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Monthly Variations of Rainfall Erosivity (R factor) in Shida Kartli, Georgia

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Abstract: Soil erosion is a global problem that tends to become more extreme on the background of climate change. Rainfall is one the main drivers of soil erosion. One of the best indicators of the potential erosion risks is the rainfall-runoff erosivity factor (R) of the revised universal soil loss equation (RUSLE). Shida Kartli is one of the main agrarian regions in the country and research on soil erosion has the great importance. The purpose of this study is to assess monthly variations of rainfall erosivity in Shida Kartli region from the RUSLE R-factor, based on the best available datasets. The rainfall erosivity index for a rainfall event, EI_{30}, is calculated from the total kinetic energy and maximum 30 min intensity of individual events. However, these data are unavailable in study region since 1990. Alternative approaches are used for the calculation of EI_{30} in this paper. Soil erosion rate is sufficiently high in eastern Georgia. According to the results of previous studies, two maximums of R-factor are calibrated in May and July in Shida Kartli. A set of equations is presented for calculating monthly and annual R factor values based on daily precipitation data for Shida Kartli in the current study. Data have been collected from 2 meteorological stations for the period from January 1990 through December 2016. Precipitation time series for both stations included 27 years. Rainfall-runoff factor (R) for each month (R_{month}) of study period has been determined and seasons with high rainfall erosivity were established for both stations.

Keywords: Soil Erosion, Precipitation, Rainfall, Erosivity, Monthly Time Step

1. Introduction

Soil is one of the vital components of the natural environment that is non-renewable on a human time-scale [1]. One of the most harmful natural processes is soil erosion. Soil erosion is a global problem that tends to become more extreme with the extreme variations in weather [2]. Soil erosion by water affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota and soil depth [3]. Soil erosion in agricultural areas has been studied intensively throughout the last decades and rates have been measured at continuous and event scales [4]. Soil erosion rate is sufficiently high in eastern Georgia, for instance in Alazani and Iori river basins. 28 t soil is lost every year by erosion in Alazani river basin and 20 t in Iori river basin respectively [5].

Soil erosion is difficult to measure at large scales, soil erosion models are crucial estimation tools at regional, national and European levels [3]. Soil loss prediction is important to assess the risks of soil erosion and to determine appropriate soil use and management [6]. Erosional soil degradation by stormwater is perceived as one of the main problems worldwide since it has large environmental and economic impacts, especially in agricultural areas [7]. Moreover, it is assumed that rainfall erosivity will potentially increase due to climate change because of the associated change in precipitation characteristics [8]. The underlying assumption is that rainfall is getting more variable and hence more extreme rainfall events could be expected resulting in increasing rainfall erosivity [9]. In the context of climate change the effect of altered rainfall characteristics on soil erosion is one of the main concerns of soil conservation studies. It is well known that several very intense rainfall events are responsible for the largest proportion of soil erosion and sediment delivery [10]. Soil erosion prediction models are effective tools for helping to guide and inform soil conservation planning and practice. The most widely used soil erosion models used for conservation planning are derived from the Universal Soil Loss Equation (USLE) [11]. These models include the USLE, the Revised USLE (RUSLE) [12], and RUSLE2 [13]. Adaptations of the USLE have also been developed for use in other parts of the world [14]. These models have in common a rainfall erosivity factor (R), which reflects the potential capability of rainfall to cause soil loss from hillslopes, and which is one of the most important basic factors for estimating soil erosion [15]. Rainfall is one of the active drivers of soil erosion owing to its potential for detaching soil particles and subsequent displacement. The numerical value used for R in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff likely to be associated with the rain. The rainfall-runoff factor (R) of the revised universal soil loss equation (RUSLE) is generally recognized as one of the best parameters for the prediction of the erosive potential of raindrop impact, and therefore of the potential transport capabilities of runoff generated by erosive storms [16]. A precise assessment of rainfall erosivity requires recordings of precipitation at short time intervals (1–60 min) for a period of at least several years [3]. One of the main disadvantages in seeking to employ the RUSLE *R* factor is the need for a relatively continuous rainfall data series, with a time resolution of at least 15 min (pluviograph data). In its simplest form, the R factor is as an average annual value, calculated as a summation of event-based energy-intensity values, EI_{30}, for a location divided by the number of years over which the data was collected. The calculation of EI_{30} requires high-temporal resolution rainfall data, typically breakpoint data, which are often unavailable in many regions of the world where rainfall is recorded only at a daily resolution [15]. Information of this nature is rarely available with good spatial and temporal coverage. Other attempts to predict rainfall erosivity from mean annual rainfall and/or mean monthly rainfall have provided results that are quite coarse, but these have been extensively cited in the scientific literature [10]. However, as rainfall erosivity is not distributed uniformly throughout the year, the assessment of soil erosion, even on a regional level, requires knowledge of the seasonal distribution of R [16], [17]. The monthly-time step is regarded as suitable for estimating soil erosion (monthly accumulation of eroded soil from consecutive rain events) and put it in relation to both the length of crop seasons and the agricultural practices [18].

The aim of this study was to compute rainfall erosivity for 2 runing meteorological stations in Shida Kartli and to obtain estimates of the monthly R factor for Shida Kartly that could be used for analyses of spatial and temporal changes in the R factor and soil erosion rates.

2. Study Area

Shida Kartili is a central region of Georgia (Figure 1). The region of shida kartli lies in a middle section of lowland between the Greater and Lesser Caucasian mountain range in East Georgia. It occupies 9.2% of the country's territory, with 7% of the country's population [19]. The region is characterized with very complex terrain. North and south parts of the region are covered with mountain ranges, while the central part, irrigated by numerous rivers, presents the main part of Kartli plain. Agriculture is the main source of income for the region's population. Due to the peculiar climate, terrain and geodynamical processes, the erosion of lands and soils in Georgia is quite large-scale. The process of land and soil erosion has intensified in recent years due to more frequent natural disasters caused by changes in the global climate [19]. Climate of the main part of the region is continental with moderate cold winter. Annual precipitation varies within 400-600 mm. Heavy rain, especially with hail, is typical during the summer period, which is very harmful for agriculture. Number of days with thunder storm is 25-45 and with hail 1-2 days during the year [20].

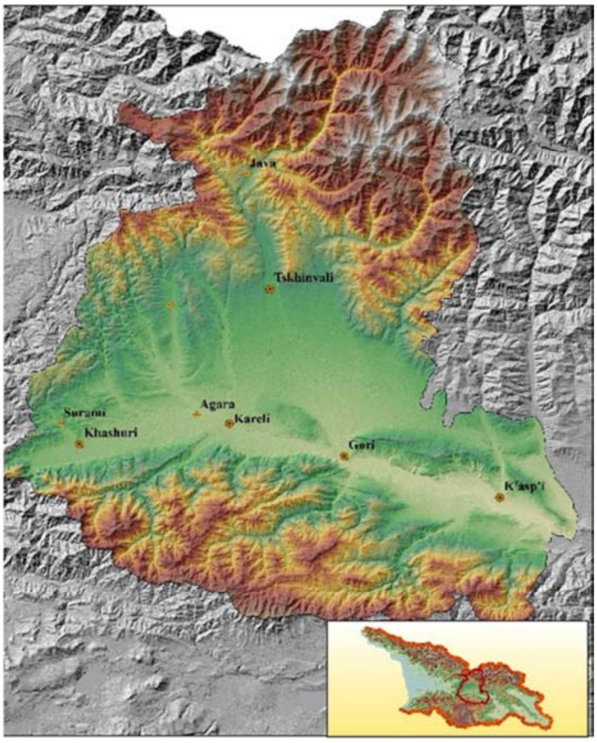

Figure 1. *Study area.*

The region of Shida Kartli is sensitive to climate changes, in particular, the region's semi-arid areas existing primarily in the Gori and Kareli municipalities [19]. Several meteorological stations operated in the region, but since 1990 there are only two meteorological stations-Gori (588 m above sea level) and Khashuri (690 m above sea level) remained in

Shida Kartli.

The daily rainfall data were provided by the National Environmental Agency of Georgia.

3. Methods and Materials

Pluviograph data were created by the meteorological stations in the study area in the 60-80s of last century. Scientific research on the study area provides data [21] on rainfall erosivity potential but it should be noted that these studies have been implemented until 1989. Frequency and intensity of the rain are very important factors, especially when the soil is loosen [22].

The erosive power of precipitation is accounted for by the rainfall erosivity factor (R-factor), which gives the combined effect of the duration, magnitude and intensity of each rainfall event [3].

Soil loss in agricultural fields is associated with the product of the total storm energy-E (MJ ha^{-1}) and the maximum intensity in 30min -I_{30}, (mmh^{-1}). The result of this product is the EI_{30} index or storm erosivity index (MJ mm ha^{-1} h^{-1}) that reflects the combined effect of soil detachment and runoff transport capacity to produce net soil erosion.

(Renard and etl, 1997) has defined the rainfall factor R (MJ mm ha^{-1} $h^{-1}yr^{-1}$) as the sum of the EI_{30} values for the whole year according to the equations:

$$R = \frac{1}{n}\sum_{j=1}^{n} \left[\sum_{k=1}^{mj}(E)(I_{30})k\right] \quad (1)$$

Where: R-annual average rainfall erosivity (MJ mm ha^{-1} $h^{-1}yr^{-1}$)
n-number of years covered by the data records
mj-the number of erosive events in a given year j
E-Total storm kinetic energy (MJ/ha)
I_{30}-Maximum 30-min rainfall intensity (mm/ha)
k-Index of number of storm in a year

$$EI_{30} = (E)(I_{30}) = \left(\sum_{k=1}^{m} e_r \Delta V_r\right) I_{30} \quad (2)$$

$where\ e_r$-unit rainfall energy (MJ ha^{-1} mm^{-1})
V_r-rainfall volume in a period of r time

$$e_r = 0.29\left[1 - 0.72_{exp}(-0.05 i_r)\right] \quad (3)$$

$$e_r = \frac{\Delta V_r}{\Delta t_r} \quad (4)$$

$where\ i_r$-rainfall intensity during the time interval (mm h^{-1})

According to abovementioned equations EI_{30} is the crucial part because most of the time rainfall intensity and storm kinetic energy data are not available at national meteorological stations. When detailed information about rainfall each 15 or 30 min is not available the EI_{30} index can be estimated from daily and monthly values of precipitation.

In this paper the approach of Loureiro and Coutinho (2001) has been used to assess the monthly R factor at the two weather stations as well as to determine the spatial variability of R between these weather stations. Loureiro and Coutinho (2001) developed a new model through multiple linear regressions for estimation of RUSLE EI_{30} parameter using monthly rainfall data of twenty-eight years from thirty-two daily-reading of rainguage stations in Algarve region, Portugal. The model has been used in many other similar studies owing to its high predicting power.

$$EI_{30\,month} = 7.05 rain_{10} - 88.92 days_{10} \quad (5)$$

Where: rain10 – monthly rainfall for days ≥10 mm, otherwise set to zero, days10 – monthly number of days with rainfall ≥10 mm.

On the other hand, [5] developed new approach for the assessment of long-term average monthly rainfall erosivity factor (R_m, MJ mm h^{-1} ha^{-1} $month^{-1}$)

$$R_M = \frac{1}{n}\sum_{y=1}^{n} \sum_{a=1}^{s}(EI_{30}) \quad (6)$$

where α indicates the number of storms in a monthly period, n is the number of years considered.

From these two equations (5) and (6) we tried to calculate the R_m according to the equation (7):

$$R_M = \frac{1}{n}\sum_{y=1}^{n} \sum_{a=1}^{s}(7.05 rain_{10} - 88.92 days_{10}) \quad (7)$$

In current research we used this equation and calculated the R-factor (MJ mm ha^{-1} $h^{-1}month^{-1}$) for each month from 1990 through 2016 for both stations in Shida Kartli.

In previously published papers it is reported, that watersheds in Shida Kartli are characterized with high intensity of erosion, where average annual soil loss reaches 19.87 t/ha [5]. During the assessment of rainfall erosivity only rainfall >10 mm is taken into the consideration [22].

A monthly tipping-bucket rain gauge database was created for the period January 1990-December 2016 for this particular study. It includes 2 stations and total 648 months. The exeption is October 1992 and March 1993 in the case of Gori, where there are no numerical data at all.

4. Results and Discussions

Initially we compared the annual precipitation of the study stations. As the results show (Figure 2), the annual precipitation in case of Khashuri is a bit higher (400-700 mm) than the annual precipitation for the station of Gori (400-640 mm).

Figure 2. *Heavy rain and hail in Shida Kartli at the begining af May 2016.*

In addition, we calculated the monthly precipitation for the study period. From the Figure 3, it is clear that, the maximum amount of precipitation is distinguished for May and June while the minimum for January and February on the station Gori. It is interesting to see the relationship between the monthly precipitation and the R-factor, for this purpose we calculated the R-factor for each month during the study period using the 5th equation (Figure 3).

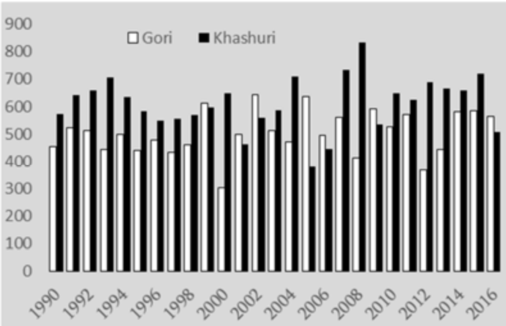

Figure 3. *Annual precipitation for the period 1990-2016.*

The obtained results show that the amount of precipitation does not play a crucial role in evaluating the R-factor, in this case the decline is the number of days with rainfall. In case of the station Gori it is clear that the R-factor is especially high during April-July and in November for the 27 year study period (Figure 3). According to the results published by Gogichaishvili, in which the precipitation data of 70-80s of the last century is analyzed, the highest rate of R-factor during April-October period is recorded in May, June, July and August in Gori [21].

The same calculations were carried out on Khashuri station. In this particular case the maximum amount of precipitation is distinguished for February. As for the case of the station Khashuri (Figure 4), the months of May, June and November are distinguished by the highest index of the R-factor. In the same research Gogichaishvili, 2002, defined that two maximums of the R-factor are expressed in Shida Kartli (Gori and Khashuri), these two maximums are in May and July. After calculating the rainfall-runoff erosivity index ($EI_{30\ month}$) for each month of the study period, we calculated the R-factor for the period of 1990-2016 for both stations with use of equation 5. According to the results, a higher rate of R-factor is observed in Khashuri for the study period.

Following the calculations we decided to focus on the April-July section of the study period, as this period is the most important by agriculture point of view.

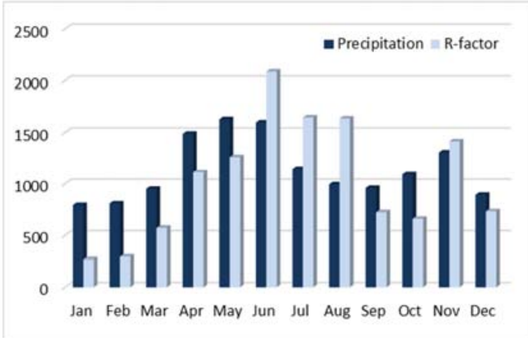

Figure 4. *Compare monthly precipitation and monthly temporal variability of R-factor for the period of 1990-2016 (Meteorological station of Gori).*

The next step was to determine how the R-factor changed during the four months of the study period, it turned out that in case of Gori (Figure 5) there is a tendency to reduce of the R-factor in April and July, while the growth tendency is observed in May and in June respectively. In this case, the tendency is to inflate substantial damage to the local community and the agricultural industry. Shida Kartli is well known for its orchards and vine and the heavy rain with hail during this period (end of May and the beginning of June) destroys most of the crop yield. As for the station Khashuri (Figure 6), in this case the indicator of R-factor growth is observed in June.

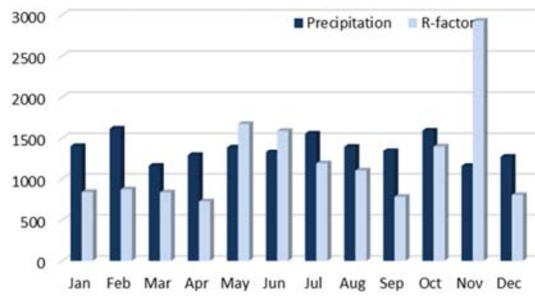

Figure 5. *Compare monthly precipitation and monthly temporal variability of R-factor for the period of 1990-2016 (Meteorological station of Khashuri).*

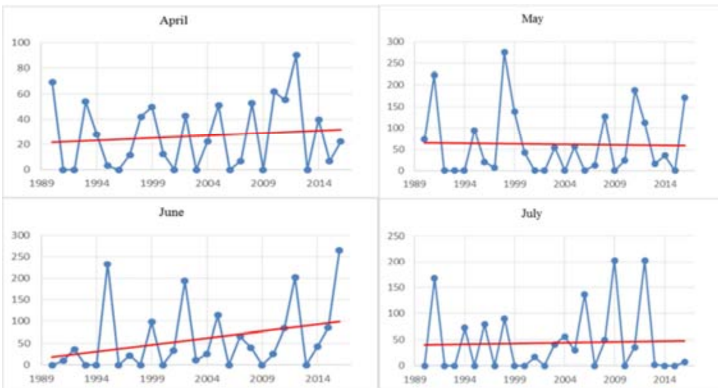

Figure 6. *Monthly variations of the R-factor for the study period (since January 1990 through December 2016) on the Gori meteorological station.*

The difficulties and shortcomings found in the research process have convinced us that this issue requires a more detailed analysis, which means firstly, more processing of data for longer period and secondly, when only rainfall data are available on a monthly basis, it is preferable to use new models, rather than simplified models not accounting for the interaction with elevation and latitude.

Table 1. *Monthly and annual Rainfall-runoff erosivity index ($EI_{30\ month}$ and R) values for the meteorological stations of Shida Kartli (January 1990-December 2016) Units: MJ mm ha^{-1} h^{-1} and MJ mm ha^{-1} h^{-1}.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Gori	9.93	10.90	21.17	41.26	46.74	77.28	61.00	60.60	26.78	24.43	52.38	27.13	459.61
Khashuri	31.02	32.24	30.91	26.82	61.98	58.83	44.05	40.77	28.89	51.80	108.48	29.72	545.54

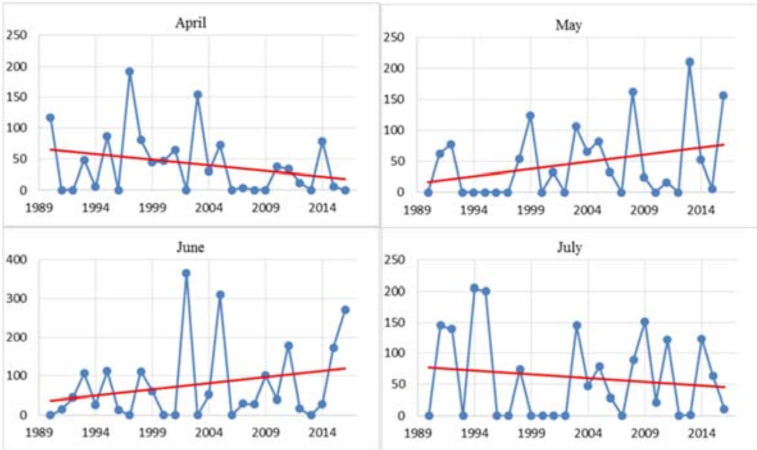

Figure 7. *Monthly variations of the R-factor for the study period (since January 1990 through December 2016) on the khashuri meteorological station.*

5. Conclusions

The rainfall erosivity factor is one of the most important factors in the application of RUSLE models for estimation of soil loss. According to the results obtained from data of both stations in Shida Kartli, the annual precipitation is stable for a 27-year period. The annual precipitation on the Khashuri station is slightly higher than the same data of the station Gori. The R-factor for this period in Gori is 459.61 MJ mm ha^{-1} $h^{-1}yr^{-1}$, while in Khashuri is significantly higher and is equal to 545.54 MJ mm ha^{-1} $h^{-1}yr^{-1}$. As for monthly variatons of R-factor for the study period: In the case of Gori, the highest rate of R-factor for the 27-year period during April-August is observed in June and in case of Khashuri weather station in May.

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