Research article

Erosion Processes and Soil Collapse

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Abstract

Soil erosion is the natural process of the removal of soil which has been created by various soil creation processes. The durability of the fertile soil top layer depends directly on these creation and removal processes. Both processes include complex interactions influenced by many factors and are therefore being explored separately. Soil erosion has been the subject of scientific research for over a century while practices aiming to control erosion have existed for thousands of years. In many places where the problem of erosion is not recognized, natural processes have completely destroyed the surface fertile soil layer and continuies to degrade the sterile layer beneath. These places are now deserts that house the ruins of once powerful civilizations. This paper presents an overview of erosion mechanisms, analytical and experimental investigations of erosion processes, with special attention paid to rainfall kinetic energy and experimental results of aggregate and soil collapse due to erosion.

Keywords: soil erosion, relief, anti-erosion measures, rainfall.

Introduction

Erosion processes are generally unnoticeable by the time the intensity of that process becomes apparent. A sudden and significant increase in the intensity of erosion is called "soil collapse". This term was not randomly selected. Normal soils are not made up of sterile and disconnected particles. On the contrary, all types of soil have various binders called "land adhesives". These are complex chemical bonds of organic and mineral compounds and elements. Due to these "adhesives" or "aggregates" as they are also called, the soil has a certain resistance to the aggressive action of rain, wind, temperature and other factors that cause erosion. Natural factors have a smaller impact on the change in the intensity of erosion processes and the occurrence of "soil collapse" than anthropogenic activities (Gavrilović 1957, Hudson 1973, USDA 2019).

The process of creating a fertile soil layer is relatively slow and can be measured after dozens of years of observing the simultaneous processes of soil creation and erosion. The positive difference between these two processes rarely exceeds the creation of two to three millimetres of new soil layer in ten years, and if the difference is negative the erosion removes the newly created soil layers.

Erosion is a dangerous phenomenon that has the potential of destabilising or even destroying civilizations. The global economic crisis between the two world wars was, among other, caused by a sharp decline in crop yields in American agriculture. Fortunately, the science of the time was able to discover the root causes - improper tillage by mechanization with the inappropriate use of chemical additives. At the same time, on the other side of the ocean in the newly formed Yugoslavia, natural circumstances and numerous armed conflicts led to the development of erosion processes, mainly due to deforestation and land use changes – a significant increase in arable land at the expense of deforestation. Although small on a global scale, in 1930 Yugoslavia was the first country in the world to adopt a legislation addressing control of erosion and torrential problems and to begin organized activities in that regard (Law on torrents, Kingdom of Yugolsavia, 1930). In the United States, laws regarding erosion and torrent control were adopted over several years from 1932 to 1938, when erosion was declared enemy No.1 (USDA). Until that time, erosion was considered to be a geomorphological phenomenon with no precise classification and no numerical calculations, where research was done by application of descriptive methods only. The responsibility for soil erosion research was transferred to engineering fields and various analytical methods were then created to study erosion processes.

Analytical Methods for Erosion Processes Research

USLE Method

The Soil Conservation Service (SCS) was the first to establish erosion monitoring stations and began work on developing a so-called Soil Loss Equation (SLE) method, which was later developed into (USLE - Universal Soil Loss Equation). The method was developed for agricultural purposes with a maximum land slope up to 20% and it is not applicable on steep mountain terrains. The method is based on a number of test stations that have to be on 9% slopes and laboratory tests (USDA).

The USLE method looks at annual soil losses and calculates them for parcel, area or state in modular sizes in kg/ha. There are also accompanying measurements of losses of soil aggregates and elements. These observations are important for planning agro-technical measures and avoiding unnecessary amounts of additives.

Erosion Potential Method

This method was developed at the Jaroslav Černi Institute specifically for the needs of water management in the field of erosion and torrential protection and protection of water reservoirs against sediment accumulation, as well as for other water management purposes. The method was developed in accordance with the procedures applied in the USA, combining experimental research and monitoring. The method is not intended to calculate annual soil losses, but to classify global erosion processes at a basin, municipality, or state level. In addition to a series of metadata, an important result is the amount of sediment reaching the downstream end of the watershed or entering the reservoir. The method applicability is not limited by land surface slope and surface constraints (Gavrilović 1957, 1968, 1972, 1988).

This method primarily classifies erosion processes and produces an erosion map that becomes the basis for all later calculations. Erosion processes are classified into five categories (classes). The most important factor is the Erosion Coefficient Z. Each category has its own Z value and a mean Z value is calculated for the basin or area. It is important to note that the coefficient Z does not depend on climatic factors but on the characteristics of the terrain itself.

Climatic factors are the input data for the calculation of the erosion production modulus expressed in m^3/km^2 per year. The annual average values of annual precipitation and mean annual temperatures are used for the calculation. These are data that exist for all areas, including deserts, and provide the basis for calculating climate indices (Gavrilović 1957, 1968, 1972, 1988).

The next step is to calculate the time needed for sediment to reach the calculation profile or the reservoir. This calculation requires data on basin characteristics and flow characteristics that allow the sediments to reach the profile or the reservoir. This method has several other parts for calculating other variables relevant to the engineering calculations required for the design of erosion protection works and torrent management.

Today, there are numerous modifications to both methods, based on an identical observation method and a computational procedure for calculating erosion. The only difference is that the authors claim that they can also calculate what the method settings exclude. Most often, there are gross changes in the coefficients, as well as the use of coefficients of one method for calculations in another (Gavrilović et al. 2009).

Both methods described have similarities but also differences, as well as target groups of users. Land use is similarly defined in both methods and given importance as the only factor under the full control of human society. Therefore, anti-erosion land use and management is the only way to prevent the removal of soil and to extend the duration of the soil top layer.

Investigation of Erosion Soil Collapse

Erosion is generally a slow and almost unnoticeable process until the moment when the erosion intensity accelerates exponentially.

Figure 1: Typical mountainous area affected by erosional soil collapse.

Figure 2: Fully removed fertile soil top layer with sandy subsoil exposed.

Figures 1 and 2 show the areas where erosion soil collapse and extreme erosion intensities occurred. Figure 1 shows a mountainous area of southern Serbia where rain and water erosion are prevalent. Figure 2 shows a slightly hilly area of the Deliblato Sands in north-east Serbia, where large areas of sandy subsoil are exposed. In this area, the prevailing forms of erosion are wind, rain and water. Namely, during dry periods the wind easily transports sandy deposits over long distances which then accumulate in various rivers, lakes and ponds. Particles removed by wind also include fertile soil, which is difficult and slow to regenerate.

The US Land Conservation Service's focus has been to reduce erosion processes by changing land uses wherever possible. The areas where erosion induced soil collapse had occurred, similar to those in Figures 1 and 2, were simply classified as "Bad land" and were not subject to any anti-erosion measures. In Serbia, this kind of approach was not possible because of the sheer size of such areas which created big torrential streams that occasionally damaged vital roads and threatened settlements and cities. Therefore, anti-erosion methods defined in the US United States were implemented and supplemented with measures to recover such areas. In many parts of Serbia, a program of anti-erosion control was implemented in combination with torrent management and afforestation measures, with positive results achieved (Stefanović et al. 2015)

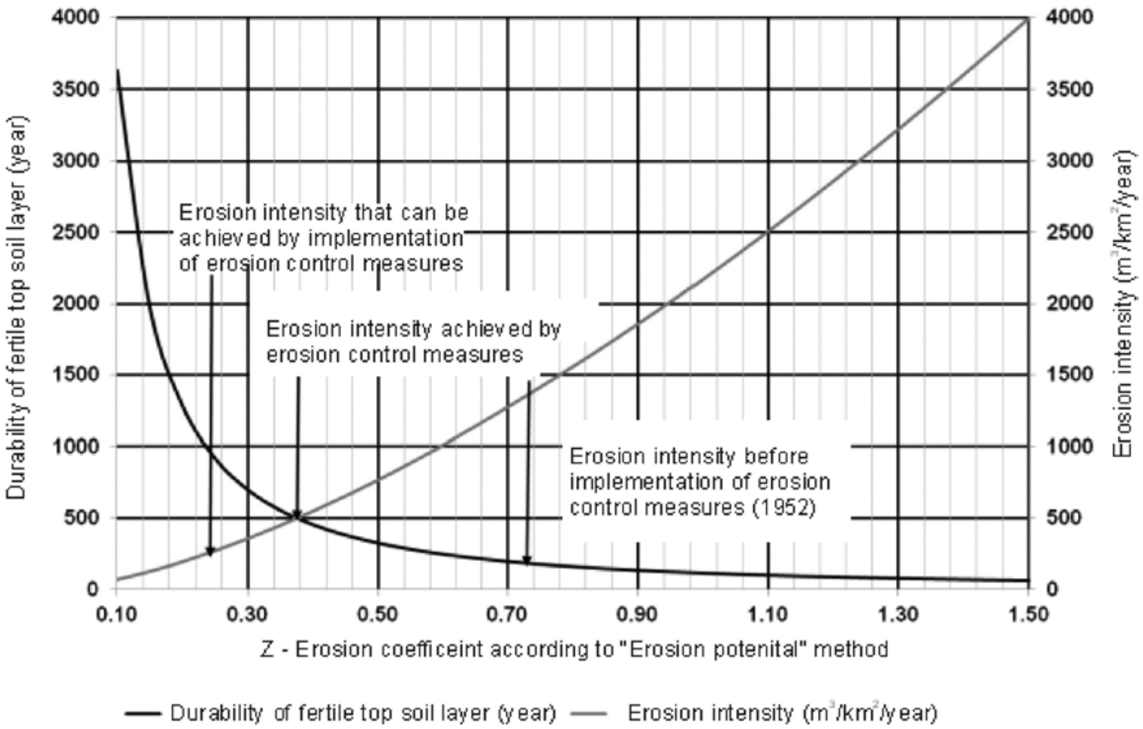

Figure 3: Dependence of top soil layer duration on erosion intensity.

Figure 3 shows the dependence of the duration of the top soil layer as a function of erosion intensity according to the Erosion potential method. The dependency is exponential and the shown values are average for Serbia. The arrows indicate three values. 1952 is when the implementation of the 1930 law began, which was interrupted by the war. At that time, the intensity of erosion was estimated to be such that the fertile soil layer was estimated to be swept away in two hundred years. Various works and anti-erosion measures have reduced the intensity of erosion so the fertile soil layer should remain for the estimated next five hundred years. The third marked point is the creation of an achievable level of erosion intensity reduction and the prolongation of the fertile soil layer for a thousand years. The dependence shown indicates that the fight against erosion in Serbia began under conditions of previously developed erosion processes and the appearance of large areas on which the erosion soil collapse occurred. For these areas, the term "erosion area" was defined, which for decades was understood as area destroyed by erosion. The problem arose when large eroded areas were afforested, turned into orchards or similar other purposes, which created a false belief that the erosion areas were gone. That the "erosion area" is a natural and inevitable feature became evident when eroded surfaces appeared in places where the protective vegetation cover was removed.

A methodology for the analytical determination of the “erosion area” has been developed as a part of the Erosion Potential Method, and it defines that “... an erosion area is an area where a change in land use changes the erosion category”.

Any change in land use causes an erosion intensity change. This change may not be great, but when the erosion intensity change is significant enough to change the erosion category, then the area is designated as an "erosion zone". It is important to note that this change may not always be in the direction of deterioration of the soil layer but also in the direction of improvement (Gavrilović 1998). The geoinformatic procedures reveal areas sensitive to changes in land use patterns. It is the only erosion factor that is variable and under the full control of humans. These are areas where such changes can either cause erosion soil collapse or prevent it.

Problems Encountered in Erosion Research

Erosion is caused by rainfall of varying intensities and durations. Between two rainfall episodes there is a dry period which can last from several hours to several months. Variability of the measured data is usually so high that it is impossible to draw conclusions, e.g. although the data shown in Figure 4 may seem confusing, this is quite normal (Gavrilović et al. 2008).

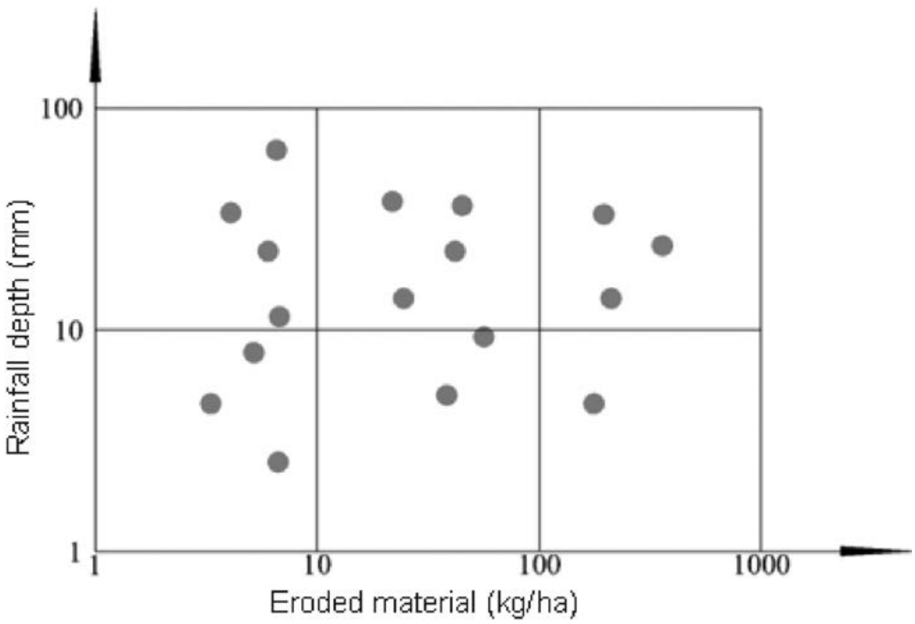

Figure 4: Scattering of data from experimental observations.

Specifically, during the dry season, temperature fluctuations affect the soil and soil erodibility increases. This process depends on several factors. For example, the first high intensity storm runoff following a longer dry period detaches these particles and transports them with the flow. A much higher intensity storm may occur on the following day but the natural erosion resistance of the soil prevents the direct erosion of larger amounts of soil particles.

In the case of the USLE method, Rain factor R is only one of five input variables. This factor depends solely on the characteristics of the rainfall observed. The other four factors has to be laboratory-determined and method defines procedures for their estimation. Data on observed rains are insufficient and therefore additional laboratory research is also needed (USDA).

Experimental Erosion Research

The aforementioned problems of analysis of data from experimental studies have imposed the need for experimental laboratory research where soil samples are exposed to different uniform artificial rains and controlled temperature regimes. In this way, a database is formed for the analysis and classification of data from experimental studies (Hudson 1973, Meyer and Harmon 1979, Holy 1980). Rain simulators of various characteristics have been constructed to produce artificial rain to which soil samples are subjected. During such investigations, the intensity of artificial rain gradually is increased until erosion of the soil sample occurs. Each type of soil has a different threshold for the appearance of visible erosion processes.

The described procedure illustrates a standard experimental method applied by US agencies. The task of these experiments is to determine the optimum rainfall intensity for irrigation systems in which no other irrigation system is possible, as well as to correct the observed losses in the test areas.

Rain Features That Cause Erosion and Soil Collapse

Erosion is a spatial phenomenon caused by rainfall that falls on the area of a few km² to continental proportions. Usual meteorological observations record daily rainfall in mm/day and intensity in mm/h or mm/min. Areas of individual parcels are expressed in acres, while areas of catchments, municipalities and states are expressed in km². Therefore all the rain data is converted to (l/s ha; l/s km²). Six characteristic rainfall intensities were shown in Table 1 for which the amounts of rainfall per second were calculated.

Table 1: Precipitation for various rain intensities.

No	Rainfall		
	mm/min	**mm/h**	**l/s km²**
1	0.25	15	4,167
2	0.50	30	8,333
3	0.75	45	12,500
4	1.00	60	16,667
5	1.25	75	20,833
6	1.50	90	25,000

For most calculations, data on the total rainfall is sufficient for selected intensities of 4-25 tonnes per second per km². The kinetic energy of the total rainfall impact can be calculated from the following equation:

$$E = mv^2 / 2$$

The total mass (volume) of the rainfall is measured at all meteorological stations, however rain droplet velocity is usually not measured and therefore is not known. Rain is an atmospheric phenomenon where water falls on the earth’s surface in the form of rain droplets that erode the soil with their kinetic energy. Rainfall is made up of water droplets of various sizes, some drops are so small that their impact is almost negligible, while large droplets may have significant impact energy. Therefore, it is impossible to calculate the impact energy of rain based only on the data of total rainfall (volume per area, or rain depth) from Table 1., because it lacks data on the rain droplet sizes and velocities at the impact to the soil surface.

This characteristic of rain is a serious problem for the study of erosion. Early research on raindrops was made in the 1930s when complex photometric equipment was used. The results of these studies have not been disputed to date, on the contrary, all new research with modern radar and laser equipment confirms the results of the research from eight decades ago. However, new research of rain droplet size distribution and velocities is not aimed at erosion research, but for different purposes (Laws 1941, Laws and Parsons 1943, Gunn and Kinzer 1949, Rosenfeld 1993).

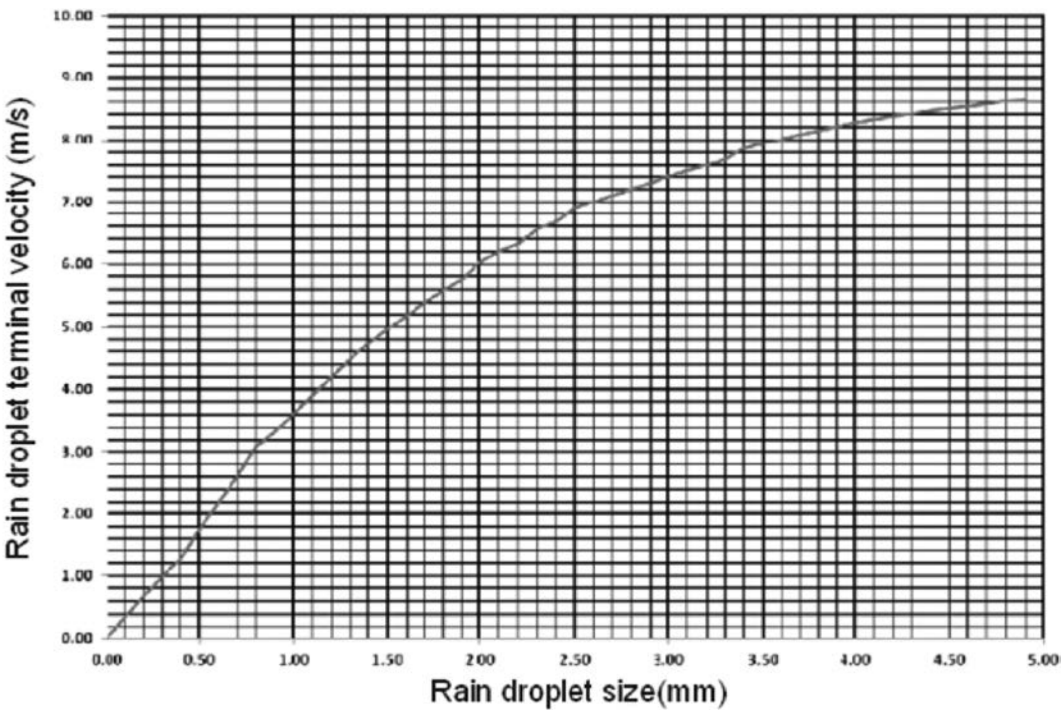

Figure 5: Terminal velocity as a function of rain droplet size.

From the moment rain droplets form in the clouds at a height ranging from several kilometres to several hundred meters above the ground, experience countless collisions, coalescence and divisions. For erosion research, terminal droplet velocity near ground level, is important. Investigations reveal that rain droplets reach their terminal velocity after only a few meters of fall. The smallest droplets are practically suspended in the air while the largest droplets with a diameter of 5 mm reach a terminal velocity of about 9 m/s. Figure 5 shows the dependence of terminal velocity and droplet size, which is confirmed by various research. Also, it is important to note that in every rain event there are various droplet sizes present.

An important element of research is the rain kinetic energy that hits the soil and causes erosion. To calculate this correctly, it is necessary to know droplet size distribution in the total rainfall event (Gavrilović 1966, 1968, 1970, 1972, Gavrilović et al. 2009). Rain droplet size distribution is an important consideration for aviation and space flights. The NASA-based Godard Institute is conducting various studies, including atmospheric phenomena. Figure 6 shows a variety of droplet sizes during rainfall events.

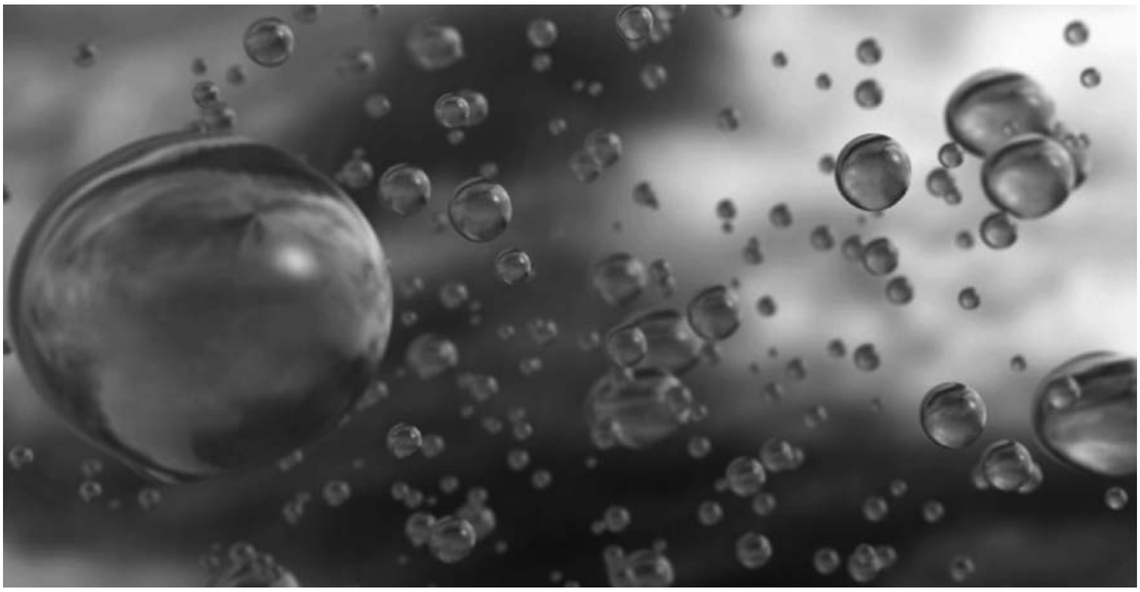

Figure 6: Diversity of rain droplet sizes (photo by NASA Godard Institute).

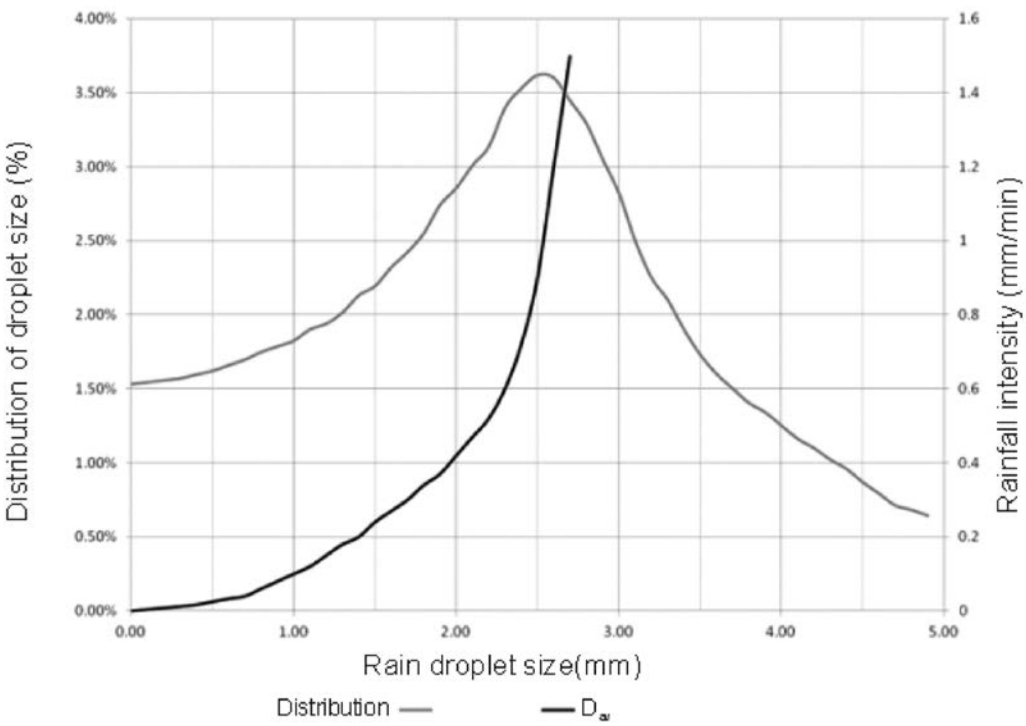

Figure 7: Distribution of droplet sizes in total rainfall and mean rainfall droplet diameter (Dav) vs. rainfall intensity.

It is a common misconception that raindrops are of the form known as the "droplet" because it is an aerodynamic form. Various studies show that raindrops are in shape of slightly flattened balls, and when they reach a diameter of about 2mm or more, a depression is created on the underside of the drop. Ran drops grow in size, because of collisions and merging (coalescing) with other droplets, up to a size of approx. 5 mm in diameter when they usually tend to break up into several smaller droplets. Rain droplets larger than 5 mm in diameter are not uncommon but there are very few in the total rainfall.

The presence of drops of various dimensions, as well as their mean diameter, depend on the intensity of the rain. Figure 7 shows distribution of rain droplet dimensions in the total rainfall of high intensity (about 1 mm/min), in 0.1 mm increments, for rain droplets sizes from 0 to 5 mm. For rainfall intensities in the range of 0.5 - 1.5 mm/min, the mean diameter of rain droplets is 2.2 - 2.7 mm. For these intensities, distribution of droplet sizes is approximate to that shown in Figure 7 (Laws 1941, Laws and Parsons 1943, Gunn and Kinzer 1949, Woodley 1970, Rosenfeld et al. 1993, Stefanović et al. 2015).

Each rain droplet contributes to the total rainfall. Rain intensities are usually expressed in mm/min or mm/h, and the cumulative rainfall is expressed in l/m² or in mm. However, this data is insufficient to calculate the energy of the rain that erodes the soil. Rain droplet velocities are unknown, as each rain event contains various droplet sizes which fall at different velocities. It is common approach for this calculation to use the terminal velocity of mean diameter of raindrops as a function of intensity. In such calculations data from previous research is used because equipment that measures raindrop size distribution and their velocities, although available for several decades, is still expensive.

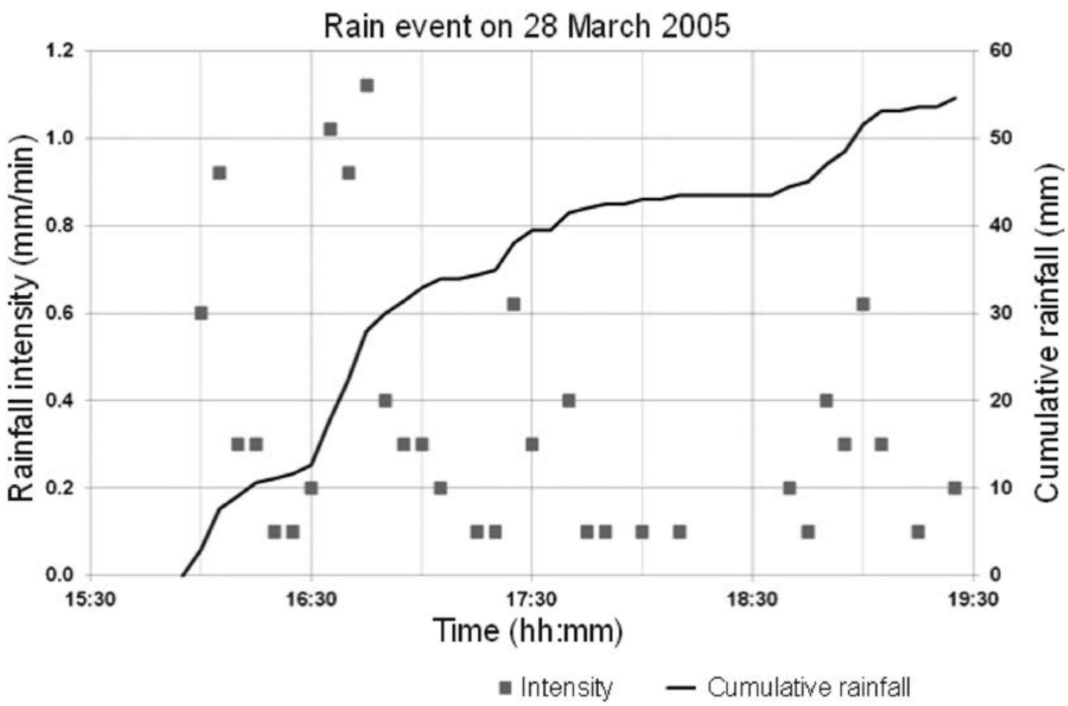

Figure 8: Pluviograph of heavy rain, observed on 28 March 2005 on the experimental catchment "Ripe".

As noted above, rains and especially heavy rains, which have a constant intensity during a rain event are extremely rare and practically not existent. Figure 8 shows the pluviograph of heavy rain observed on 28 March 2005 at the Ripe experimental catchment. Rain was monitored by an automatic weather station, which records five-minute values. The rain event lasted for a total of 210 minutes with interruptions, and the effective rain duration was 155 minutes. During that time, 54.6 mm of rain fell. Half of the total rain fell in 25 minutes and a quarter in 30 minutes. The last quarter of the rain had been falling for 100 minutes and that rain did not have enough energy for erosion processes. The shape of the shown pluviograph is common for heavy rainfall in the investigated area, and it is clear that without observing the rainfall intensity over time it is not possible to correctly estimate rain kinetic energy responsible for erosion. That is why in practice there are numerous methods for approximate calculations of rain kinetic energy (IJČ 2018).

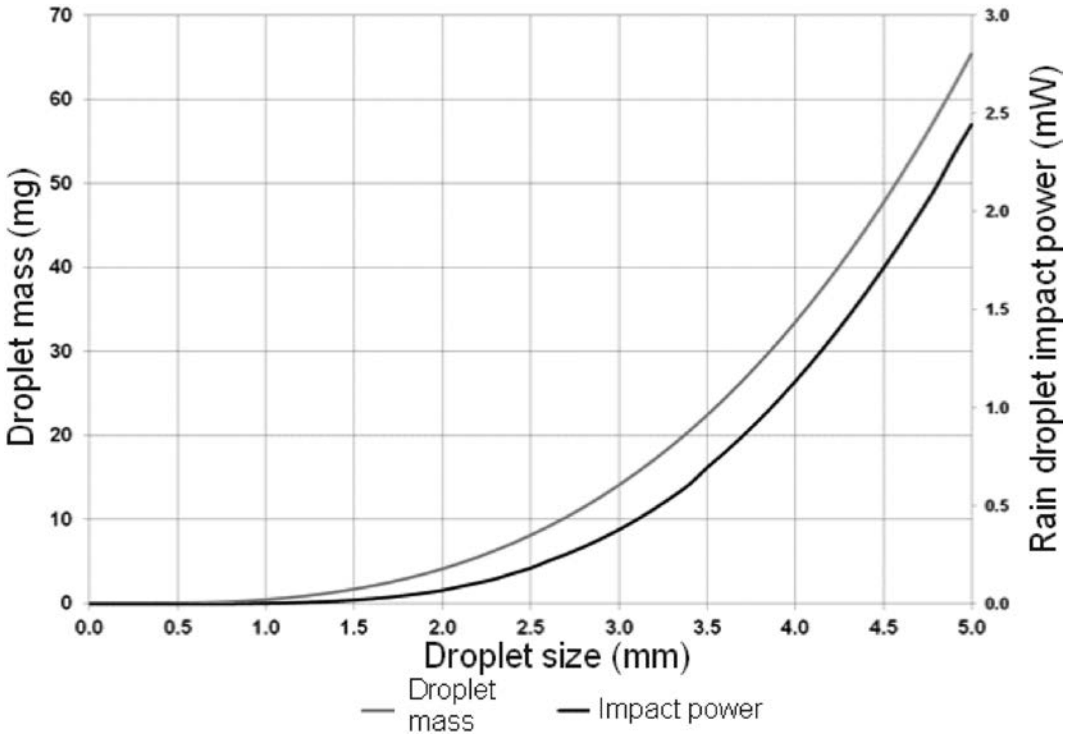

Figure 9: Mass and impact power of rain drops for 0-5 mm diameters.

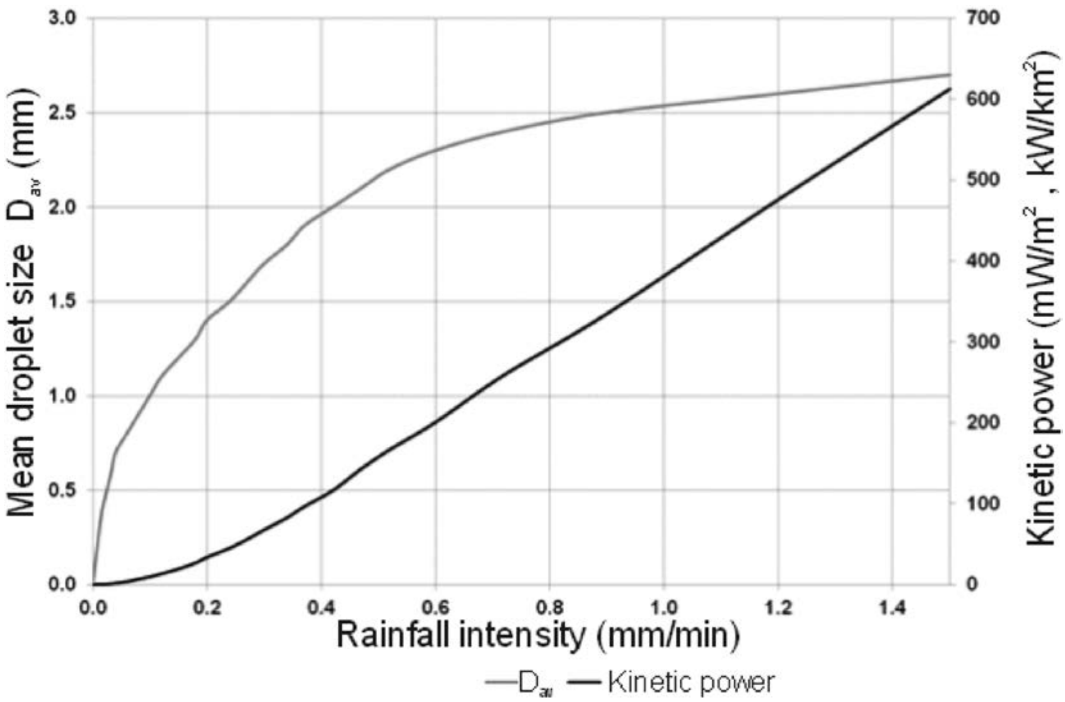

Figure 10: Mean droplet diameter and impact power as a function of rain intensity.

Figure 9 shows the values of droplet mass and the impact power for rain droplets 0 - 5mm in diameter. This is the maximal kinetic energy of individual droplets, provided that it has not collided with other droplets prior to reaching terminal velocity (Woodley 1970, Rosenfeld et al. 1993).

The only approximate method of calculating rain energy is based on the intensity of the rain and the corresponding mean diameter of the rain droplets, as shown in Figure 7. The impact energy of individual rain droplets is very small but there is an enormous number of them, each is a kind of projectile that hits the ground.

Figure 10 shows the dependence of the droplet mean diameter and the impact power as a function of rainfall intensity. Impact power is calculated for an area of 1 m² or 1 km². The total energy of rain depends on the intensity and duration of the rain.

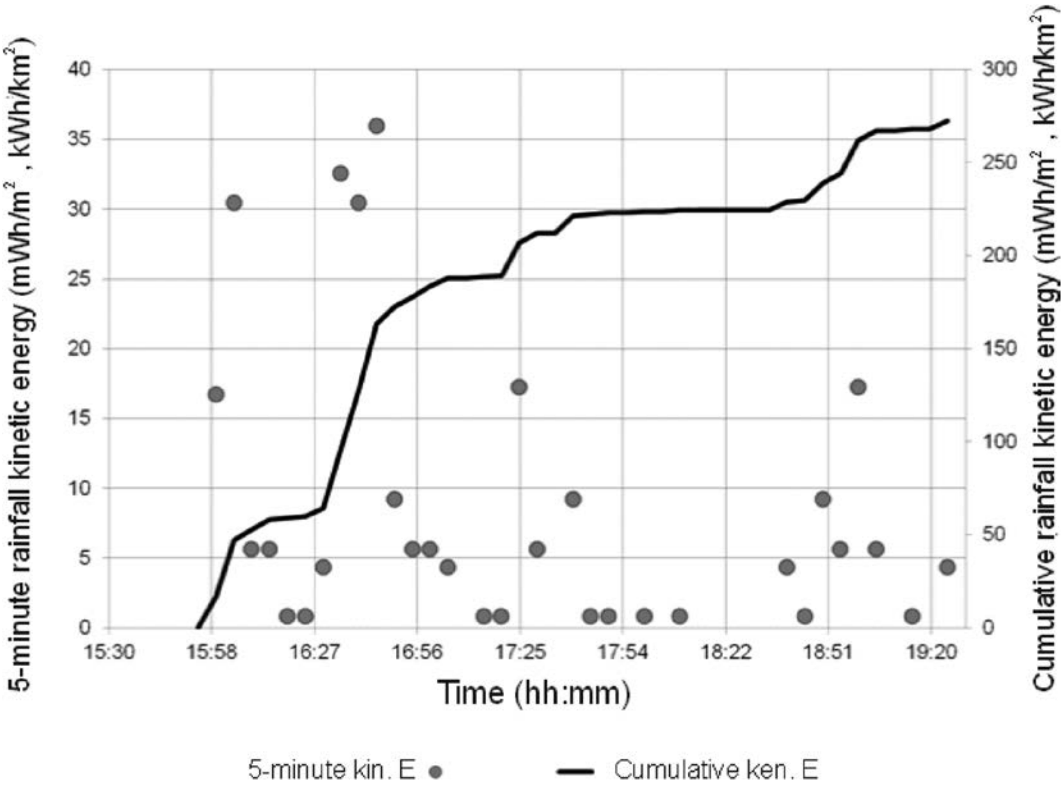

Figure 11: Total rain energy, rainfall recorded on 28 March 2005, Ripe experimental catchment.

In the rainfall example recorded on 28-03-2005, a calculation of the total kinetic energy at which rain-induced soil erosion occurred, was made and shown in Figure 11. Energy of the whole rainfall is calculated in 5-minute increments as rain intensities were recorded in same time intervals. Such a calculation is common in calculating the rainfall kinetic energy that is delivered to the ground. The data presented do not allow for a determination of soil collapse due to erosion because each interval of recorded rain has different characteristics.

This is why rain simulators were introduced in erosion research, which allowed for the investigation of the erosion phenomenon from rain of uniform intensity. Rain simulators have made it possible to clarify the relationship between rain intensity and soil loss, which is the task of the USLE method. Results of these experiments lead to the determination of rainfall intensities that caused erosion to occur, but failed to determine the conditions of the occurrences of the erosion-induced soil collapse. Rain simulators are essential to determine the optimum intensity and duration of artificial rain for irrigation. For erosion research, they provide reliable results for low to medium erosion intensities, but with increases in erosion intensities, results from simulators start to significantly deviate from the observed values (Meyer 1979, Holy 1980, Gavrilović 1990). After numerous research efforts, it has been discovered that this discrepancy is caused by the fact that the rainfall simulator creates rain similar to that of natural rain, in which rainfall of all dimensions is consistent with the intensity of the rain. While this may seem unimportant, during each rain event a large number of raindrops of different sizes, velocity and impact energy fall to the ground. The soil surface is not flat and smooth but rather uneven, so small-sized droplets often hit one of countless slopes or fall into cracks, which adsorb kinetic energy without the eroding effect. Only drops of larger diameters can have an erosion effect because they have a high velocity and with their dimension overcome the cracks and unevenness of the soil (Gavrilović 1990).

Figure 12: Photo of a “crater” from a larger rain drop - Photo Z. Gavrilović.

Figure 12 shows an enlarged detail of the soil during rain. A rounded crater formed from a larger rain droplet (4-6 mm). A typical uneven surface of the soil is visible on which traces of impact from other drops as well as micro depressions are filled with water. To the right of the marked "crater" are several light drops of various dimensions just before the impact on the water surface. They do not produce any erosion effect. The photograph shown in Figure 12 was selected from a large number of images taken at a rate of 200 frames per second, which is the lower limit for usable photographs in erosion research.

Demolition of Land Aggregates and Erosion Soil Collapse

After extensive research, it was concluded that it is desirable for laboratory experiments to generate artificial rain in which most of the rain droplets are approximately the same size. The generator of such characteristics was constructed at the Jaroslav Černi Institute, Belgrade, for developing the Erosion Potential Method. Introduction of rainfall with uniform droplet sizes enabled advances in erosion research (Gavrilović 1968, 1970, Tokay and Short 1996).

Samples of various soils were "bombarded" by rain droplets of various sizes and intensities. The results of these studies have enabled the development and improvement of the Erosion Potential Method, which, since then, has been improved several times and new modules have been added. In 1998, a method for determining "erosion areas" was developed, which is still the standard method for this task. It is a natural and inherent characteristic of the soil, independent of the current erosion intensity (Gavrilović and Stefanović 1998).

During the development of the method, engineering practice needs were identified and the development was prioritized. At that time further studies of soil collapse due to erosion were neglected because there was a wide spread belief that just determination of "erosion area" had been sufficient to combat erosion. However, this is not true because knowledge and understanding of the conditions of occurrence of soil collapse due to erosion is the basis for a more precise determination of the "erosion area".

Tests of Demolition of Land Aggregates

Testing of the soil aggregate destruction was performed by preparing batches of non-disturbed soil samples that have been exposed to rainfalls of various intensities and droplet sizes from the rainfall simulator. Soil samples were collected in cylinders 10 cm high. The sample batches were arranged so that there was no possibility of interference between the samples (Gavrilović 1968). The duration of rainfall was measured, and the time at which artificial rain destroyed 25%, 50%, 75% and 100% of samples was recorded. Many of the samples were completely eroded during the experiments, but there were samples where erosion ceased at 75%, 50% and 25%, even after artificial rain continued.

In this paper, the results of an experiments performed with three dimensions of raindrops and rainfall intensities are shown. Investigations reveal that rain intensities below 0.5 mm/min do not cause any noticeable erosion, due to relatively small rain droplets. Erosion occurred when rain intensity became greater than 0.5 mm/min, and rain droplets were larger than 1.2 mm. Droplets of 4.75 mm and 6.20 mm were used in experiments, with intensities of 1 - 1.45 mm/min. The summary of investigation results are shown in Table 2. The data are sorted according to the time required for soil aggregate destruction.

Experimental results showed that soil samples, especially arable land, showed erosion resistance. Namely, most of the samples withstood heavy rain during which 50% of the samples were destroyed during a relatively short period after which erosion slowed significantly or stopped. Subsequent testing found that the land adhesives remained undisturbed in samples.

In samples from the same soil type and plant culture, where the samples were completely destroyed, a lack of soil adhesives was observed.

The analyses so far have observed the relationship between rainfall intensity, droplet size and time intervals needed for destruction of samples (Gavrilović 1968, 1970, Gavrilovic et al. 2009). Addtionally, in Table 2 the value of rain kinetic energy was also presented. The results show that the highest percentage of samples was destroyed with relatively low energy rainfall.

Dense vegetation (grass, shrubs and forest) has shown a significant effect on erosion. The total energy needed to achieve the same percentage of sample destruction was approximately ten times greater than that of arable land, and these longer sample degradation times were recorded as well.

Table 2: Results of the soil aggregate destruction experiment with different dimensions and intensities of rainfall.

No	Soil Type	Plant culture	Rainfall			Rainfall Kinetic Energy		Degree of degradation %
			Intensity (mm/min)	Droplet size (mm)	Duration (hh:mm)	per second (mWh/m²)	Total (mWh/m²)	
1	Podzol	Plowland Wheat	1.01	6.20	0:20	0.168	202	50%
2	Podzol	Plowland Wheat	1.01	6.20	0:22	0.168	222	50%
3	Degraded Vertisol	Plowland Wheat	1.01	6.20	0:26	0.168	262	50%
4	Podzol	Plowland Wheat	1.01	6.20	0:26	0.168	262	50%
5	Degraded Cambisol	Pasture	1.45	4.75	0:28	0.245	412	50%
6	Degraded Vertisol	Plowland Wheat	1.01	6.20	0:30	0.168	303	50%
7	Degraded Cambisol	Plowland Corn	1.01	6.20	0:32	0.168	323	50%
8	Degraded Cambisol	Plowland Corn	1.01	6.20	0:34	0.168	343	50%
9	Degraded Cambisol	Plowland Corn	1.01	6.20	0:35	0.168	353	50%
10	Degraded Vertisol	Plowland Wheat	1.01	6.20	0:36	0.168	363	50%
11	Podzol	Meadow with gullies	1.45	4.75	0:51	0.245	751	50%
13	Degraded Cambisol	Pasture	1.45	4.75	0:53	0.245	780	50%
12	Podzol	Plowland Corn	1.00	4.75	0:53	0.169	538	75%
14	Podzol	Grassland landslide	1.00	4.75	0:53	0.169	538	100%
15	Podzol	Meadow with gullies	1.45	4.75	0:56	0.245	824	50%
16	Podzol	Grassland landslide	1.00	4.75	0:56	0.169	569	100%
17	Podzol	Plowland Corn	1.00	4.75	0:57	0.169	579	75%
18	Degraded Cambisol	Pasture	1.45	4.75	1:00	0.245	883	50%
19	Podzol	Meadow with gullies	1.45	4.75	1:02	0.245	913	50%
20	Podzol	Plowland Corn	1.00	4.75	1:03	0.169	640	75%
21	Podzol	Forest oak	1.00	4.75	1:03	0.169	640	75%
22	Podzol	Grassland landslide	1.00	4.75	1:06	0.169	670	100%
23	Podzol	Plowland Wheat	1.00	4.75	1:11	0.169	721	100%
24	Podzol	Acacia forest	1.00	4.75	1:18	0.169	792	75%
25	Podzol	Forest oak	1.00	4.75	1:18	0.169	792	75%
26	Podzol	Common grassland	1.01	6.20	1:21	0.168	817	50%
27	Podzol	Common grassland in soifluction	1.45	4.75	1:21	0.245	1,192	100%
28	Podzol	Forest oak	1.00	4.75	1:26	0.169	873	75%
29	Podzol	Plowland Wheat	1.00	4.75	1:26	0.169	873	100%
31	Podzol	Common grassland	1.01	6.20	1:28	0.168	888	50%
30	Podzol	Acacia forest	1.00	4.75	1:28	0.169	893	75%
33	Podzol	Common grassland in soiflution	1.45	4.75	1:32	0.245	1,354	50%
32	Podzol	Plowland Wheat	1.00	4.75	1:32	0.169	934	100%
34	Podzol	Common grassland in soiflution	1.45	4.75	1:33	0.245	1,369	100%
35	Podzol	Acacia forest	1.00	4.75	1:36	0.169	975	75%
36	Cambisol in podzolification	Orchard	1.00	4.75	1:42	0.169	1,036	100%
37	Cambisol in podzolification	Orchard	1.00	4.75	1:42	0.169	1,036	100%
38	Cambisol in podzolification	Orchard	1.00	4.75	1:49	0.169	1,107	100%
39	Podzol	Common grassland	1.01	6.20	1:51	0.168	1,120	50%
40	Podzol	Meadow	1.00	4.75	1:53	0.169	1,147	75%
41	Diluvium sediment	Vineyard	0.98	4.75	1:57	0.166	1,164	100%
42	Cambisol	Plowland	0.51	1.20	2:00	0.018	129	50%
43	Podzol	Meadow	1.00	4.75	2:11	0.169	1,330	75%
44	Podzol	Plowland Wheat	1.00	4.75	2:11	0.169	1,330	100%
45	Recent sediments	Weeds and nettle	0.98	4.75	2:13	0.166	1,323	100%
46	Podzol	Plowland Wheat	1.00	4.75	2:13	0.169	1,350	100%
47	Diluvium sediment	Vineyard	0.98	4.75	2:14	0.166	1,333	100%
48	Recent sediments	Weeds and nettle	0.98	4.75	2:18	0.166	1,373	100%
49	Podzol	Meadow	1.00	4.75	2:20	0.169	1,421	75%
50	Podzolificated Cambisol	Vineyard	0.98	4.75	2:21	0.166	1,403	75%
51	Diluvium sediment	Vineyard	0.98	4.75	2:22	0.166	1,413	100%

No	Soil Type	Plant culture	Rainfall			Rainfall Kinetic Energy		Degree of degradation %
			Intensity (mm/min)	Droplet size (mm)	Duration (hh:mm)	per second (mWh/m²)	Total (mWh/m²)	
52	Podzolificated Cambisol	Vineyard	0.98	4.75	2:25	0.166	1,443	75%
53	Cambisol	Plowland	0.51	1.20	2:27	0.018	158	50%
54	Podzol	Plowland Wheat	1.00	4.75	2:32	0.169	1,543	100%
55	Cambisol in podzolification	Meadow	0.98	4.75	2:36	0.166	1,552	25%
56	Podzolificated Cambisol	Vineyard	0.98	4.75	2:37	0.166	1,562	75%
57	Cambisol	Plowland	0.51	1.20	2:46	0.018	179	50%
58	Podzol	Dense shrubbery	0.98	4.75	2:51	0.166	1,701	50%
59	Podzol	Dense shrubbery	0.98	4.75	2:52	0.166	1,711	50%
60	Cambisol in podzolification	Meadow	0.98	4.75	2:53	0.166	1,721	25%
61	Podzolificated Cambisol	Vineyard	0.98	4.75	2:55	0.166	1,741	100%
62	Podzolificated Cambisol	Vineyard	0.98	4.75	2:58	0.166	1,771	100%
63	Podzol	Shrubbery	0.98	4.75	2:59	0.166	1,781	25%
64	Podzolificated Cambisol	Vineyard	0.98	4.75	3:07	0.166	1,861	100%
65	Podzol	Shrubbery	0.98	4.75	3:17	0.166	1,960	25%
66	Recent sediments	Weeds and nettle	0.98	4.75	3:20	0.166	1,990	100%
67	Cambisol in podzolification	Meadow	0.98	4.75	3:25	0.166	2,040	25%
68	Podzolificated Cambisol	Meadow	0.51	1.20	3:47	0.018	245	50%
69	Recent sediments	Willow grove	0.98	4.75	3:50	0.166	2,289	50%
70	Cambisol	Forest	0.51	1.20	3:53	0.018	251	50%
71	Podzolificated Cambisol	Meadow	0.51	1.20	4:11	0.018	270	50%
72	Podzolificated Cambisol	Meadow	0.51	1.20	4:19	0.018	279	50%
73	Recent sediments	Willow grove	0.98	4.75	4:37	0.166	2,756	50%
74	Recent sediments	Willow grove	0.98	4.75	4:37	0.166	2,756	50%
75	Cambisol	Forest	0.51	1.20	4:52	0.018	315	50%
76	Cambisol	Forest	0.51	1.20	5:21	0.018	346	50%
77	Cambisol	Clover	0.51	1.20	6:53	0.018	445	50%
78	Cambisol	Clover	0.51	1.20	8:10	0.018	528	50%
79	Cambisol	Clover	0.51	1.20	8:13	0.018	531	50%

Conclusion

Soil erosion is a phenomenon that occurs suddenly when long-term erosion damages an organic - mineral matter of the soil called soil adhesives. The presented data indicate that only by preserving the vegetation cover and soil cultivation can the development of erosion be prevented in turn preventing the occurrence of erosion soil collapse. Soil collapse due to erosion requires further research because new insights can contribute to the prevention or decrease of this harmful phenomenon.

It is necessary to focus research and innovations on the development of new equipment for experimental research because the existing equipment and methods was developed decades ago and since than modernization was reduced only to digital acquisition and data processing. Without technological advances in measuring equipment, it will not be possible to detect phenomena and processes that are inaccessible to the equipment currently in use. This will help the necessary advancement of scientific knowledge of erosion processes and their more precise determination, erosion classification and identification of erosion-prone areas.

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