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Variability of kinetic energy of rainfall and its significance in soil erosion

■ DEVDATTA V. PANDIT AND R.K. ISAAC

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See end of the Paper for authors' affiliation

Correspondence to:

DEVDATTA V. PANDIT
Department of Soil Water Land Engineering and Management, Sam Higginbottom Institute of Agriculture, Technology and Sciences, ALLAHABAD (U.P) INDIA

■ **ABSTRACT :** The kinetic energy of rainstorm plays a paramount role in surface sealing, runoff and erosion process. Knowledge of relationship between rainfall intensity and kinetic energy and its variations in time and space is important for erosion prediction. Rainstorm kinetic energy, as a function of the mass and terminal velocity of raindrops has often been suggested as an ability of rainfall to detach soil particles. Therefore, this study was carried out to evaluate the variability of rainfall and it's kinetic energy for Allahabad . Time of occurrence of rainfall , rainfall amount ,intensity and kinetic energy were evaluated. Kinetic energy was estimated with brown-foster's equation and by Wischmeier's equation of kinetic energy. Among four rainy months , maximum rainfall amount of 222.94 mm was observed for the month of August and lowest rainfall amount of 92.64 mm was observed for June. Kinetic energy by both the models was found to be maximum for July with K.E-1 as 38.71 MJ/ha, K.E-2 as 43.20 MJ/ha and for August K.E-1 as 39.33 MJ/ha and K.E-2 as 42.88 MJ/ha respectively. For rest of the months i.e. for September and June kinetic energy was in decreasing trend. Co-efficient of determination for monthly variation of kinetic energy was found to be R^2 = 0.965.

■ **KEY WORDS :** Kinetic energy of rainfall, Soil erosion

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Soil erosion is a natural process that can be accelerated dramatically following improper land use and management. Human activities can result in erosion rates that area many times higher than natural rates. Worldwide, erosion is considered to be the most widespread and serious form of soil degradation (Mabit and Benard,2007). With decrease of agricultural land use due to natural, social and economic factors, the amount of material lost to erosion has decreased. However, the measurements proved that erosion on agricultural land is by no means negligible and is most intensive on cultivated land (Komac and Zorn, 2005). Since this category of land use is constantly decreasing due to abandment of agricultural practice, the existent agricultural areas and prevention measures against soil degradation are of utmost importance. Rainfall represents a distribution of differently sized drops that attain corresponding different terminal velocities in stable air. Rainfall kinetic energy and rainstorm intensity are predominant factors contributing to surface sealing , runoff and soil erosion process (Renard *et al.* ,1997). The determination of both the parameters is, therefore, of paramount important for runoff and erosion prediction purposes. Bonell (1998) observed that any change in rainfall characteristics which favours higher intensities would encourage the occurrence of overland flow and cause erosion. The study of mechanisms of water erosion brings out two characteristics of precipitation, which makes it the dominating causative factor of the phenomenon: intensity and depth of amount (which depends on the intensity-duration combination) (WMO, 1983). Hudson (1995) defined three attributes of rain pertaining to erosion. Intensity of a rain, generally expressed as mm/h, is usually highly variable during the course of a rainstorm. The time pattern of rain intensity also differs from storm to storm, from place to place and from season to season. The second attribute is the duration of a rain, the length of time from the start of a rainstorm to its ending. As the third parameter Hudson states the energy of a rainstorm, being the summation of the kinetic energies of all raindrops falling on a unit area. Thus kinetic energy represents the total energy available for detachment and transportation of soil particles. The most widely used kinetic energy-intensity relationship is that proposed by Wischmeier and smith (1958) and that of Brown-foster's equation (1987) was used to estimate the kinetic energy in this study.

■ METHODOLOGY

Study area :

Location and extent :

The district Allahabad is located the north part of India and south-east part of State Uttar Pradesh, Which was inaugurated on 1947. Allahabad district lies in the southern-east part of state (Uttar Pradesh) between $24^0 47'00''$N to $25^0 47'00''$N North latitude and $81^0 19'00''$E to $82^0 21'00''$E East longitude. It has an area of 5246 sq km. The state is bounded by district Bhadohi and Mirzapur in the East, Kaushambi and Banda in the west, Pratapgarh and Jaunpur in the North and Banda and Madhya Pradesh are in the south. Allahabad district had an annual rainfall of 600mm to 800mm. Ganga and Yamuna, which originates, respectively, from Himalaya Glacier, are the two major rivers of the Allahabad district. The population of the Allahabad district according to the census of 2001 was 4952000 living in 8 Tehsils (Sadar, Soraon, Koraon, Karchana, Bara, Meja, Phoolpur, Handia). The density of population is 1059 person per sq m. The people are urban, rural and tribal. The topography is very severe, The district may be divided in the three distinct physical parts. the trans-Ganga or the Gangapar plain, the doab and trans-Yamuna or the Yamunapar tract which are formed by the Ganga and its tributary, the Yamuna, the latter joining the former at Allahabad, the confluence being known as Sangam.

Climate :

The climate of Allahabad is characterized by a long and hot summer, a fairly pleasant monsoon and cold seasons. The winter usually extends from mid-November to February and is followed by the summer which continues till about the middle of June. The south-west monsoon then ushers in the rainy season which lasts till the end of September. October and the first half of November constitute the post-monsoon season.

Rainfall :

The rainfall of Allahabad generally decreases from the south-east to the north-west. About 88 per cent of the annual rainfall is received during the monsoon season. July and August being the months of maximum rainfall. The normal rainfall in the Allahabad is 600-800 mm but the variation from year to year is appreciable on an average there are about 48 rainy days in a year, the variation in different parts of the district being negligible

Seasons :

Seasonal change in weather exerts a great influence on economic life of the Allahabad , especially on agriculture and cultivation which is the main occupation of them. The seasons are characterized more by the difference in the amount of rainfall than temperature.

On the basis of rainfall, temperature and wind velocity and direction, the year may be conveniently divided in to the following four seasons:

- Cold weather season or winter season (December to February)
- Hot weather season or spring season (March to June)
- South-West Monsoon or summer season (June to September)
- Retreating South-West Monsoon or autumn season (October to November)

Data analysis :

Statistical analysis and normalization of rainfall data was done and statistical parameters *i.e.* mean, median, standard deviation, skewness , kurtosis were calculated. Monthly statistical values for the month were :

	June	July	August	September
Std. dev	21.40	21.07	24.69	29.76
Skew	1.75	1.62	2.77	2.79
kurtosis	2.81	2.62	9.77	11.21
mean	17.83	17.79	19.02	23.06
median	10.51	8.48	10.50	13.95

Kinetic energy of rainfall :

The result of various studies had suggested that soil splash rate is a combined function of rainfall intensity and some measure of raindrop fall velocity (Ellison,1944; Bisal,1960). In particular, rainfall kinetic energy Ek (product of mass and fall velocity squared) has often been suggested as an indicator of rainfall erosivity, *i.e.* the ability of rain to detached soil particles (Mishra, 1951; Free, 1960). Rose (1960) concluded that rainfall momentum is a slightly better predictor of soil detachment than kinetic energy, but Hudson (1971) demonstrated that for natural rainfall, momentum and kinetic energy exhibit similar relationships with intensity.

Kinetic energy of rainstorm is given by the formula given by Brown and Foster (1987):

$$\mathbf{K.} = \sum \mathbf{0.29[1 - 0.72 * exp(-0.05i)]} \qquad \text{......(1)}$$

where,

i = (mm/h) intensity of rainstorm.

Wischmeier (1965) also gave equation for calculating kinetic energy of rainstorm :

$$\mathbf{E = 0.119 + 0.08731ogI,} \qquad \text{......(2)}$$

where,

E is kinetic energy of storm in MJ/h.mm.

I is rainfall intensity in mm/h.

■ RESULTS AND DISCUSSION

Fig.1 and Fig.2 show annual and monthly variations of rainfall for the study area. Extreme rainfall amount for the study area occurred in the year 1994 with rainfall amount of 1099 mm Lower amount of rainfall were observed for the year 1996, 1997, 2002 with rainfall amount as 404.5 mm 396.6 mm and 447.8 mm, respectively. Variation of rainfall amount for rest of the year was less and for year 2005, 2006 and 2007 rainfall amount was observed in same range of 913 to 945 mm. From Fig.2 variation of monthly rainfall for the months of June, July, August and September was observed. Maximum monthly rainfall amount was maximum for the month of August with amount of 222.94 mm and July with the amount of 217.13 mm and September with amount of 213.82 mm whereas, June was observed with lowest amount of 92.64 mm. For the observed rainfall amount variation of intensities for the particular precipitation event was also observed.

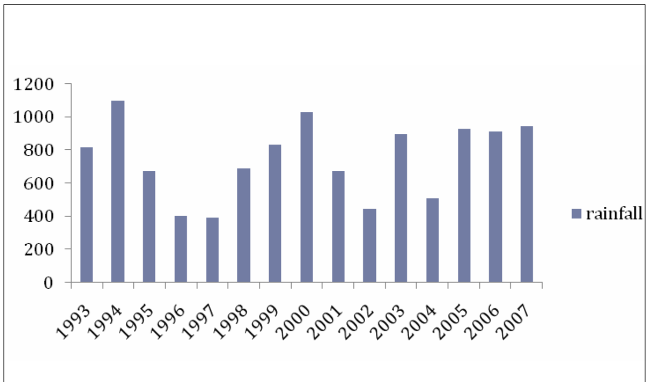

Fig.1: Annual variation of rainfall amount

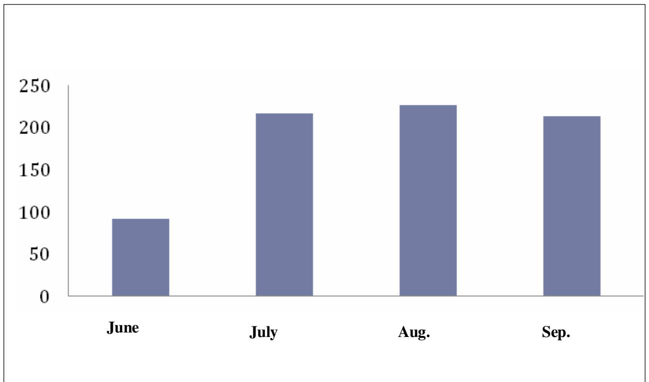

Fig.2: Monthly variation of rainfall amount

Annual variation kinetic energy :

Fig.3 shows annual variation of kinetic energy by different models, that by Brown-foster's equation (K.E-1 and Wischmeier's equation K.E-2 of kinetic energy. From Fig.3 it was observed that highest kinetic energy was observed in the year 1994 with K.E-1 was 11.27 MJ/ha and K.E-2 was 12.07 MJ /ha. Lower values of kinetic energy were observed for the year 1996 followed by the year 2002, which were K.E-1 5.67 MJ /ha , K.E-2 was 6.34 MJ/ha and K.E-1 was 5.38 MJ /ha , K.E-2 was 6.11 MJ/ha, respectively. From this result it was observed that rainfall kinetic energy represented the total energy available for detachment and transportation of soil particles as stated by Salles *et al.* (2002) which gave relevant results. It was also observed that kinetic energy was higher for the high intensity of rainfall, this explains that why, annual kinetic energy was higher for the year 1994, lower intensity of rainfall gave lower values of energy which indicates that such type of precipitation were less efficient at detaching soil particles, this result confirms the observations obtained by Sharma *et al.* (1989) in their study.

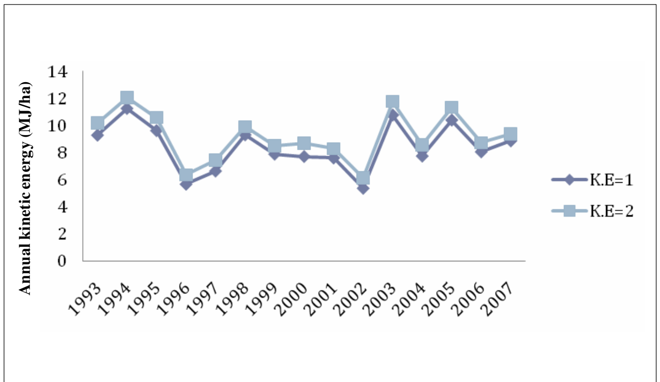

Fig.3: Annual variation of kinetic energy

Monthly variation of kinetic energy :

Fig.4 shows the monthly variation of kinetic energy with both the equations of kinetic energy. Among the four rainy months kinetic energy was maximum for the month of July and august with the values as K.E-1 was 38.71 MJ/ha, K.E-2 was 43.20 MJ/ha and K.E-1 was 39.33 MJ/ha, K.E-2 was 42.88 MJ/ha, respectively. The intensity observed for these month were also in increasing trend which gave higher kinetic energies for these months. Kinetic energy values for the month of September and June were in decreasing trend and the intensity for these months also varied accordingly resulting in less values of kinetic energy. This observations supports the earlier observations of Mihra (1951) and Free (1960) that lower values of kinetic energy has lower potential of soil detachment rate and kinetic energy is an important factor in estimation of soil loss.

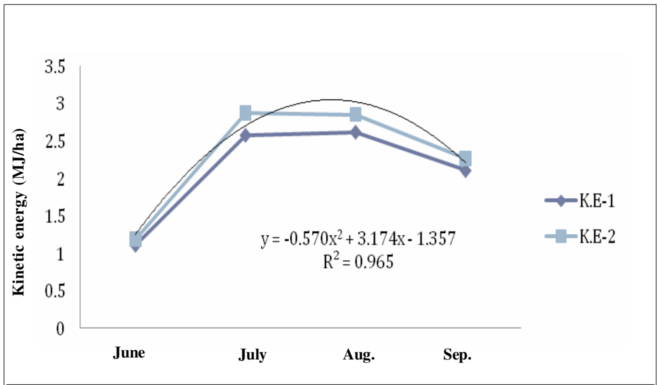

Fig. 4: Monthly variation of kinetic energy

Monthly annual variation of kinetic energy in June:

Fig.5 shows the monthly annual variation of kinetic energy in June. June was observed to be the minimum kinetic energy month as shown in (Fig.4). The kinetic energy of June as compared with the other three months of July, August, September was lower which revealed that the storm energy to detached the soil particles was lower than other rainy months. Annually kinetic energy for June was observed maximum for the year 2001 and 2004, respectively. K.E-1 was 1.659 MJ/ha and K.E-2 was 1.841 MJ/ha for the year 2001 and K.E-1 was 1.671 MJ/ha , K.E-2 was 1.829 MJ/ha for the year 2004. Lower kinetic energy of storm was observed for the year 1995 which was K.E-1 as 0.934 MJ/ha , K.E-2 as 1.019 MJ/ha and that for the year 1999 K.E-1 was 0.766MJ/ha, K.E-2 was 0.768 MJ/ha, respectively. Thus, according to Lal (1990,1996) for lower values of kinetic energy does not, however, suggest that there is reduced soil detachment rate, unless conservation measures are not adopted.

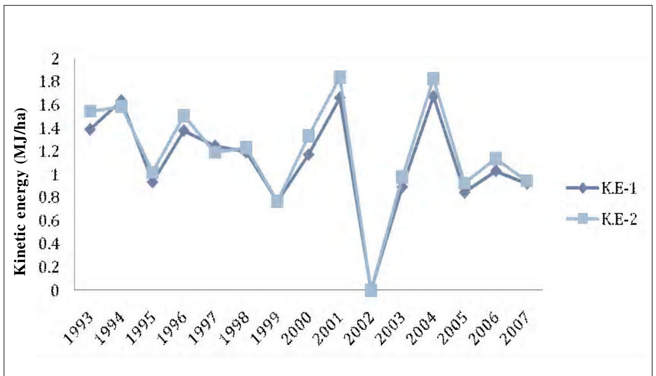

Fig. 5: Monthly annual variation of kinetic energy in June

Monthly annual variation of kinetic energy in July :

Fig.6 shows the monthly annual variation of kinetic energy for July. Study shows that July was among maximum precipitation month (Fig.2) and also it was maximum kinetic energy month (Fig.4). Storm kinetic energy in this month was found maximum for the year 2005 and 2006, and was minimum for the year 2002 followed by the year 1993. Values observed for the year 2005 K.E-1 as 4.60 MJ/ha, K.E-2 5.18 MJ/ha and values for the year 2006 observed for K.E-1 was 4.511 MJ/ha, for K.E-2 was 4.95 MJ/ha. Minimum values observed in the year 1993 for K.E-1 was 1.79 MJ/ha ,K.E-2 was 2.18 MJ/ha and for the year 2002 values for K.E-1 was 0.621 MJ/ha ,K.E-2 was 0.675 MJ/ha. The values observed for the month of July supports the observation of Hulme and Viner (1998) that changes in total rainfall results in different intensities which affects the kinetic energy of storm, which increases or decreases it's potential to detach the soil particles.

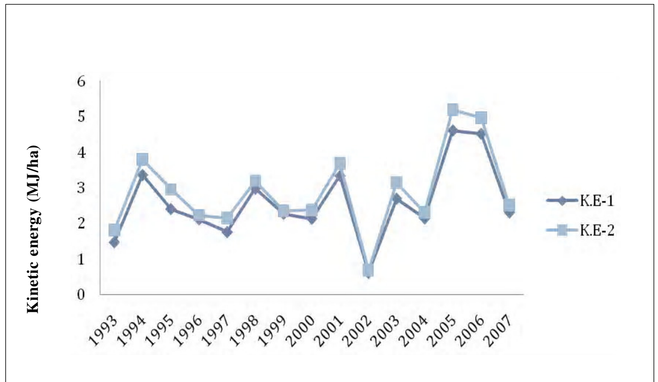

Fig. 6: Monthly annual variation of kinetic energy in July

Monthly variation of kinetic energy in August :

Fig.7 shows the monthly annual variation of kinetic energy for the month of August. From this study it was observed that August also contributed to the maximum storm kinetic energy (Fig.4) and also maximum precipitation was observed for this month (Fig.2). Maximum values of kinetic energy were observed for the year 1994 and 2007 and minimum values were observed for the year 1996 and 1997, respectively. For the year 1994 values observed were K.E-1 was 5.02 MJ/ha, K.E-2 was 5.42 MJ/ha, for the year 2007 values were K.E-1 was 4.41 MJ/ha ,K.E-2 was 4.61 MJ/ha, respectively. Minimum values for the year 1996 were K.E-1 was 1.30 MJ/ha, K.E-2 was 1.16 MJ/ha and for the year 1997 values were K.E-1 was 1.48 MJ/ha , K.E-2 was 2.38 MJ/ha, respectively. This observed result showed that the intensity had relationship with the kinetic energy of particular storm, this result supported the earlier observation of Sharma et al (1989) that there exist relationship between kinetic energy and rainfall intensity, as energy increased with increased in intensity and decreased with decreased in intensity.

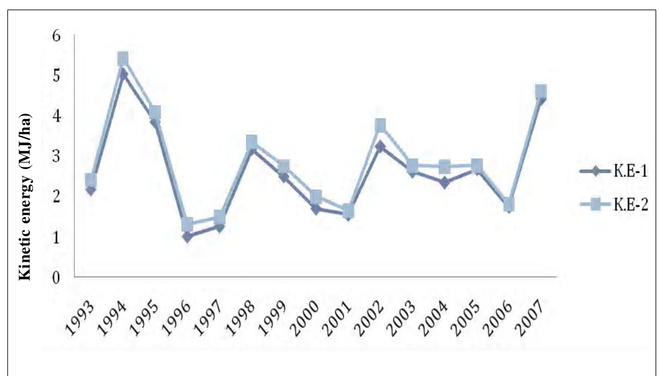

Fig. 7: Monthly annual variation of kinetic energy in August

Monthly annual variation of kinetic energy in September :

Fig.8 shows the monthly annual variation of kinetic energy in the month of September. This study shows that

September was the month where more variation was observed in storm kinetic energy (Fig.4) along with precipitation amount and storm intensity. Maximum values of kinetic energy were observed for the year 1993 and 2003. In 1993 value for K.E-1 was 4.25 MJ/ha, for K.E-2 was 4.42 MJ/ha and in the year 2003 for K.E-1 was 4.58 MJ/ha, for K.E-2 was 4.89 MJ/ha. Minimum values of kinetic energy observed for the year 2006 for K.E-1 was 0.78 MJ/ha , for K.E-2 was 0.84 MJ/ha. Similar variations were also observed by Wischmeier and Smith (1958) for such condition they concluded that storm kinetic energy showed variations when, intensity increases it also increases kinetic energy and when intensity decreases kinetic energy also decreases for particular storm event.

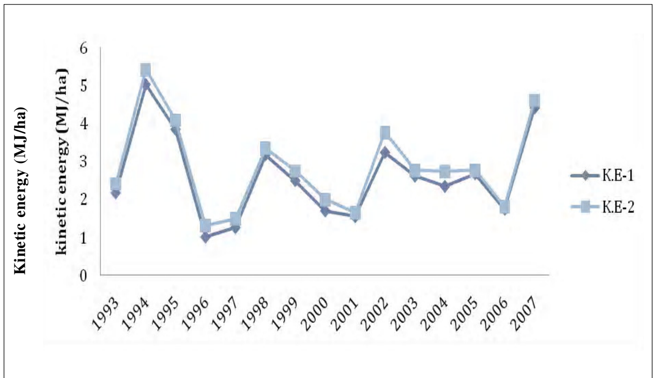

Fig. 8: Annual variation of kinetic energy in September

Conclusion :

From this study it was concluded that the principle characteristics of storm are its intensity, duration, total amount and frequency. Rainfall intensity is expressed as the rate of rainfall in inches or millimeter per hour. The intensity is an important characteristic of rainfall because, other things being equal, more soil erosion is caused by one rainstorm of high intensity than by several storms of low intensity. Generally the high intensity portion of a storm has a shorter duration than the low intensity portion. The relationship of kinetic energy –intensity was observed in this study which showed that higher the intensity of storm, higher will be its kinetic energy.

Authors' affiliations:

R.K. ISAAC, Department of Soil, Water Land Engineering and Management, Sam Higginbottom Institute of Agriculture, Technology and Sciences, ALLAHABAD (U.P.) INDIA

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