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Rainfall trends and their impacts on soil erosion in North watersheds of Iran

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ABSTRACT: This study focuses on rainfall changes and their impacts on soil erosion in the northeastern watersheds of Iran. For this purpose, long-term recorded precipitations data used for the period 1971 – 2008, and then calculated long-term rainfall erosivity (R factor) of the Revised Universal Soil Loss Equation (RUSLE) used Modified Fourier Index (MFI) for this period. Non parametric test of Mann – Kendall used to detect any likely trends in precipitation and R factor. Result of trend analysis showed that in all stations, annual and autumn time series of Rainfall and R factor have significant increasing trend at 95 and 99 percent confidence level. Increasing in autumn rainfall will certainly affect soil erosion, since in autumn land surface cover against is limited. Data analysis also indicated that rainfall pattern have changed from snow to precipitation, which these changes affected soil erosion because soil is without vegetation and top soils don't have any protect at these seasons. As a concluding remarket, soil erosion depended on a complex interaction of climate, soil properties, topography, and cover management. Therefore, plans focus Integrated Resource Management (IRM) in large-scale hydrological units /watersheds /basins are necessary to alleviate climate change impacts.

Keywords**:** Rainfall erosivity, Soil erosion, Mann - Kendall, Trend.

INTRODUCTION

Warming of the climate system is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea levels. The understanding of past and recent climate change has been progressing significantly through improvements and extensions of numerous datasets and more sophisticated data analyses across the globe. Climate change is predicted to impact upon the variability and seasonality of temperature and humidity, thereby involving the hydrologic cycle. Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the global instrumental record of surface temperature since 1850 (Trenberth , 2007). Changes in global extreme temperatures have been widespread over the last 50 years, the rate of which is almost double that over the last 100 years.

Effects of climate change on ecosystems, hydrological and terrestrial biological systems are gaining importance, especially in the last three decades (Rosenzweig , 2007). The evidences for current impact/vulnerability of altered frequencies and intensities of extreme rainfall are found in soil erosion/landslides, land flooding, transportation systems and infrastructures. Changes in rainfall variability also affect agriculture, forestry and ecosystems, hydrology and water resources, human health, tourism and energy supplies. Rainfall has much larger spatial and temporal variability than temperature, and it is therefore more difficult to identify the impact it has on changes in many systems. Rainfall is a primary source of energy for soil erosion problems in many locations in northeastern watersheds of Iran, which leads to environmental damage through on and off-site effects.

The predicted climate change is expected to increase risks of soil erosion, which can exacerbate soil degradation and desertification (O'Neal , 2005). A relationship between rainfall change and water erosion processes in terrestrial ecosystems shows that change in rainfall affects soil erosion processes by altering soil features, vegetation, cultivation systems, plant litter and landform (Wei , 2009). Also rainfall induced soil erosion affects soil properties and soil carbon dynamics. The magnitude of the expected change in soil erosion risks with climate change will most likely depend on local and regional conditions (Blanco and Lal, 2008). As the model studies indicate an increase in annual rainfall amount from 1-20% may increase soil erosion by 1.7-241% in the 21st century (Blanco and Lal, 2008). In the humid tropics, heavy rainfall would increase runoff and cause flooding of lowlands. While the amount of rainfall may decrease in arid and semiarid regions, the erosivity of rains may increase (Blanco and Lal, 2008). Thus, decrease in precipitation rates may not always result in lower soil erosion rates. Indeed, predicted decreases in rainfall in arid and semiarid regions are just as likely to increase water erosion as in humid regions (Pruski and Nearing, 2002).

Soil erosion, by water or wind, represents the most important soil degradation process and affects more than 1 billion hectares globally (Foster, 2003). The global soil loss by erosion would be in the range of 150-1500 million tons per year, which is about one third of all soil degradation (Robert, 2001). Projected changes in climate are expected to affect the hydrologic cycle, increasing the intensity, amount, and seasonality of precipitation in many parts of the world and thus affecting soil erosion.

The study of rainfall erosivity is thus highly relevant for soil degradation mitigation. Despite its applied relevance, the climatology of rainfall erosivity (i.e. it's inter annual and seasonal variation, spatial patterns, etc.) is surprisingly the topic of very few studies. In the context of climate change, a relevant question is whether or not long-term trends can be detected over the last decades that may help confirm the projections made by global climate models. Very few studies have analyzed trends in rainfall erosivity. Meusburger , (2012) analyzed the spatio-temporal variability of rainfall erosivity in Switzerland and found an increasing trend from May to October. Focusing on the Mediterranean side of the IP, De Luis , (2010) found an overall decrease in annual rainfall and increases in rainfall concentration, while changes in rainfall erosivity varied in space. Their analysis was based on the Modified Fournier Index (MFI, Arnoldus, 1977) with monthly precipitation data. This is an important concern, since rainfall erosivity depends largely on a few number of short but very intense rain episodes that are largely smoothed when data is aggregated at coarser time resolutions.

This study focuses on rainfall changes and their impacts on soil erosion in the northeastern watersheds of Iran. For this purpose, long-term recorded precipitations data used for the period 1971 – 2008, and then calculated long-term rainfall erosivity (R factor) of the Revised Universal Soil Loss Equation (RUSLE) used Modified Fourier Index (MFI) for this period.

MATERIALS AND METHODS

Study area and data sources

The present study has been undertaken for the Gorganrood drainage basin in the northeast of Iran. The rivers that flow to the Caspian Sea through the Iranian coast have a drainage basin of 135,000 km2, most of which is located on the northern flank of the Alborz Mountain chain. Around 130 rivers flow into the Caspian Sea through the northern, southern and western coasts. Gorganrood on the East coast is a river that cut through Alborz and drains the Copet-Daq mountain range and ends at the Caspian Sea and the basin covers an area of 10197 km2 and it drains a large area of the Golestan Province between the latitudes 36°35′and 38°15′N and longitudes 45°10′ and 56°26′E. Elevations range from -21 to 3945m with a relief characterized by mean elevation about 907 m and low gradients about 1.27%. The mean annual rainfall in the area is 491 mm with ranges between 252.6 in the west and 641.3 mm in the east. Major land uses in the study area include forest, agriculture and pasture (36, 34 and 18%). For the investigation of rainfall changes and their impacts on soil erosion in the northeastern watersheds of Iran long-term recorded precipitations data used for the period 1971 – 2008. The data base consisted from 8 climatological stations which have more than 30 years continuous records were chosen (Fig.1). And table 1 presents the information of the stations.

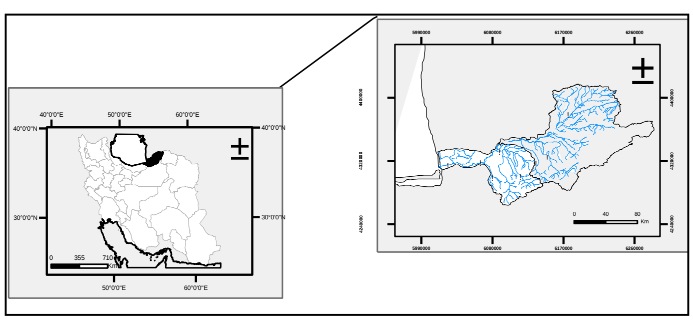

Figure 1. Location of the study area and climatological stations

Table 1. Geographic characteristics of the climatological stations

Stations	X	Y	Elevation (m a.s.l)	Average precipitation (mm)
Ghafarhaji	245052	4098462	34	572
Aghghalla	278102	4100003	-114	574
Taghi Abad	289060	4083488	148	707
Baghesalian	298137	4112137	14	347
Zaringol	318315	4083729	307	812
Ramian	334246	4098755	208	848
Node	345784	4104520	255	824
Tamer	367584	4150504	183	517

Methodology

Parametric ordinary least square (OLS) linear regression and non-parametric Mann–Kendall are the confirmatory data analysis tools. However, each statistical test is designed for specific purposes with different assumptions in sampling distribution. Parametric trend tests are regarded to be more powerful than the non-parametric ones when the data is normally distributed, independent and has homogeneous variance (Hamed and Rao 1998). The main disadvantage of the OLS method is that it cannot reject outliers properly (Wilcox1998). Also, the impact of time dependent missing data can bias the parametric precipitation trends if assumed to be zero or at the daily average for the month (pal and Al Eabbaa, 2011). Non-parametric Mann–Kendall method on the other hand is a distribution-free method, more resistant to outliers, can usually be used with gross data errors, and can deal with the missing data values unlike the parametric method (Wilcox 1998).

Mann–Kendall method has widely been used in environmental monitoring for its simplicity and the focus on pair-wise slopes (Gibbons and Coleman, 2001). However, non-parametric methods are fraught with more uncertainty in the statistical estimates than the parametric method (Alexander 2006).

Mann-Kendall

The Mann-Kendall test is the most widely used non-parametric trend test in the previous hydrologic studies. It is based on the correlation between the ranks of time series and their time order (Hamed, 2008). According to Mann (1945), the null hypothesis H_0 states that the deseasonalized data (x_1, x_2… x_n) are a sample of n independent and identically distributed random variables (Yu , 1993). The alternative hypothesis H_1 of a two-sided test is that the distribution of x_i and x_j are not identical for all i, j ≤ n with i ≠ j. The test statistic S is calculated with Equations (1) and (2).

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_k) \qquad (1)$$

$$\mathrm{sgn}(x_j - x_k) = \begin{cases} +1 & if \quad (x_j - x_k) \rangle 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) \langle 0 \end{cases} \qquad (2)$$

The test statistic S has mean zero and its variance is calculated with equation (3).

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5) \right] \qquad (3)$$

Where m is the number of groups of tied ranks (equal observations), each with t_i tie observations.

Kendall (1975) showed that for the cases that n is larger than 10, the distribution of S tends to normality and the standard normal variate z is computed by using the equation (4).

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S\rangle 0 \\ 0 & if \quad S=0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S\langle 0 \end{cases} \quad (4)$$

In a two-sided test for trend, the H_0 should be accepted if $|z| \le z_{\alpha/2}$ at the level of significance. A positive value of S indicates an upward trend and a negative value indicates a downward trend (Kahya and Kalayci, 2004).

The Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) was used to evaluate the potential of water erosion on the Grande River Basin using a database constructed over the last 10 years. This model was described by Wischmeier and Smith (1978) and can be expressed by the following equation:

$$A=R\times K\times LS\times C\times P \quad (5)$$

Where A is the average annual soil loss per unit of area (t $ha^{-1}yr^{-1}$), R is the rainfall–runoff erosivity factor (MJ mm $ha^{-1}h^{-1}yr^{-1}$), K is the soil erodibility factor (t h $MJ^{-1}mm^{-1}$), LS is the topographic factor (dimensionless) which includes slope length factor (dimensionless) and slope steepness factor (dimensionless), C is the cover-management factor (dimensionless), and P is the support practice factor (dimensionless).

Rainfall–runoff erosivity factor (R)

Erosivity is the potential of a rainfall to cause erosion in a given soil with no protection. The R factor takes into account both total precipitation and kinetic energy of raindrops that fall onto the soil, and is affected by rainfall intensity and raindrop size.

For estimation of the monthly rainfall–runoff erosivity, the equation developed by Renard and Freimund (1994), which is also known as Fournier Index, was applied. This Index has been used widely in several studies of soil loss and erosivity mapping, as in Irvem (2007), Mello (2007), Pandey (2007) and Besko (2009).

$$EI_i = \frac{125.92\times(\frac{r_i^2}{P})^{0.603} + 111.173\times(\frac{r_i^2}{P})^{0.691} + 68.73\times(\frac{r_i^2}{P})^{0.841}}{3} \quad (6)$$

Where EI_i is the average monthly erosivity (MJ mm ha^{-1} h^{-1} $month^{-1}$) for month i, r is the average monthly rainfall (mm) for month i, and P is the mean annual precipitation (mm). The annual rainfall-runoff erosivity factor is obtained by summing the respective monthly values.

"HoltWinters()" function

In additional, the simple exponential smoothing method that provides a way of estimating the level at the current time point has been used for annual rainfall erosivity. Smoothing is controlled by the parameter alpha; for the estimate of the level at the current time point. The value of alpha; lies between 0 and 1. Values of alpha that are close to 0 mean that little weight is placed on the most recent observations when making forecasts of future values. To make forecasts using simple exponential smoothing in R, we can fit a simple exponential smoothing predictive model using the "HoltWinters()" function in R. To use HoltWinters() for simple exponential smoothing, we need to set the parameters beta=FALSE and gamma=FALSE in the HoltWinters() function the beta and gamma parameters are used for Holt's exponential smoothing, or Holt-Winters exponential smoothing.

RESULTS AND DISCUSSION

Trend analyses tests require that data are serially independent. This is the main assumption for both parametric and non-parametric tests (Sheikh and Bahremand, 2011). In this study to check the likely presence of serial correlation, the Auto Correlation Function (ACF) analysis has been conducted. The results of ACF indicated that for most of the stations, the serial correlations of time series of the variables of interest are either non-significant at 95%

confidence level or relatively small which have been ignored in this study. As an example, Figure 2 presents the autocorrelation of time series for the some stations.

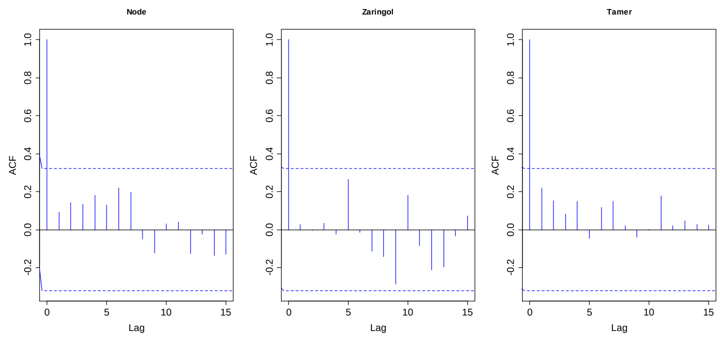

Figure 2. Autocorrelation function analysis graph for time series of climatological variables in stations lines indicate 95% confidence interval

The results of the trend analysis of the annual rainfall using the Mann-Kendall test presented in Figure 3. It is noteworthy that two different levels of confidence have been assumed for trend significance. The significance level of 99% indicates the existence of a strong trend and the significance level of 95% indicates the existence of a weak trend. Results showed that all stations in this study have increasing trend. So that the Ghfarhaji and Baghesalian stations have significant increasing trend at 99 % level. And also stations of Node and Tamer have increasing trend at 95% level.

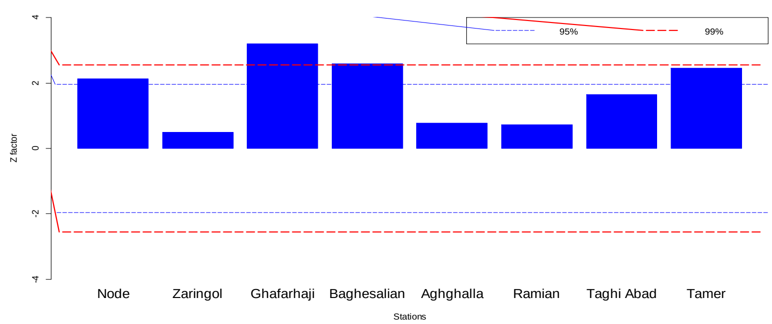

Figure 3. Trend test statistics for annual rainfall in Gorganrood basin's climatological stations

Investigation of seasonal rainfall trend showed that there are no apparent and no homogenous trends across the stations in the study area for seasonal of summer and winter precipitation, except for the autumn and spring which shows a strong decreasing trend at 95% and 99% significance level. Summer precipitation in 5out of 8 stations shows an increasing trend and other station shows a decreasing trend, but don't have increasing or decreasing trend at 95% or 99% levels. Winter precipitation like summer precipitation in 5 out 8 stations shows an increasing trend, so, Ghafarhaji and Baghesalian station have increasing trend at 99% level (figure4).

Autumn and spring precipitations have increasing trend in all stations at the different level. Node and Tamer station have increasing trend in autumn at 99% level, and Ghafarhaji station have increasing trend at 99% level in spring (figure 4). Increasing in autumn rainfall will certainly affect soil erosion, since in autumn land surface cover against is limited. Furthermore in autumn, heavy rainfall on already saturated soils can cause soil loss through (increased) surface run-off.

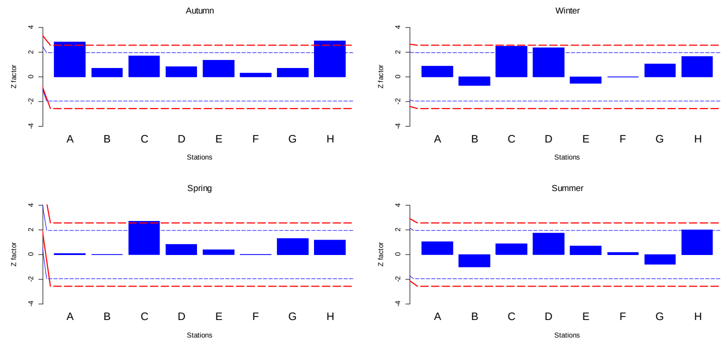

Figure 4. Trend test statistics Z computed for seasonal precipitation in stations

(A= Node, B= Zaringol, C= Ghafarhaji, D= Baghesalian, E= Aghghalla, F= Ramian, G= TaghiAbad, H= Tamer)

And also increasing rainfall in spring will affect soil erosion because runoff from the agricultural land may be greatest during spring months when the soils are usually saturated, snow is melting and vegetative cover is minimal. And in spring impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material that will affect soil erosion. So, because of all these factors, majority of the spring sediment load is generated in a very small % of upland areas (e.g., 75 to 85% of the load from 15 to 20% of the area).

Data analysis also indicated that rainfall pattern have changed from snow to precipitation, which these changes affected soil erosion because soil is without vegetation and top soils don't have any protect at these seasons. And this has coincided with a pattern of increasing rainfall, especially in winter months. Furthermore, this increase in rainfall has been mainly during the winter months, the very time when soils under autumn cereals are at their most vulnerable.

The impacts of climatic changes on soil erosion having several effects on soil properties including soil organic matter that is vital for soil stability to reduce soil erosion. land degradation from water-induced soil erosion is a serious problem in north watersheds of Iran, and only fragmentary information on the same is available, among various impacts of rainfall changes on the environment, the rainfall induced top soil erosion is an important area to look at. Rainfall erosivity is the rainfall parameter in RUSLE2. The annual erosivities, R, were computed using monthly rainfall data and equation (6). An analysis of long-term annual rainfall erosivities showed that rainfall erosivity varies from year to year depending largely on rainfall intensity and amount, as shown in Figure (5).

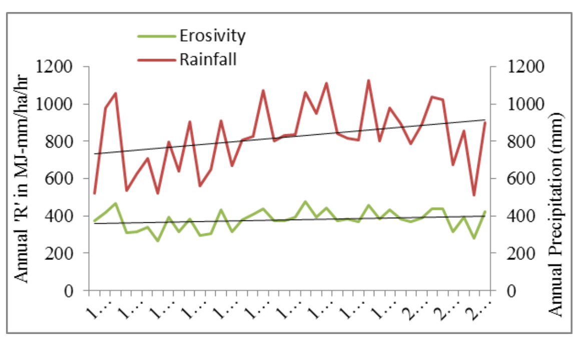

Figure 5. Inter-year variation of annual rainfall erosivity and rainfall and their trends in Node Station

The output of HoltWinters() showed that the estimated value of the alpha parameter of stations are close to zero, for example 0.23, 0.20 and 0.12 for Node, Zaringol and Tamer, Respectively (figure 6). Therefore, the forecasts are based on both recent and less recent observations (although somewhat more weight is placed on recent observations).

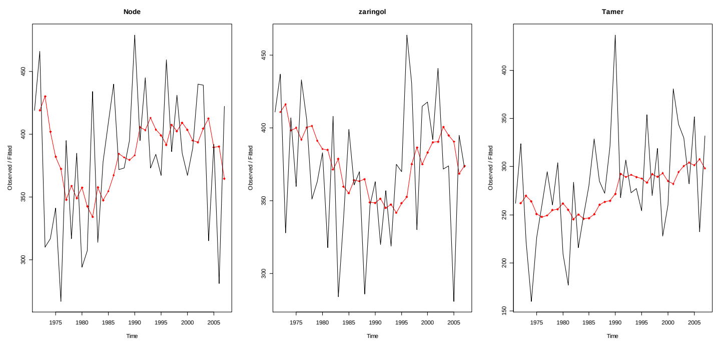

Figure 6. the original time series of annual rainfall erosivity against the forecasts (the original time series in black, and the forecasts as a red line)

In additional, annual rainfall erosivity forecasted for the years 2008-2022. The forecast for a year, a 80% prediction interval for the forecast, and a 95% prediction interval for the forecast. For example, the forecasted annual rainfall erosivity for Node Station at 2020 is about 378 MJ mm ha^{-1} $h^{-1}year^{-1}$, with a 95% prediction interval of (231.6, 524.5). The forecasts for 2008-2022 for Node, Zaringol and Tamer Stations are plotted for example in Figure (7).

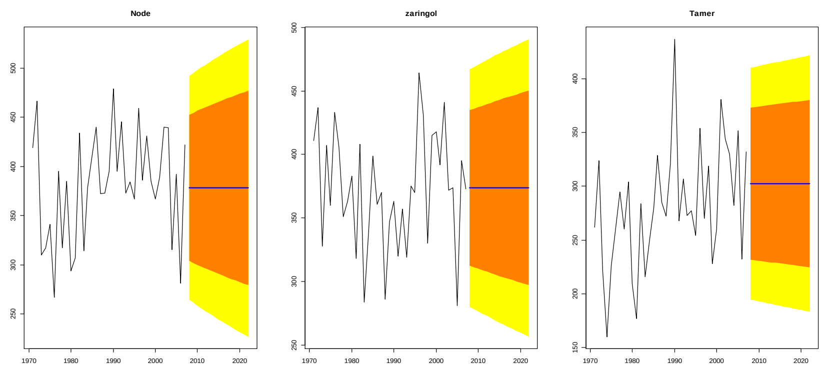

Figure 7. the forecasts annual rainfall erosivity for 2008-2022 for three stations (the 80% prediction interval as an orange shaded area, and the 95% prediction interval as a yellow shaded area)

CONCLUSION

The present study brings out some of the significant changes in a range of seasonal precipitations in northeast watersheds of Iran. Mann-Kendal method was employed for estimation of the magnitude of the trends. Precipitation has an increasing tendency in the spring and autumn seasons. These seasonal changes of rainfall could be due to either or the cumulative effect of multiple actors, namely the changes in the number of rainy days, rainfall intensity and extremes, sea surface temperature changes. In other words, the atmospheric circulation is changing. And also results shows that all station have increasing trend of annual precipitation. Furthermore, none of the stations don't have decreasing trend at 95% or 99% level.

The climate change is expected to increase risks of soil erosion by affecting hydrological cycle, increasing intensity, amount and seasonality of rainfall, which can exacerbate soil degradation and desertification. Change in rainfall affects soil erosion processes by altering soil features, vegetation, cultivation systems, plant litter and landform. Decrease in rainfall rates may not always result in lower soil erosion rates because the magnitude of soil erosion changes depends on local and regional conditions and a combination of various physical and management factors. Sedimentation of downstream water bodies due to runoff is also a concern under the changing climate since sediment yield has a non-linear response with respect to storm patterns, soil water deficit and vegetation cover, which are bound to change due to climate change. Result showed that soil erosion pattern showed an increasing trend due to increase in both the extremes and total accumulated rainfalls. Therefore soil loss increases with increase in erosivity, is maximum when erosivity is maximum, and, like erosivity, depends both on rainfall amount and intensity. There could be a substantial reduction in soil loss due to vegetation establishment because of the effect of vegetation retarding erosion. Therefore, maintaining ground vegetative cover especially when rainfall erosivity is the highest in a given year is important in order to reduce the impact of rain drops and overland flow.

As a concluding remarket, soil erosion depended on a complex interaction of climate, soil properties, topography, and cover management. Therefore, plans focus Integrated Resource Management (IRM) in large-scale hydrological units /watersheds /basins are necessary to alleviate climate change impacts.

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