the projected growth of heavy rainfalls of >30 mm of rainfalls in the 21st century as the model results indicate. The increase of the mean R value can also be estimated locally. The joint calculations of the REMO – ALADIN models show the changes of mean values in Figure 4. The biggest change can be seen in the central and north-western parts of the Carpathian Basin in this period.

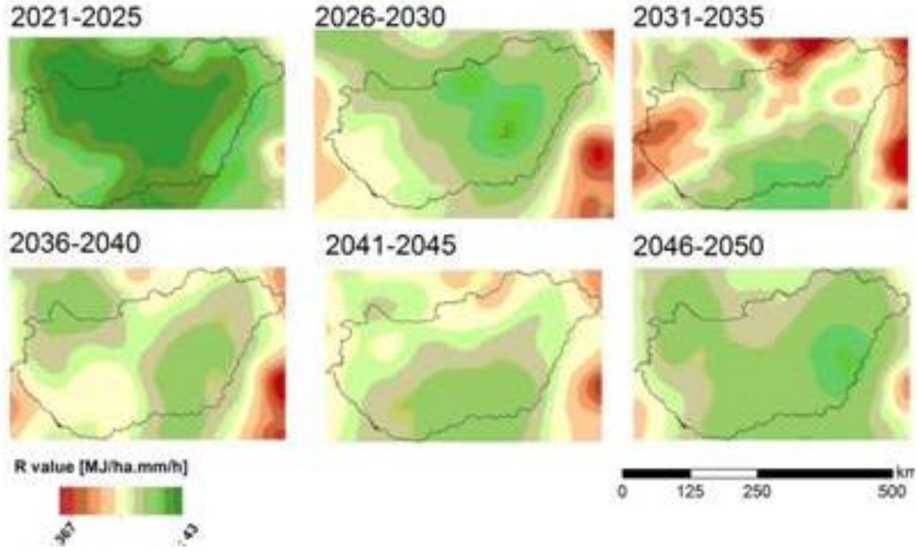

Fig. 3 Changes in the R value compared to the raw data of the 1961-1990 period

Table 3 Changes in the R value compared to the base period (1961-1990)

	ALADIN		REMO	
	2021- 2050	**2071-2100**	**2021- 2050**	**2071-2100**
Mean	+60.45 %	+50.99 %	+51.93 %	+53.17 %
Minimum	+41.38 %	+28.79 %	+27.86 %	+29.81 %
Maximum	+90.37 %	+72.61 %	+82.11 %	+86.19 %

DISCUSSION AND CONCLUSION

According to earlier analyses, the rainfall intensity index of the Carpathian Basin increased in the summer over the past 100 years (Lakatos et al., 2011). Based on the modeled characteristics of different climate change scenarios (eg. the number of rainy days, >30 mm of rainfalls), the previously mentioned growth characterizing the summer is not likely to continue, but the annual intensity is likely to increase due to fewer but heavier, more intense rainfall events (Tables 4 and 5). The amount of precipitation will not become less, but its annual distribution will be rearranged. The 20% reduction in summer precipitation will be compensated by the increase in winter precipitation, but the growing number of more intensive rainfalls indicates an increase in rainfall intensity.

In order to estimate the R value for this century, we used the Modified Fournier Index. We could reveal a significant correlation between the R and the MFI by using the precipitation data of the past nearly 30 years. By applying this trend and the data provided by the model results, we calculated a 50-80% increase in rainfall intensity for this century. Yet, the estimated 1,000-1,500 MJ/ha increase in intensity significantly lags behind the maximum values (5,000 to 6,000 MJ/ha) of certain regions in Italy, Croatia, or Slovenia (as well as western Scotland and southern Spain) (Panagos et al., 2014). The estimated value of R concerning Hungary comes near to the contemporary mean R values (1,300-1,600 MJ/ha) of the previously mentioned countries. Of course, it must be taken into account that the Carpathian Basin is characterized by very different environmental features and land use.

One of the most obvious effects is how the increasing precipitation intensity influences agriculture. In order to measure it (either on model or standard Hungarian levels), versions of the Wischmeier-Smith formula (EPIC, USLE, RUSLE, etc.) are used the most. Although they operate with 5-7 variables, rainfall intensity (R) is the one that affects the extent of soil erosion the most. In terms of the extent of soil erosion, slope length, steepness, soil type are also sensitive parameters, but they can be considered stable at this scale. Land cover is also susceptible to the extent of soil erosion. In our case, however, the change should be a consequence rather than the cause of soil erosion growth. A change in land cover/land use could be a point of intervention which could help reduce the extent of erosion. Calculating the extent of soil erosion is not easy because the critical period from May to September. The climate data provided by the models predict greater R values and greater erosivity values in the long run despite decreasing summer precipitation. Apart from the rainfall erosivity factor, the extent of soil erosion is also regulated by terrain-, soil-, and land-cover-related data. The complexity of the system means that the conclusions drawn from the R data can only be considered as the mean values of longer periods, but the consequences of their possible effect may be useful to provide support for regional development.

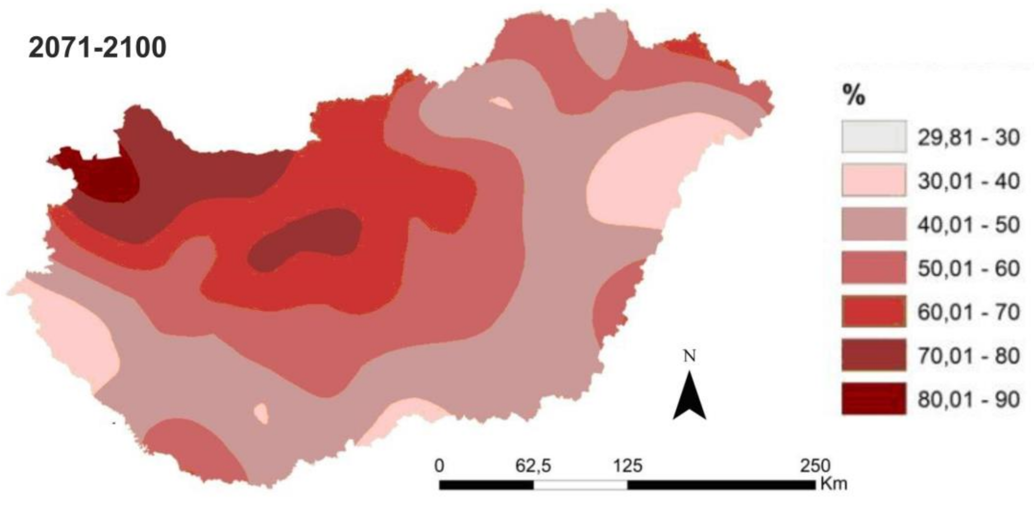

Fig. 4 The increase of the mean R value for the years 2071-2100 as calculated with REMO–ALADIN data

Table 4 Changes in the amount of annual precipitation in mm compared to the base data of the 1961-1990 period as calculated by the REMO and ALADIN models (Szabó et al., 2011)

Period	Annual mean	Spring	Summer	Autumn	Winter
2021-2050	-1 to 0	-7 to +3	-5	+3 to +14	-10 to +7
2071-2100	-5 to +3	-2 to +2	- 26 to -20	+10 to +19	-3 to +31

Table 5 Changes in precipitation and temperature compared to the base data of the 1961-1990 period as calculated by the REMO and ALADIN models (Blanka et al., 2013)

Parameter	The extent of change compared to the mean values of the 1961-1990 period			
	REMO 2021-2051	ALADIN 2021-2051	REMO 2071-2100	ALADIN 2071-2100
Precipitation (mm/year)	-42.6 – 58.5	-31.6 – 53.1	-16.5 - 101	-21.4 - (-84.2)
Temperature (°C/year)	1.2 – 1.5	1.7 - 2	3.4 – 3.7	3.4 – 3.7
RR> 30 mm (day/year)	0.7 – 1.0	0.6 – 1.2	1.0 – 1.5	0.9 – 1.3

On the basis of our results, it is necessary to provide more reliable and accurate raw data to define the R value (eg. using the ENSEMBLES model), and to further investigate soil erosion by applying vegetation change scenarios.

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