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A Scenario of Rainfall Erosivity Index Research

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Abstract: Rainfall erosivity index is an important index to evaluate the soil loss due to rainfall. Rainstorm plays a paramount role in surface sealing, runoff and erosion process. Research on rainfall erosivity index is important in understanding the mechanism of soil erosion processes. This paper gives a scenario on the important research work done by the scientists to evaluate the erosivity index by using various methods and approaches. The aim of this paper was also to highlight that methodology of the scientists which they have used to get the appropriate erosivity index value for their study. The quality and representativeness of erosivity index has significance in estimation of soil loss, as rainstorm is initiating factor in soil erosion by raindrops.

Keywords: Soil Erosion, Erosivity Index

I. Introduction

Soil is one of our most precious resources. One of the most serious environmental problems that we face is the soil degradation. Due to this degradation process we lose our food production rate, as soil is the most important medium for growing crops. Soil erosion is a natural process occurred throughout geological history. Human activities, particularly agriculture and deforestation, however, have increased erosion rates, as they tend to remove the protective vegetation and reduce the stability of the soil. This human influenced process is termed accelerated erosion. Since 1950 accelerated erosion has resulted in the loss of 1/5 of the topsoil from the world's agricultural land and 1/5 of the topsoil from tropical forests. A United Nations study has found that 10.5 per cent of the planet's most productive soils - an area the size of China and India combined - have been seriously damaged by human activities since World War II. As many as 9 million hectares of arable land have been irreversibly damaged by overgrazing, deforestation and unsustainable agricultural practices.

A further 1.25 billion hectares is considered to be seriously degraded and could be restored, but only at great cost. It has been estimated that total global soil erosion costs agriculture many hundreds of billions of US dollars every year. This includes the cost of water treatment, dredging of waterways and lost food production, but does not include damage to aquatic ecosystems or the value of the soil itself. Just how long soil losses can be tolerated before soil productivity is significantly affected depends very much on soil depth. On deeper soils regular erosion losses may be maintained for 100 to 200 years without any obvious loss of productivity, however any regular loss of soil in excess of natural replacement rates is unacceptable as it means that significant damage is being done to one of our primary assets - the soil. The erosion process is influenced by soil erodibility, climate, vegetative cover, topography, and season. Wind and water are the two main initiating factors for soil erosion. Water droplets or the rainfall makes water erosion to occur at any place or region. The splash process begins when water droplets strike the soil surface. Raindrop force serves to break down aggregates on the soil surface and detaches soil particles from the mass. Detached particles are splashed and fall back to the surface in a more dispersed state.

Quantification of soil loss

Soil conservation researchers and scientists have worked from many years to estimate soil loss from individual fields or slope to determine land use practices which will ensure long term productivity of the soil. Soil loss prediction techniques have developed over many years of understanding of erosion process and conducting of many erosion experiments. Earlier estimates of soil loss were based on qualitative in nature and suggested that some cultural practices differed in their ability to control soil erosion. Initially, mathematical equations were developed using single independent variable, but these single factors were for local conditions, where other contributing factors were considered constant. Scientists such as, Zing (1940), Musgrave (1947), Smith and Whitt (1947, 1948), were some of the scientists who pioneered the quantification of soil loss in their research and gave many equations from their study for soil loss estimation. In 1958, Wischmeier, a statistician with the Soil Conservation Service, was put in charge of analysing and collating over 10000 annual records of- erosion on plots and small catchments at 46 stations on the Great Plains. Wischmeier and Smith's aim was to establish an empirical model for predicting erosion on a cultivated field so that erosion control specialists could choose the kind of measures needed in order to keep erosion within acceptable limits given the climate, slope and production factors. Thus, universal soil loss equation was designed to measure the soil loss from particular field, which was useful and working tool for conservationist, scientist and planners.

II. Water Drop Erosivity

Rainfall consist of infinite water droplets, when these droplets strikes or come in contact with the soil which are possessing kinetic energy in them, they break the soil particles. The splash process can be characterized as two sub processes; the detachment or the dislodgement of the particles from the surface mass and the transport of these particles in random directions. These sub processes are the result of the water-soil collision. The water drop effects can be related to the drop's diameter, mass, velocity, shape, fall height, drop force and impact pressure. This water drop erosivity is also termed as erosivity index, which is represented by 'R' in USLE equation. This erosivity factor is the ability of rainfall to erode the soil particles. Hence, many scientist and researchers have worked on this factor and given many equations for its quantification. Work of these researchers is reviewed in this paper to get the scenario of their research, which can help in understanding of soil loss process to design new equations.

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III. Estimation of Rainfall Erosivity Index

Wischmeier and Smith (1958) observed that the function of R in the universal soil loss equation is to quantify the interrelated erosive forces of rainfall and runoff . The parameter evaluate R must be predictable on probability basis from metrological data . It must be definable for specific storms, seasons and specific period of time as well as on annual basis and seasonal or annual evaluation must be influenced by all significant rains rather than only by annual maxima. The parameter erosivity index (EI) meets all requirements , derived by Wischmeir and smith (1958). The term erosivity index is defined as product of kinetic energy of rainfall into 30 – min maximum intensity of rainfall, EI = K.E × I30 . The terminal velocities of drops falling freely through the atmosphere are proportional to drop size , and for equal mass the kinetic energy is proportional to velocity squared. Therefore, kinetic energy per unit of rainfall increases as intensity increases.

Pawel Licznar (1990) has calculated and analysed annual R-factor local values for 103 stations in Poland in his study. Calculations were made by means of single hidden layer perceptron artificial neural network on the base of monthly precipitation totals from years 1961 to 1980. For most of the analyzed stations calculated average annual R-factor values were low or moderate, at the range from 50 to 80 MJ⋅ha-1⋅cm⋅h-1. A strong relation between calculated average annual factor values and station elevation above sea level was observed. Because of this, geostatistical algorithms incorporating elevation information should be used for further updating the isoerodents map of Poland was suggested.

Hassan (1991) has investigated some of the factors controlling the rainfall-runoff relationship and, consequently, predicting flood events in a catchment. Primarily, the research was concerned with the study of rainfall and runoff with respect to various hydro meteorological and physical factors. An equation to predict the peak discharge was proposed. The prediction equation illustrates that the maximum peak discharge can be obtained as a function of rainfall intensity, rainfall duration, duration of rainfall up to time of concentration, and the previous discharge. Such analyses are considered vital as the basis for flood warning systems in the area under consideration.

Miguel and Pedro (1993) has shown the inadequacy of most rainfall erosivity indexes and specially the Wischmeier rainfall erosivity index, for properly estimating erosivity in southern Portugal and in Mediterranean climates. In order to measure raindrop size distribution of natural rainfall automatically and continuously, a device was installed at the Vale Formoso experimental erosion centre. The main objective was to correlate field measurement to model estimates. The relatively small amount of rain which fell at the station last year meant that it was only possible to check the calibration of the device . Classical raindrop distributions were compared with the data and relationship between rainfall intensity and kinetic energy of rainfall were obtained and are compared with that proposed by RUSLE.

Bagarello and D'Asaro (1994) observed that the computation of single storm erosion index EI , which is the basis to determine the rainfall factor of the universal soil loss equation (USLE) , is tedious and time consuming and requires a continuous record of rainfall intensity. In this article, simplified method for estimation of single – storm EI in the Mediterranean area were developed. In particular, data from 32 Sicilian locations and 3 additional locations in continental south Italy were at first used to derived and test a regionalized relationship for estimating the EI index from only one storm amount data. A potential relationship with an exponential equal to 1.54 was obtained. Regionalized relationship for estimating the kinetic energy and EI for an event as a function of rainstorm amount and maximum 30 minutes intensity were also developed and tested since in Mediterranean area an erosive event may generally last for several days, a rule of grouping daily rainfall data in order to produced the amount of each erosive events was finally developed and tested.

OBI and Salako (1995) had studied rainfall erosivity for Guinea Savanna, forest and coastal belts of south eastern Nigeria. The highest rainfall amount range from 117 to 183 mm per rain event whereas as maximum 6 minutes intensities ranged from 191 mm/h to 254 mm/h. advanced storm were dominant in the region. The values of Kowal and Kassam kinetic energy equation were 1.6 times higher than values obtained from Wischmeier and Smith's equation. The mean erosivity values using EI30 index ranged from 12,814 to 18,611 MJ.mm./ha.hrs. Rainfall erosivity differences were more prounced between the guinea savanna forest belts than between forest and coastal belts. The high erosivity of rains in southeastern Nigeria can be attributed to heavy storms of comparatively high intensities, and often long duration. The magnitude of rainfall erosivity provides a useful insight into the causes of catastrophic erosion problems in southeastern Nigeria.

Connolly *et al* (1998) found that Short-time-intensity rainfall is often required in experimental and predictive studies of runoff, erosion and pollutant transport. While daily rainfall records of up to 100 years duration were commonly available in Australia, few short-time-intensity records of even 25 years duration have been maintained. This paper, describe and test a model that allows disaggregation of measured daily rainfall into short-time-intensity data. Parameters were derived from a relatively short, measured time-intensity record. The model simulates number of events on a rain day, and starting time, duration, rainfall amount, time to peak intensity and peak intensity of each event. A double exponential was used to generate internal intensity for each event. The model is relatively simple and can be parameterized with a measured time-intensity record as short as three years. The model adequately reproduced characteristics of rainfall from four locations in Australia with contrasting climates. The disaggregation model has application with simulation or experimental studies where information about the time distribution of rainfall is required. The model would be suitable for incorporation into cropping system and other models.

Helming (1999) found that the kinetic energy of rainstorm plays a paramount role in surface sealing, runoff, and erosion process. Typically, the kinetic energy rate is calculated based on terminal velocity of vertically falling rain drops. Few studies have investigated the effect of wind speed on raindrop velocity, rainfall energy and on inclination angles of raindrops. This study was an attempt to determine the effect of wind speed on the kinetic energy of rainstorm, the relationship between rainstorm intensity and wind speed , raindrop impact angle distribution with respect to wind speed, inclination angle, and soil surface geometries. The results suggested that wind speed has considerable effects on rainstorm energy, and thus has an impact on surface sealing and soil erosion processes.

Mannaerts and Gabriels (2000) observed the rainfall erosivity values derived from a 7-year rainfall recording in the Cape Verde islands, Central East Atlantic. The data set consisted of 63 storm events, continuously registered in 15-min intervals.

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Kinetic energy of storm rainfall corresponded to established values in other tropical locations. Two algorithms to estimate erosivity, expressed as energy times intensity, using daily rainfall or storm depth and duration as predictor variables were derived. Erosivity of design storms for various return frequencies was calculated for some locations in Santiago island. An indicative range for the annual rainfall erosion R-index was given. Data analysis further showed the extreme seasonal concentration of precipitation and erosivity at this location, with a very high fraction of total annual erosivity contained in the annual maximum 24-h rainfall.

Ramprasad *et al* (2000) observed the importance of the size of raindrop in causing soil detachment and splash has long been recognized, although the total energy expended on erosion by splash may be small. The aggressiveness of rainfall or its capacity to cause detachment can be expressed in terms of drop size, rainfall intensity and kinetic energy or momentum. An attempt was been made to determine the rainfall erosivity EI. Of two gauged stations where continuous rainfall recorders were installed, on the basis of rainfall characteristics. Thus, the relationship between average storm EI_{30} rainfall erosivity for 30 minutes interval. Values and average depths of rainfall could be developed for the Bheta Gad basin of the Gomati River in the Hindu-Kush Himalayas. The analysis has revealed that if factors other than rainfall remain constant, soil splash erosion from cultivated fields is directly proportional to the rainstorm parameter identified as EI.

Mohan and Bhandari (2000) observed the mean monthly rainfall, erosivity, kinetic energy of erosive rainfall and erosion index factors for district solan (H.P) . Inter relationships among erosivty rainfall, monthly rainfall, kinetic energy and erosion index were also developed. The erosion index worked out to be 244 units for solan district. The relationships worked out between erosive rainfall and total rainfall, and between kinetic energy and erosive rainfall were linear.

Sudhishri and Patnaik (2004) observed the average annual and seasonal rainfall of eastern Ghat high land (EGHL) zone varies from 1300 to 1900 mm and 1000 to 1600 mm respectively. June and July are the most erosive months in the rainy seasons. Erosion index during the month from May to September accounts for about 83.7 per cent of annual value. Highest erosion index was recorded during year 1995 and lowest in 1997. The average annual and seasonal erosion index varies from 618.78 to 1061.66 and 388.03 to 945.39 respectively. Linear regression equations were developed between the kinetic energy (K.E) , erosion index (EI 30),erosive rain (ER) and total rainfall and EI & PI for 5, 10, 15, 30, and 60 minutes duration. Iso –erodent maps for seasonal and annual erosion index were also developed for EGHL zone for standardizing the conservation practices.

Fornis *et al* (2005) has studied the soil erosion process, specifically detachment of soil particles by raindrop impact, kinetic energy is a commonly suggested indicator of the raindrop's ability to detach soil particles from the soil mass. Since direct measurement of kinetic energy requires sophisticated and costly instruments, the alternative approach is to estimate it from rainfall intensity. This study aimed at establishing a relationship between rainfall intensity and kinetic energy for rainfalls in Central Cebu, Philippines as a preface of a wider regional investigation. Drop size distributions of rainfalls were measured using the disdrometer RD-80. There are two forms of kinetic energy considered here. One is kinetic energy per unit area per unit time (KE_R, J /m^2 /h) and the other is kinetic energy per unit area per unit depth (KE, J/m^2/mm). Relationships between kinetic energy per unit area per unit time (KE_R) and rainfall intensity (I) were obtained using linear and power relations. The exponential model and the logarithmic model were fitted to the KE–I data to obtain corresponding relationships between kinetic energy per unit area per unit depth of rainfall (KE) and rainfall intensity. The equation obtained from the exponential model produced smaller standard error of estimates than the logarithmic model.

Diodato (2005) observed that Seasonal rain erosivity was important in the structure and dynamics of Mediterranean ecosystems. This paper contributes to the quantitative assessment of RUSLE's monthly erosion index in a data-scarce Mediterranean region. Therefore, a regionalized relationship for estimating monthly erosion index (EI_{30}-month) from only three rainfall parameters has been obtained. Knowledge of the seasonal and annual distribution of erosivity index, permit soil and water conservationists to make improved designs for erosion control, water harvesting or small hydraulic structures. Although a few long data sets were used in the analysis, validation with established monthly erosivity index values from other Italian locations, suggest that the model presented (R^2 = 0.973) is robust. It was recommended to monthly erosivity estimates when experimental data-scarce rainfall become available.

Agnese *et al* (2006) observed the single-storm erosion index, EI, of the USLE and RUSLE models may vary appreciably with the rainfall measurement interval (t). However, the effect of (t) on EI has not been investigated in the Mediterranean area. Approximately 700 erosive events and 1.5 years of rainfall energies measured by a rainfall impact measurement device were used to evaluate the effect of the rainfall measurement interval (5 min $\leq$ t $\leq$ 60 min) on the erosivity determinations in the Mediterranean semi-arid area of Sicily. According to both literature and practical considerations, a reference time interval equal to 15 min was used in this investigation. Hourly rainfall data led to an appreciable underestimation of the mean value of EI (i.e., by also a factor of two, depending on the location). In the range 5 min $\leq$ t $\leq$15 min, the effect of the rainfall measurement interval on the predicted erosivity was negligible (i.e., mean values differing by a maximum factor of 1.10) as compared with the uncertainties in the soil loss predictions. Two methods were developed for estimating the reference single-storm erosion index, (EI)15, from hourly rainfall data in Sicily. Method 1 converts the erosion index calculated on a 60- min measurement interval basis to (EI)15. Method 2 estimates (EI)15 by using the storm rainfall depth and the maximum rainfall intensity. Testing the two methods against two independent data sets produced a maximum difference between the estimated and the calculated mean values of (EI)15 equal to 7% for method 1 and 11% for method 2. Both methods may be applied in practice, depending on the available rainfall data. For a given rainfall intensity, the specific power, P, measured at eight time intervals (5 min $\leq$ t $\leq$60 min) was in the range ±10% of the mean of the eight P values.

Mikos *et al* (2006) has observed that rainfall and runoff erosivity is often assessed by using the *R* factor. For its computation different methods may be used. The aim of this study was to compare some estimation methods for the alpine climate in the Slovenian Alps. Monthly and annual *R* factor values were calculated according to the RUSLE, using daily precipitation data for the period 1990–2002 in Solčava, which is typical of the alpine region in Slovenia. In this alpine area with rather low rainfall intensities, the expression for computing the rainfall kinetic energy proposed yielded on average 17.9% higher rainfall erosivities than the RUSLE approach. The newly proposed *A* index yielded on average 40% lower rainfall erosivities than the RUSLE approach. These lower values of rainfall erosivity were caused by the structure of rainfall during erosive events in the alpine region. The analysis in the alpine climate in Slovenia does not support the use of the proposed *A* index as a replacement for the usually used *R* factor when assessing rainfall erosivity.

Brodie and Rosewell (2007) found that rainfall intensity as a contributing factor to the amount of suspended particles washed from urban areas during storms. Moreover, it has been postulated that the square of rainfall intensity (I^2) provides a measure of the rainfall kinetic energy (KE) available for wash off processes. This study provides a theoretical analysis of the potential inter-relationships between intensity (I^2) and rainfall KE. A hypothetical raindrop size distribution (DSD) was used to derive rainfall energy characteristics. A special form of the Marshall–Palmer DSD was developed that ensured conservation of rainfall mass over the analyzed range of rainfall intensities. This 'conserved rainfall mass' DSD was used to calculate the specific KE variants of rainfall (the time-specific KE_I and the volume-specific KE_P). It was found that KE_I has a $\log_e$-based relationship with rainfall intensity. Empirical relationships widely used in soil erosion studies have generally adopted a $\log_{10}$ basis. A direct relationship between the two KE variants and I^2 appears to be absent. A new KE variant (KE_{IA}) was proposed and it was demonstrated that this variant supports the hypothesis that I^2 is a measure of the KE of rainfall. KE_{IA} is the kinetic energy potentially transferred from raindrops to the proportion of the unit area impacted at a specific instant in time. It is a function of KE_I and raindrop circumferential area. Relationships based on variants of rainfall momentum (M) were also investigated. The relationship between MI and KEI was nearly linear as a fitted power function has an exponent close to unity (equal to 0.93). This suggested that KE and M could be effectively interchangeable if used in particle wash off estimation.

Salako (2008) found a decreasing trend of rainfall in West Africa, where rainfall erosivity is also considered to be high. Therefore, this study was carried out to evaluate the variability of rainfall and its erosivity in two contrasting zones in southern Nigeria between 1977 and 1999 to understand the implications of climate variability on rainfall erosivity. The study sites were Ibadan, a sub-humid zone, and Port-Harcourt, a humid zone. Time of occurrence of rainfall, rainfall amount (A), intensity (I_{15} and I_{30}), kinetic energy (E) and rainfall erosivity factor (R), were evaluated. Kinetic energy was estimated with Brown– Foster (BF) equation, making the rainfall erosivity (product of kinetic energy and intensity) to be designated as EI30-BF and EI15-BF. The frequency of rainfall during daylight (06:00– 18:00 h) was 48% for Ibadan and 69% for Port-Harcourt. This study suggested a decreasing trend in erosivity due to the decreasing trend in rainfall amount in West Africa. However, the trend did not imply lesser soil erosion and environmental degradation risks.

Tingting *et al* (2008) observed that soil erosion was very serious in Thailand especially in northern Thailand. Important on-side effects of soil erosion may be the decline in qualities of soil related to agricultural productivity. So it was very important to assess the soil erosion risk for the sustainable development of agriculture. This study was conducted with objective of modeling and assessing soil erosion risk in the northern Thailand with the application of IMAGE\LDM. Rainfall erosivity index, relief index, soil erosivity index and land cover index are four basic factors used in IMAGE\LDM. Soil erosion risk can be grouped into six classes. Furthermore, the spatial distribution characteristics were also analyzed with the application of GIS in the view of elevation, land use types. From the result we can find soil erosion risk was high in the altitude between 100 and 400. Soil erosion risk was lower in the forest area than in the agriculture and plantation area.

Jebari1 *et al* (2008) observed that the Tunisian Dorsal area is representative of the semiarid Mediterranean region in terms of water resources availability as well as exceptional rainfall characteristics, runoff generation, and soil loss risk. In this context, soil properties, surface management practices together with highly intensive rainfall make the soils vulnerable to erosion. If the exceptional rainfall characteristics are linked to different erosion types, the erosion risk could be evaluated in a simple and straightforward way. In this regard, a short time-scale rainfall data base from the Dorsal area was analysed in this paper. The procedure used involves finding a representative duration between 1-60 min for the exceptional rainfall characteristics. Rainfall intensities of different return periods are then related to the different erosion types. The identified exceptional rainfall durations between 1-60 min were analyzed in terms of number of events, depth, average intensity and maximum intensity. Results showed that the 15-min duration maximum intensity can be used to evaluate erosion risk based on soil erosion type. The developed methodology can be used to evaluate erosion risk in semiarid regions based on exceptional rainfall characteristics. In practical terms the results can be used to better manage catchments that are vulnerable to soil erosion.

Nel *et al* (2009) had studied that high-resolution rainfall data from two stations in the northern KwaZulu-Natal Drakensberg provide insight into the effect of altitude on individual rainfall event characteristics. The effect of altitude on the duration and erosivity (rainfall intensity and kinetic energy) of concurrent rainfall on the escarpment and in the foothills was analysed using 5-min interval data for the calendar year 2003. A cumulative total of 229 rainfall events, measured at the Royal Natal National Park station (1392 m a.m.s.l.) and a temporary station on the escarpment at Sentinel Peak (3165 m a.m.s.l.), were considered, of which 79 rainfall events were found to fall concurrently at the two stations. The data indicate that the concurrent events generate rainfall for longer on the escarpment, but that the amount of rain produced as well as the intensity at which it falls was less than that in the foothills, both in summer and winter. The escarpment appears to limit erosivity, with only 11 events meeting the set criteria for erosivity in the foothills but failing to meet the same criteria on the escarpment. This decrease in erosivity contrasts with previous models for the Drakensberg that demonstrated higher erosivity in the upper reaches, but concurs with studies in mountainous regions elsewhere which found that erosivity decreases with altitude. It was tentatively suggested that the difference in rainfall characteristics could be related to the sources of precipitation and the manner in which the escarpment zone affects the formation and distribution of rainfall. The paper also highlighted the need for further research into the association between rainfall structure and synoptic conditions and the effect that the escarpment had on modifying large-scale rain producing Systems in the KwaZulu-Natal Drakensberg.

IV. Conclusion

This study shows that, good research work has been done by the researchers on rainfall erosivity index, inspite of many constraints. The methodology used by these scientists was good and appropriate in estimating the erosivity for their region. From their study researchers concluded that the principle characteristics of storm are its intensity, duration, total amount and frequency. Results of the scientists indicated that erosivity i.e. product of kinetic energy of rainfall and maximum 30-minutes rainfall intensity, is the initiating factor in rainfall soil erosion and runoff generation processes. It was also proved that erosivity index varied with the rainfall, which indicates the ability of rainfall to detach the soil particles. Various techniques and methods used for calculating erosivity index by researchers, it suggests that there is need to update the kinetic energy and erosivity predictor equations as more experimental data becomes available, which will make the prediction of erosivity index more representative and appropriate for any particular region.

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