

I. Lesson Title: WATER EROSION

II. Overview:

Water erosion is the wearing away of the soil surface by water from rain, runoff, snowmelt, and irrigation. Rainwater in the form of runoff is the main driver of water erosion. It refers to the movement of soil organic and inorganic particles along the soil surface with flowing water and deposition of the eroded materials at lower landscape positions and in aquatic ecosystems. The eroded material can either form a new soil or simply fill lakes, reservoirs, and streams. Water erosion occurs in all soils to varying degrees. Slight erosion is actually beneficial to the formation of soil but severe or accelerated erosion adversely affects soil and environment. Understanding the mechanisms and magnitude of water erosion is vital to manage and develop erosion control practices.

III. Specific Outcomes: At the end of this module, the students can

1. discuss erosion, its causes and its impact.
2. discuss the factors affecting erosion by water
3. differentiate the types of water erosion.
4. estimate soil losses using USLE and RUSLE.

IV. Materials Needed: Handouts, blackboard, LCD/LED monitor, computer/laptop

V. Duration: 360 minutes

VI. Lesson Content:

Erosion is the wearing away of land. It is also defined as detachment, transportation and deposition of soil particles. Erosion reduces the productivity of agricultural land, and the resulting sediment causes stream pollution and reduces the capacity of reservoirs. Natural agents such as water, wind and gravity are eroding the land surface since geologic times.

Classification of erosion

- Accelerated erosion - soil erosion caused by man's activities, such as tillage and construction. Disturbances due to human or animal influences can reduce vegetative cover and compact soil.
- Geological erosion, which occurs where soil exists in its natural environment under native vegetation, is important to agriculture because it includes soil-forming processes as well as eroding processes.

Major causes of soil erosion and hydrological imbalance in the Philippines

- shifting cultivation
- logging
- grazing
- mining
- road construction.

EROSION BY WATER

Water erosion is the detachment and transport of soil from the land by water, including runoff from melted snow and ice. Water erosion is accelerated by farming, forestry, and construction activities.

Factors Affecting Erosion by Water

- Climatic factors
 - Precipitation - rainfall amount, intensity, and energy all impact erosion rates. Erosion may also be affected by raindrop energy, drop diameter, and runoff rates.
 - Temperature – has effect on evaporation and transpiration.
 - Wind – same with temperature that has effects on evaporation and transpiration, it changes raindrop velocities and the angle of impact
 - Humidity – it is associated with temperature and rate of soil water depletion
 - solar radiation – same with the effect of humidity
- Physical properties of soil
 - soil detachability – increases as the size of the soil particles or aggregates increase
 - soil transportability – increases with a decrease in the particle or aggregate size.

Clay particles are more difficult to detach than sand, but clay is more easily transported. The properties that influence erosion include soil structure, texture, organic matter, water content, clay mineralogy, and density, as well as chemical and biological characteristics of the soil. In nonagricultural soils, the type and amount of vegetation or disturbance can also influence erodibility. No single soil characteristic or index has been identified as a satisfactory means of predicting erodibility.

- Vegetative influences

The major effects of vegetation in reducing erosion are

- (1) interception of rainfall – by absorbing the energy of the raindrops on plant canopy and surface residue, reducing surface sealing and runoff
- (2) retardation of erosion - by resisting erosive forces
- (3) physical restraint of soil movement
- (4) improvement of aggregation and porosity of the soil – by roots and plant residues
- (5) increased biological activity in soil
- (6) transpiration - decreases soil water, resulting in increased storage capacity and less runoff

Any practice that maintains a residue cover on the soil surface decreases erosion potential, while any practice that removes, burns, or buries vegetative residue increases the potential for soil erosion.

- Topographic features
 - Slope length – longer slopes can increase accumulation of overland flow which tends to increase concentrated flow erosion
 - Slope steepness – soil in steep slopes is more easily detached and transported downslope

- Shape - including concave, uniform, or convex. Concave slopes, with flatter slopes at the foot of the hill, deliver less sediment than convex slopes

Raindrop Erosion

Raindrop erosion is soil detachment and transport resulting from the impact of water drops directly on soil particles or on thin water surfaces. The relationship between erosion, rainfall momentum, and energy is determined by raindrop mass, size distribution, shape, velocity, and direction. Factors affecting the direction and distance of soil splash are slope, wind, surface condition, and impediments to splash such as vegetative cover and mulches.

Raindrop impact on bare soil not only causes splash but also breaks down soil aggregates and causes deterioration of soil structure. This leads to increased surface sealing, runoff, and erosion.

Sheet Erosion

Sheet erosion is the removal of thin layers of soil over the whole soil surface. Raindrop splash and surface flow cause sheet erosion, with splash providing most of the detaching energy and flow providing most of the transporting capacity. Sheet erosion is insidious because it is difficult to see. It is apparent on upper portions of convex slopes.

- The signs of sheet erosion are:
 - only a thin layer of topsoil; or the subsoil is partly exposed; sometimes even parent rock is exposed;
 - quite large amounts of coarse sand, gravel and pebbles in the arable layer, the finer material has been removed;
 - exposure of the roots;
 - deposit of eroded material at the foot of the slope.

The beating action of raindrops combined with surface flow causes initial rilling. Raindrops detach the soil particles, and the detached sediment can reduce the infiltration rate by sealing the soil pores. The eroding and transporting ability of overland flow depends on the rainfall intensity, infiltration rate, slope steepness, soil properties, and vegetative cover.

Interrill Erosion

Interrill erosion is a combined splash and sheet erosion. The relationship among interrill erosion to be a function of soil properties, rainfall intensity, and slope is generally expressed as

$$D_i = K_i i q S_f C_v \quad (7.1)$$

where D_i = interrill erosion rate in kg/m²-s,
 K_i = interrill erodibility of soil in kg-s/m⁴,
 i = rainfall intensity in m/s,
 q = runoff rate(m/s)
 S_f = interrill slope factor = $1.05 - 0.85 \exp^{-4 \sin \theta}$
 C_v = cover adjustment factor, including effects of soil surface cover, canopy cover, root characteristics and/or sealing and crusting, with values from near zero to 1.0,
 θ = slope in degrees.

Rill Erosion

Rill erosion is the detachment and transport of soil by a concentrated flow of water. Rills are small enough to be removed by normal tillage operation. Rill erosion is the predominant form of erosion under most conditions. It is the most serious where intense storms occur on soil with high-runoff-producing characteristics and highly erodible topsoil.

Rill erosion is a function of the hydraulic shear τ of the water flowing in the rill, and two soil properties, the rill erodibility K_r and the critical shear τ_c , the shear below which soil detachment is negligible. Detachment rate D_r is the erosion rate occurring beneath the submerged area of the rill. The relationship among these variables is

$$D_r = K_r(\tau - \tau_c) \left(1 - \frac{Q_s}{T_c}\right) \quad (7.2)$$

where D_r = rill detachment rate in kg/m²-s,
 K_r = rill erodibility resulting from shear in s/m,
 τ_c = critical shear below which no erosion occurs in Pa,
 Q_s = rate of sediment flow in the rill in kg/m-s,
 T_c = sediment transport capacity of rill in kg/m-s,

$$T_c = B \tau^{1.5} \quad (7.3)$$

τ = hydraulic shear of flowing water in Pa

$$\tau = \gamma r s, \quad (7.4)$$

where B = a transport coefficient based on soil and water properties generally between 0.01 and 0.1 (dimensionless),
 γ = specific weight of water in kg/m³,
 r = hydraulic radius of rill in m,
 s = hydraulic gradient of rill flow

Example 7.1

Determine the rill erodibility (K_r) from the following observations:

observed runoff rate = 1.0 L/s
 sediment concentration in runoff = 0.12 kg/L
 rill length = 20 m
 width = 0.15 m
 gradient (S) = 0.07
 hydraulic radius (R) = 0.01 m
 soil transport coefficient (B) = 0.1 kg Pa^{-1.5}
 soil critical shear (τ_c) = 2 Pa

Solution:

sediment delivery = runoff $\times$ concentration = 1.0 $\times$ 0.12 = 0.12 kg/s
 Q_s = sediment delivery/rill width = 0.12/0.15 = 0.8 kg/m-s
 D_r = sediment delivery/(rill length) = 0.8/20 = 0.04 kg/m²-s
 τ = 9810 $\times$ 0.01 $\times$ 0.07 = 6.87 Pa
 T_c = $B \tau^{1.5}$ = 0.1 (6.87)^{1.5} = 1.80 kg/m-s

$$K_r = \frac{D_r}{(\tau - \tau_c) \left(1 - \frac{Q_s}{T_c}\right)} = \frac{0.04}{[(6.87 - 2) \left(1 - \frac{0.8}{1.8}\right)]} = 0.015 \text{ s/m}$$

Gully Erosion

Gully erosion is defined as the removal of soil by a concentrated water flow, large enough to form channels or gullies. These gullies carry water during heavy rain or irrigation and gradually become wider and deeper. Gully erosion produces channels larger than rills. These channels carry water during and immediately after rain, and, as distinguished from rills, gullies cannot be obliterated by tillage. Gully erosion generally occurs in intermittent streams near the upper ends of headwater tributaries.

The rate of gully erosion depends primarily on the runoff-producing characteristics of the watershed; the drainage area; soil characteristics; the alignment, size, and shape of the gully; and the slope in the channel. A gully develops by processes that may take place either simultaneously or during different periods of its growth. These processes are (1) waterfall erosion or head-cutting at the gully head, (2) erosion caused by water flowing through the gully or by raindrop splash on exposed gully sides, (3) alternate freezing and thawing of the exposed soil banks, and (4) slides or mass movement (sloughing) of soil into the gully. Runoff then removes loose soil from the gully floor.

Stream Channel Erosion

Stream channel erosion consists soil removal from stream banks or soil movements in the channel. Stream channel applies to the lower end of a headwater tributaries and to streams that have nearly continuous flow relatively flat gradients, whereas. Stream bank erodes either by runoff flowing over the side of the stream bank erosion or by scouring and undercutting below the water surface.

Stream bank erosion, less serious than scour erosion, is often increased by the removal of vegetation, overgrazing, tilling too near the banks, or straightening of the channel. *Scour erosion* is influenced by velocity and direction of flow, depth and width of the channel, and soil texture. Poor alignment and the presence of obstructions such as sandbars increase meandering the major cause of erosion along the bank.

SOIL LOSSES

Soil losses vary considerably with the erosion factors. The importance of soil losses is indicated by the effect of erosion phase on crop yield. On eroded soils, the decrease in yield is due to less water available to the plant. On some soils, these crop yield decreases can be largely overcome by higher fertilization levels. For shallow soils on sloping terrain, erosion may completely destroy productivity if appropriate conservation practices are not initiated

Offsite impacts of eroded sediment can alter channel shapes and alignment, increasing the frequency and severity of flooding, shortens the useful lives reservoirs, increases maintenance costs in irrigation ditches carry undesirable pollutants such as phosphates which alter downstream nutrient balances, or pesticides, which can have a wide range of adverse impacts on plants, animals, and humans.

A method of estimating losses based on statistical analyses of field plot data from small plots located in many states (Figure 7.2) was developed, resulting in the Universal Soil Loss Equation (USLE). A revised version of the USLE (RUSLE) was later developed as a computer application. The RUSLE2 is an enhanced version of RUSLE that runs on a Windows platform. Scientists have been developing process-based computer models, the Water Erosion Prediction

Project (WEPP) which estimate soil loss by considering the processes of infiltration, runoff, detachment, transport, and deposition of sediment.

Predicting Upland Erosion

Most recent erosion prediction methods, such as RUSLE and the WEPP model, are computer based, and for some applications, can be run over the Internet. To demonstrate erosion prediction principles, this chapter will present the USLE technology in SI units.

The average annual soil loss can be estimated from the equation

$$A = RKLSCP \quad (7.5)$$

where A = average annual soil loss in Mg/ha,
 R = rainfall and runoff erosivity index for geographic location
 K = soil erodibility factor (Eq. 7.6),
 L = slope length factor (Eq. 7.7),
 S = slope steepness factor (Eq. 7.8),
 C = cover management factor (Table 7.1),
 P = conservation practice factor (Eq. 7.9).

A nomograph to estimate K for a given soil on which it is not known can be calculated from the regression equation

$$K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3) \quad (7.6)$$

where M = particle size parameter (% silt + % very fine sand) $\times$ (100-% clay),
 a = percent organic matter,
 b = soil structure code (very fine granular, 1; fine granular, 2; medium or coarse granular, 3; block, platy or massive, 4)
 c = profile permeability class (rapid, 1; moderate to rapid, 2; moderate, 3; slow to moderate, 4; slow, 5; very slow, 6).

The topographic factors, L and S can be calculated from the equations

$$L = \left(\frac{l}{22} \right)^m \quad (7.7a)$$

where L = slope length factor,
 l = slope length in m,
 m = dimensionless exponent.

m could be found from the equation

$$m = \frac{\sin \theta}{\sin \theta + 0.269(\sin \theta)^{-0.8} + 0.05} \quad (7.7b)$$

where θ = field slope steepness in degrees = $\tan^{-1}\left(\frac{s}{100}\right)$,
and where s = field slope in percent.

For conditions where rill erosion is greater than interrill erosion (like soils with a large silt or fine sand content), *m* should be increased up to 75 percent; where rill erosion id less than interrill erosion (on short slopes or high-clay content soils), *m* should be decreased down to 50 percent.

For slopes shorter than 4 m,

$$S = 3.0 (\sin \theta)^{0.8} + 0.56 \tag{7.8a}$$

For slopes longer than 4 m and *s* < 9 percent,

$$S = 10.8 \sin \theta + 0.03 \tag{7.8b}$$

For slopes longer than 4 m and *s* ≥ 9 percent,

$$S = 16.8 \sin \theta - 0.50 \tag{7.8c}$$

The cover management C-factor includes the effects of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management, and the expected time distribution of erosive events.

Table 7.1 Typical C-Factors for a Number of Land Cover conditions

Vegetation	Tillage Practice		
	Conventional	Conservation	No-Till
Continuous corn or soybeans	0.36	0.27	0.10
Corn and soybean rotation	0.35	0.24	0.10
Corn-corn-oats-meadow	0.12	0.11	0.07
Corn-oats-meadow-meadow	0.05	0.03	0.03
Permanent pasture (good)			0.01
Permanent pasture (poor)			0.04
Winter wheat-fallow	0.20	0.17	0.04
Spring barley	0.06	0.02	
Wheat-barley-fallow rotation	0.21	0.13	0.02
Winter wheat and pea rotation	0.11	0.02	
Cotton	0.40	0.30	
Peanuts–use soybeans			
Sorghum–use corn			
Non Agricultural	Good	Poor	
Rangeland	0.01	0.15	
Forest	0.001	0.002	
Forest after fire	0.01	0.15	
Unpaved road	0.35	0.45	
Construction Site	0.50	1.00	

* These values are for example only.

The conservation practice *P* can be found from the equation

$$P = P_c \times P_s \times P_t \tag{7.9}$$

where *P_t* = contouring factor based on slope (Table 5.3),
P_s = strip cropping factor for crop strip widths recommended in Table 5.3
 (1.0 for contouring only or for alternating strips of corn and small

grain, 0.75 for 4 year rotation with 2 years of row crop, and 0.50 with 1 year of row crop),

P_t = terrace sedimentation factor (1.0 for no terrace, 0.2 for terraces with graded channel sod outlets, and 0.1 for terraces with underground outlets).

The P-factor is likely to be the least reliable of all the USLE factors, as the impacts of conservation practices vary with climate, soils, vegetation, and topography of the field, contoured rows, and terrace channels. RUSLE2 incorporates more complex topographic and climatic considerations and calculates the P-factor internally. The WEPP model addresses contouring through a management input, and informs the user when contour ridges overtop.

Example 7.2

Determine the soil loss for the following conditions: $R = 5000$ as the erosion index; $K = 0.058$; $l = 50$ m; $s = 5\%$; $C = 0.14$ (approximate for corn-corn-oats-meadow rotation with good management); and the field has no conservation practices ($P = 1$).

Solution:

The slope angle in degrees:

$$\theta = \tan^{-1}(0.05) = 2.86^\circ$$

The dimensionless exponent:

$$\begin{aligned} m &= \frac{\sin \theta}{\sin \theta + 0.269(\sin \theta)^{-0.8} + 0.05} \\ &= \frac{\sin (2.86)}{\sin (2.86) + 0.269 [\sin(2.86)]^{-0.8} + 0.05} \\ &= 0.40 \end{aligned}$$

The L-factor:

$$L = \left(\frac{l}{22}\right)^m = \left(\frac{50}{22}\right)^{0.40} = 1.4$$

The S-factor:

$$S = 10.8 \sin (2.86) + 0.03 = 0.57$$

The annual soil loss:

$$\begin{aligned} A &= R K L S C P = 5000 \times 0.058 \times 1.4 \times 0.57 \times 0.14 \times 1 \\ &= 32 \text{ Mg/ha-yr} \end{aligned}$$

Running the online WEPP Model at <http://octagon.nserl.purdue.edu/weppV1/> for a corn-soybeans-wheat-alfalfa rotation at Memphis climate in Grenada soil on a uniform slope predicts a similar erosion rate of 26 Mg/ha for conservation tillage.

Example 7.3

If the soil loss for the conditions in Example 7.2 is to be limited to 10 Mg ha⁻¹, what practices could be adopted to accomplish this level?

Solution:

Since C, P, and L are the only variables that can be changed, the following combinations are possible by substituting the appropriate factors in Equation 7.5.

Conservation Practice	L	C	P	A (Mg/ha)	Remarks
(1) None	1.4	0.14	1	19	Soil loss too high
(2) Contoured	1.4	0.14	0.55	10	Satisfactory
(3) Contoured and spring tillage	1.4	0.12	0.55	9	Satisfactory
(4) Conservation tillage, no contours	1.4	0.11	1	15	Soil loss too high
(5) Terrace at 24 m spacing	1.0	0.14	0.33	4.5	Satisfactory
(6) Terrace with conservation tillage	1.0	0.11	0.33	3.5	Satisfactory

Note that any practice that includes contouring will be adequate to reduce soil erosion to acceptable levels. The low C-factor due to the incorporation of oats and meadow in the rotation offers considerable conservation benefits in this case.

Sediment Delivery

Sediment delivery downstream in a watershed may be estimated from the USLE and a sediment delivery ratio. The soil loss equation estimates gross sheet and rill erosion, but does not account for sediment deposited en route to the place of measurement, nor for gully or channel erosion downstream.

Sediment delivery ratio – defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point. The sediment delivery ratio varies roughly as the inverse of the drainage area to the power of 0.2. For watersheds of 2.6, 130, 1300, and 26,000 ha, ratios of 0.65, 0.33, 0.22, and 0.10, as average values by Roehl (1962).

Example 7.5

The predicted annual erosion rate for a typical hillslope in a sensitive watershed is 3.2 Mg ha⁻¹. The watershed is about 1000 ha in size. Estimate the amount of sediment delivered from this watershed.

Solution:

Using Roehl's assumptions, the delivery ratio is about 0.22. Using this value to calculate the sediment delivery gives:

sediment delivery = 3.2 × 0.22 = 0.7 Mg/ha

0.7 Mg/ha × 1000 ha = 700 Mg per year

VII. Activity : Group discussions; laboratory exercise; seatwork; board work; field trips

VIII. Evaluation

1. What is erosion?
2. What are the types of water erosion? Describe each type.
3. If the soil loss for a given set of conditions is 4.5 Mg/ha for a 60-m length of slope, what soil loss could be expected for a 240-m slope length if the slope is 5 percent?
4. If the soil loss from a field with a 5 percent slope is 45 Mg/ha for upslope and downslope farming, and the cover management factor is 0.25, what is the estimated soil loss if the field is contoured and the C factor is changed to 0.15? What would be the soil loss if strip cropping was substituted for contouring?
5. Calculate the interrill erosion rate during a storm with an intensity of 32 mm/h, an interrill erodibility of $2\,000\,000\text{ kg-s/m}^4$, and slope of 12 percent. (Convert intensity to units of m/s.)
6. On a 60-m long slope, what is the relative difference in water erosion between slopes of 2 and 10%, assuming other factors are constant (compare USLE equations and WEPP Internet interfaces)?
7. If the soil loss for up- and downslope farming at your present location is 80 Mg/ha from a field having a slope of 6% and a slope length of 120 m, what will be the soil loss if the field is terraced with a horizontal spacing of 24 m? Assume that the cover-management conditions remain unchanged and the P-factor is 0.5 for contour farming.