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MANAGEMENT OF EROSION RAVAGED SOILS OF SOUTHEASTERN NIGERIA

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Abstract

Soil is among the most precious resources to humans on earth; and without the soil, life as we know it, would not exist. The soil is a finite resource that must be protected. This is more so, as the rate of land degradation and soil loss is becoming increasingly alarming across the globe. In southeastern Nigeria, gully erosion has already taken an immense toll on the socioeconomic and environmental wellbeing of the people. Soil erosion is one of the most destructive forms of land degradation on earth, with gully erosion as a major environmental hazard in Southeastern Nigeria. Many communities in Southeastern Nigeria have lost landmarks, lives and properties to soil erosion. This paper looks at the causes, impacts and management of soil erosion as a prerequisite to sustainable land resources use and management, and subsequently, sustainable agricultural production and food security.

Keywords: Erosion, sustainable, land resources, management, food security

Introduction

Soil is the thin layer on the surface of the earth that supports terrestrial life. It houses countless species of living organisms; thereby creating a dynamic and complex ecosystem. Some of the ecosystem services provided by the soil are: biomass production, including agriculture and forestry; storing, filtering and transforming nutrients, substances and water; biodiversity pool, such as habitats, species and genes; physical and cultural environment for humans and human activities; source of raw materials; acting as a carbon pool; archive of geological and archaeological heritage (FAO and ITPS, 2015).

Indeed, soil is fundamental to the survival and sustainable development of human societies (Madueke *et al*., 2019, 2021). This is buttressed by the assertion of Pimentel and Burgess (2013) that humans depend on the land for over 99.7% of their food. As such, preserving cropland and maintaining soil fertility is of fundamental importance to the socioeconomic wellbeing of human societies (Pimentel and Burgess, 2013).

Similarly, Millennium Ecosystem Assessment (2005) related soil ecosystem services to the constituents of human wellbeing, as shown in Figure 1. Also, the Commonwealth Human Ecology Council (2021) stated that the importance of soil on life is a matter of life or death, as humans cannot survive without it. Indeed, as Franklin D. Roosevelt once said, "the nation that destroys its soil destroys itself." Unfortunately, the finite soil resource is currently threatened by various forms of land degradation (Montanarella *et al*., 2015, 2016; Madueke *et al*., 2019). Land degradation is in itself, a global challenge that impacts negatively on the sustenance and survival of billions of people (Nkonya *et al*., 2016). Soil erosion has been identified as one of the most destructive forms of land degradation on earth (FAO and ITPS, 2015; Melaku *et al*., 2018; Madueke *et al*., 2019). Moreover, the impacts of soil loss go beyond the on-site loss of topsoil, nutrients, organic matter, crop residues, soil quality and growing plants (Madueke *et al*., 2019). The off-site impacts include the inundation of downhill farms by eroded soils, silting of drainage channels and reservoirs, water pollution and the degradation of aquatic habitat (Steffen *et al*., 2015; Madueke *et al*., 2019). This underscores the need for effective soil erosion prevention and control.

Globally, it has been reported that up to 10 million hectares of croplands are lost due to soil erosion on an annual basis, fundamentally aggravating the prevailing state of land degradation and food insecurity (Pimentel and Burgess, 2013). In many communities in Southeastern Nigeria, landmarks have been destroyed, ancestral burial sites washed away, economic trees felled, towns and villages balkanized, and lives lost (Jimoh, 2006; Umahi, 2011). This is even more so in Anambra state, where Akamigbo (1990) reported that gully erosion alone has carted away up to 10 % of the land area. At this rate, if drastic actions are not taken to stem the tide, Anambra state may eventually cease to exist. This paper, consequently seeks to explore and review the dynamics of soil erosion in Southeastern Nigeria, elucidating the causes, impacts and management, as a prerequisite to sustainable land allocation, resource use and management.

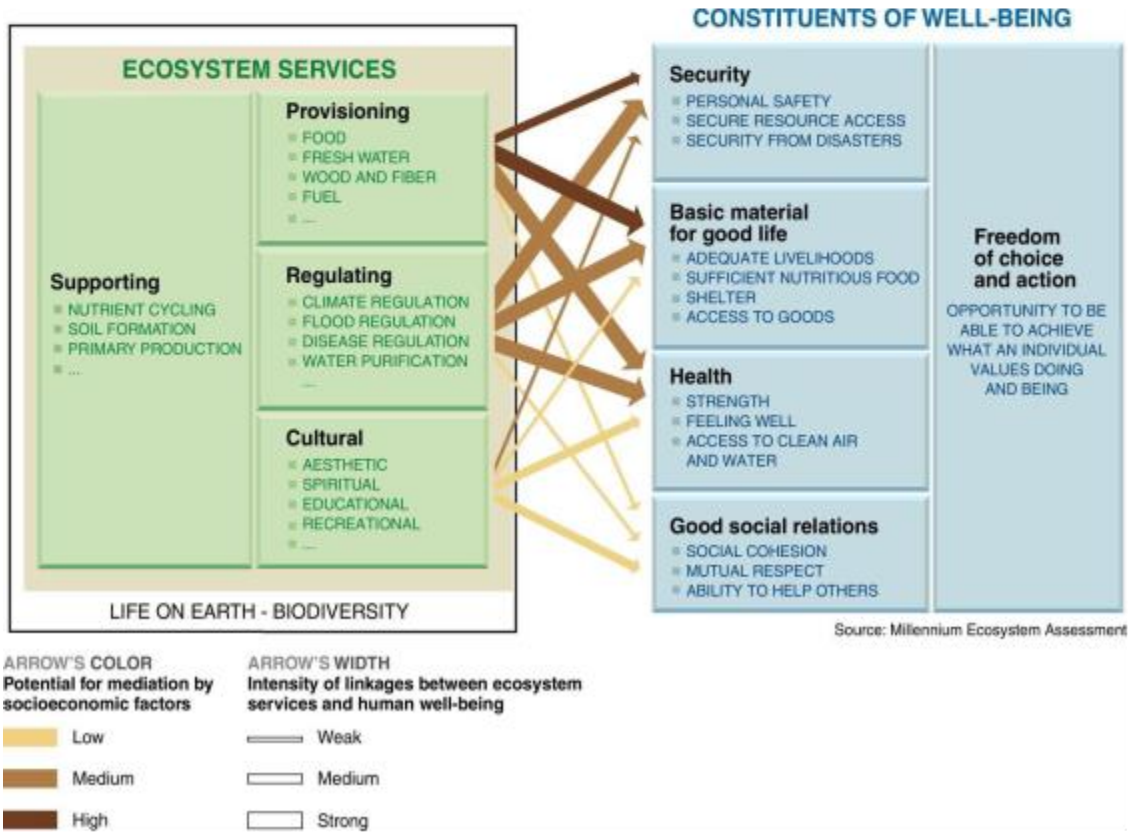

Figure 1: The relationship between soil ecosystem services and human wellbeing. (Source: Millennium Ecosystem Assessment, 2005)

Causes of Soil Erosion in Southeastern Nigeria

Soil erosion is the detachment of soil particles from soil aggregates on a site, the transportation of the detached sediments out of the site either by raindrop splash or runoff, and the subsequent sediment deposition downstream as a result of loss of kinetic energy of the running water. Soil erosion is a naturally occurring process on all land; it only becomes a major concern when the rate of erosion exceeds a certain threshold level (usually, the rate of soil formation) and becomes rapid (Blanco and Lal, 2008). Soil erosion is currently viewed as a major threat to human survival because, as reported by Pimentel and Burgess (2013), soil is generally being lost from croplands at a rate, 10 to 40 times faster than the rate of soil formation.

Soil erosion by water is initiated by the detachment of soil particles due to the action of flowing water and rainfall. The detached particles are transported by erosion agents from one place to another, where they are deposited to complete the soil erosion process. Accelerated erosion by water goes through three steps, viz: Detachment or loosening of soil particles; Transportation of soil particles; Deposition of transported particles at regions of lower elevation and slope (Fenli *et al.*, 2002).

Rain enhances the translocation of soil through the process of splashing. The raindrops detach soil aggregates, redepositing them as particles, which may subsequently plug soil pores, reducing infiltration (USDA, 1996). Once the soil dries, these particles develop into a crust, such that with subsequent rainfalls, runoff is further increased, which in turn increases soil erosion (USDA, 2008; Chong-feng *et al.*, 2014; Ma *et al.*, 2014).

There is no unique cause of soil erosion; however, the predominant causes of soil erosion are either related to naturally-occurring events or human influence and activities (Labrière *et al*. 2015; Sobral *et al.*, 2015; Zaman *et al.*, 2018). The rate and magnitude of soil erosion by water is controlled by (Blanco and Lal, 2008; Ritter, 2012; USDA, 2012; Issaka, and Ashraf, 2017):

- **Rainfall amount and intensity**: The greater the intensity and duration of a rainstorm, the higher the rainfall erosivity, which in turn, increases the soil erosion potential.
- **Soil erodibility**: This is a measure of the ability of soils to resist erosion, depending on the texture, structure, organic matter content and permeability of the soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.
- **Slope of the terrain**: Steeper and longer field slopes, result in higher soil erosion potentials. Soil

erosion by water increases as the slope length increases due to the greater accumulation of runoff.

- **Vegetative cover**: Presence of vegetative cover helps to maintain the structure of soils thereby reducing the amount of soil erosion. Areas with less vegetative cover would naturally be more prone to soil erosion. The destruction of natural vegetative cover by indiscriminate cutting of trees, overgrazing, forest fires, etc., needs to be discouraged. The potential for soil erosion increases if the soil has little or no vegetative cover. Plant residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of runoff water and allows excess surface water to infiltrate. Vegetation and residue combinations that completely cover the soil and intercept all falling raindrops close to the surface are the most efficient in controlling soil erosion (e.g., forests, permanent grasses).
- **Tillage Practices**: Soil erosion by water is affected by tillage operations - depth, direction and time of plowing, type of tillage equipment used as well as the number of passes. Generally, the less the disturbances of vegetation or residue cover at the surface of the soil, the more effective the tillage practice in reducing water erosion. Minimum till or no-till practices are effective in reducing soil erosion by water.
- **Anthropogenic/Engineering Activities and Urbanization**

  Human activities are the main factor accelerating soil erosion. The improper agronomic land uses that predispose lands to erosion include:

¬ Deforestation
¬ Keeping the land bare
¬ Growing crops that accelerate soil erosion
¬ Removal of organic matter and plant nutrients
¬ Cultivation along the land slope
¬ Faulty irrigation methods
¬ Tillage practices for agricultural purposes
¬ Overgrazing by livestock

Other human activities are (Eriksson and Kidanu, 2010):

¬ Disturbing the soil during excavation / construction
¬ Unregulated open-caste mining operations
¬ Inadequate or absence of drainage channels, resulting in too much water and high flow velocity over unprotected soils, leading to many tons of fertile soil and water being lost and land becoming unproductive
¬ Poorly maintained roadside drainage channels that are either blocked artificially or filled with silt leading to overflow and increased runoff
¬ Problems often caused by developments outside the road reserve, i.e., poor farming practices on slopes, deforestation, etc., are resulting in siltation and erosion damages to roads and land downstream (lower catchment)
¬ Frequent conflicts with the land owners who are refusing to allow drainage of water over their land
¬ Concretes/interlocking pavements in urban settings that lead to high flow concentration.

Impacts of Soil Erosion

The impacts of soil erosion are extensive and could be on-site or off-site (Madueke *et al*., 2019).

The on-site implications of soil erosion by water extend beyond the removal of valuable agronomically productive topsoil. Its impacts extend to its negative effects on crop emergence, growth and yield due to loss of plant nutrients thereby undermining the effectiveness of the farmer to work his land; as well as the washing away of organic matter, plant residues, fertilizers and manure. The soil quality, structure, stability and texture can also be affected by the loss of soil.

1. **Food insecurity:** Given the high population density of the states in Southeastern Nigeria, the problem of insufficient productive agricultural land is already a major issue that soil erosion exacerbates, engendering increased food insecurity. In line with this, Akamigbo (1990) reported that gully erosion alone has carted away up to 10 % of the land area. As such, a drastically increasing population that is matched by a corresponding decrease in available land automatically translates into inadequate food production, hunger, poverty and food/socioeconomic insecurity.
2. **Soil compaction:** When the subsoil becomes compacted and stiff, it reduces infiltration rate, increasing runoff, which in turns results in greater and more devastating erosion (Zaman *et al.*, 2018). Similarly, the loss of the porous organic matter-rich topsoil results in the exposure of compacted, relatively clayey subsoil, with attendant reduction in infiltration rate and increase in soil erosion. It can also be a product of the loss of soil aggregation, and subsequent surface crusts due to splash erosion (Magdoff, and van Es, 2021).
3. **Reduced organic matter content:** A major proportion of soil organic matter is found in the topsoil, with a concentration ranging from 1 – 6 % (Magdoff, and van Es, 2021). When the topsoil is eroded, the organic matter is automatically lost. This affects the morphological, physical and chemical properties of the soil, while considerably reducing its productive potentials. The loss of the soil organic matter may further exacerbate soil erosion, as it results in reduced structural stability, water holding capacity and infiltration rate, which translates into greater soil detachment by raindrops, as well as increased runoff. Furthermore, loss of topsoil

organic matter will reduce the ability of the land to regenerate new flora/vegetative cover resulting to further degradation (Zaman *et al.*, 2018). According to Narendar *et al*. (2017), in cases of intense soil erosion, lost nutrients (nitrogen phosphorus, potassium, calcium, etc.) are three times more than nutrient particles remaining in the soil.

4. **Long-term erosion:** If an area is historically prone to soil erosion, it becomes even harder to protect it in the future. This is because, over time, the soil structure, organic matter and the regenerative capacity of the soil becomes compromised, making it harder for the soil to recover at the long run (Zaman *et al.,* 2018). This is why prevention is fundamental because, once the erosion process has been initiated; the negative progression is inevitable if active measures are not taken to stem the tide.

5. **Surface crust development:** Surface crusts are formed as a result of splash erosion (Magdoff, and van Es, 2021). The attendant sealing of surface soil pores affects both the physical and biological properties of the soil. Notably, it results in decreased infiltration and water storage, while increasing runoff, which is accompanied by increased soil erosion, particularly in regions with little or no vegetative cover (USDA, 2008; Chong-feng *et al.*, 2014; Ma *et al.*, 2014).

6. **Loss of human life:** Soil erosion, particularly, gully erosion and land slide have reportedly resulted in the loss of human lives in Southeastern Nigeria (Tekwa and Usman, 2006; Abdulfatai *et al.*, 2014; Anzaku *et al.*, 2019; Egboka *et. al.*, 2019). Abdulfatai *et al.* (2014) reported that up to 23 people lost their lives in a single gully event in Ibori, Ugbalo, Ewu-Eguare, Idogalo and Oludide communities of Edo State, while about 826 families could potentially be rendered homeless in Oko community in Anambra state. Similarly, Hassen and Bantider (2020) reported the loss of 12 lives on a gully site in Ethiopia.

7. **Destruction of roads, bridges, buildings and other infrastructural developments:** Gully erosion and landslides result in extensive damage to roads, bridges, buildings and other human infrastructure (Tekwa and Usman, 2006; Abdulfatai *et al.*, 2014; Anzaku *et al.*, 2019; Egboka *et. al.*, 2019). In fact, Egboka *et. al.* (2019) reported that bridges, buildings, roads, telecommunication infrastructure, railway lines and electric poles, are continuously washed away by gully erosion in Southeastern Nigeria.

8. **Loss of crops and livestock:** Soil erosion is a major threat to sustainable food production around the globe (Lal and Moldenhauer, 1987; Pimentel and Burgess, 2013). It results in the washing away of crops already in the field, which translates into extensive economic losses for the farmers (Madueke *et al.*, 2021). Similarly, it has been reported that past soil erosion has resulted in an average annual crop yield decline of up to 8.2% in sub-Saharan Africa (Pimentel and Burgess, 2013). Livestock housing, along with the livestock, may also be lost if the building caves in during intense storms as a result of landslides (Abdulfatai *et al.*, 2014; Hassen and Bantider, 2020).

9. **Loss of land with cultural value:** Land of immense cultural value, like ancestral homes and burial sites, has been lost to gully erosion (Obiadi *et al.*, 2011; Egboka *et al.*, 2019). In fact, buried corpses may even be excavated over time by sheet or rill erosion. This may have extensive socio-cultural consequences on the local population.

The off-site impacts of soil erosion by water are not as apparent as the on-site impacts, but they are as important. Eroded soil that are deposited down slope may prevent or delay the emergence of seeds, bury small seedlings, fill up road drainages, contribute to road damages, silt in streams, watercourses and rivers, affecting the indigenous aquatic life and the navigability of the water courses. Other impacts include: siltation of rivers, irrigation channels and reservoirs; damage to sea coast and formation of sand dunes; disease and public health hazards.

1. **Water pollution and poor water quality:** A major problem with runoff from agricultural fields is that there is a greater likelihood that there could be sediments and contaminants from the use of fertilizers or pesticides (Zaman *et al.*, 2018). These pollutants are washed into rivers and streams where they result in the degradation of aquatic habitat and poor water quality, for both ecological and household use. The nutrients in the sediments also lead to algal bloom, rapid exhaustion of aquatic oxygen and ultimately, the death of fishes and other aquatic organisms (Weaver and Summers, 2001).

2. **Flooding:** A large proportion of eroded soils usually end up in streams and rivers, resulting in unwanted sedimentation. The heavy layers of sediments keep streams and rivers from flowing smoothly, while also occupying space that was hitherto meant for water, eventually leading to flooding (Madueke *et al.*, 2021). This sometimes leads to various extreme effects like killing humans and animals, and damage to buildings and other infrastructural developments.

3. **Impacts on hydropower plants (HPPs):** Hydropower plants supply the much-needed energy for human and societal wellbeing. It has however been reported that the performance of these hydropower plants can be reduced by up to 7% as a result of the impacts of large quantities of sediments generated during the course of soil erosion (Goudie, 2000). The sediment can lead to significant damage of hydropower turbines and other mechanical equipment, presumably as a result of the breakdown of the oxide coating on the blades (Munyaneza *et al.*, 2015).

Soil Erosion Management

Figure 2 shows a schematic illustration of the dynamic mechanisms of soil erosion control, highlighting measures that target specific parts of the erosion process. The two basic approaches are:

1. Reducing runoff amount and
2. Reducing runoff velocity.

Soil erosion prevention/control measures can generally be classified into agronomic and engineering measures. There are however, urban planning and allied measures, whose proper implementation in the course of infrastructural development, would equally prevent soil erosion.

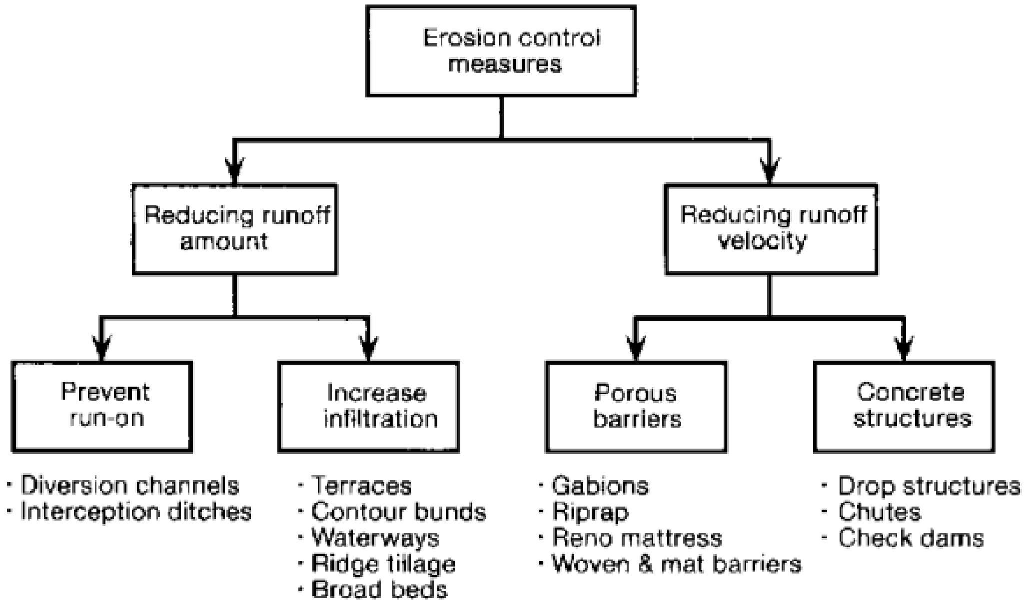

Figure 2: Schematic illustration of the dynamic mechanisms of soil erosion control

Agro-Ecological Erosion Soil Conservation Measures

Practices that protect soil surface particles from being detached by soil erosion agents using agro-ecological measures are highly recommended. They include:

1. **Mulching:** Mulch is any material, organic or mineral in nature, such as saw dust, straw, paddy husk, groundnut shell, crop residues, leaves, paper, stones, loose soil etc. which is spread on the surface of the soil in order to protect the soil from the impact of rain drops, avoid surface crusting, reduce evaporation and thereby conserve soil moisture (Sharma. and Singh, 2013). In addition to erosion reduction, mulch increases soil water holding capacity by reducing compaction. It increases infiltration by slowing down runoff and giving it more time to soak into the soil; reducing erosion from bare soil and supplying nutrients and organic matter to the soils (Adekalu *et al.*, 2007).

2. **Cover crops and vegetation:** Erosion from cultivated fields can be reduced if the land has enough crop canopies during the peak season (Sharma and Singh, 2013). Cover crops increase soil health, improves soil structure and reduces the need for costly inputs such as fertilizer and mechanical tillage. Cover crops protect water quality by slowing erosion and runoff and increasing water infiltration and retention. Soil surface is protected by vegetation from raindrop impact which acts as a detachment agent of soil particles. Franz *et al.* (2018) noted that vegetation is the most common natural element used to control erosion as it aids in protecting the soil and preventing erosion. Vegetation can reduce the soil erosion rate by 90% (Franz *et al*., 2018). It has also been reported that vegetation reduced the average runoff and sediment yield by up to 51% and 32% respectively (Bai *et al*., 2019).

3. **Protective grasses on river banks and waterways:** Bank erosion mostly occurs along river courses, streams and water channels and it is a function of the frequency and magnitude of the kinetic energy of the flowing water. Protective grasses increase the resistance of stream banks to erosion and play an important role in the maintenance of fish and wildlife populations, while also contributing to the aesthetics of the riverbanks. Grassed water ways have the ability to trap suspended sediments at rates greater than 90% (Fiener and Auerswald, 2003).

4. **Conservation tillage:** This is an improvement over conventional tillage. Conservation tillage is the land preparation system that retains at least, 30 % of plant residue on the soil surface after land preparation (Baldwin, 2006). There are two major types of conservation tillage viz: minimum and the zero tillage. In zero tillage, the land for crop cultivation is left undisturbed from harvest to planting or not ploughed at all, while in the case of minimum tillage, just holes for planting are made and only at the places where the crop is going to be planted or grain sown. A combination of zero tillage with crop residue mulch is more effective in runoff and erosion control (Adimassu *et al.*, 2019).

5. **Buffer zones:** Buffer zones are neutral zones that lie between two or more land types. It might be the region between rivers, streams and/or lakes or an existing gully and the surrounding upland region. Extensive soil conservation measures are implanted in this zone, or it is left undisturbed. The buffer zone moderates the impacts of flash floods on the surrounding uplands, while reducing the velocity of runoff, enabling extensive infiltration and sediment deposition before runoff gets to the water body. Buffer zones increase the capture of sediment and organic material. Matthew *et al*. (2007) reported that buffer zones can increase the trapping of sediment and infiltration from 10 to 90%. Also, vegetated buffer zones decrease the runoff velocity, thereby, reducing soil erosion.

6. **Contour cultivation:** The practice of land tillage or crop cultivation up or down a slope increases the extent and magnitude of soil erosion in a region. On steep slopes, this practice enables rain water to gain velocity, facilitating soil erosion by runoff. Contour farming is a cropping system in which all cultivation operations are done on contour. It provides the greatest possible conservation of rain water, reducing soil loss via water erosion. The purpose of contour farming is to place rows and tillage lines across the normal surface flow. The resistance developed by the crop rows and by furrows, between the ridges, to the water flow, which in turns, reduces runoff velocity and gives more time to water to infiltrate into the soil (Sharma. and Singh, 2013).

7. **Nitrogen fixation by legumes:** Introduction of short duration legumes in crop rotation may be helpful in increasing the nitrogen content of the soil. The symbiotic rhizobium, commonly associated with the Leguminosae has been recognized for its contribution to the nitrogen fixation. A large part of the nitrogen fixed is utilized by the plant for its growth and development, which in turn, gives better ground cover, good soil protection from the direct impact of raindrops and reduces soil erosion (Sharma. and Singh, 2013).

8. **Strip cropping:** Strip cropping is a system under which ordinary farm crops are planted in relatively narrow strips, across the slope of the land. They are arranged in such a way that strips of erosion permitting crops are always separated by strips of close growing or erosion resisting crops. According to Sharma and Singh (2013), the erosion resisting crops usually:
   - Check the velocity of the runoff water coming from the erosion permitting strips.
   - Act as a filter that arrests the eroded soil within the close growing strips.
   - Allow water to remain for a longer time in the soil, making it available to plants.
   - Give physical protection against wind and raindrops.
9. **Green manuring:** Green manuring is the practice of ploughing green crops, usually legumes, into the soil to improve organic matter content, soil fertility, structural stability, water holding capacity, infiltration rate, etc. of the soil (Sumiahadi *et al.*, 2020). This ultimately leads to greater soil fertility, improved plant vegetative growth, denser surface cover, and reduced soil detachment from raindrops and runoff, all of which translate into reduced soil erosion (Sharma. and Singh, 2013).

10. **Crop rotation:** Crop rotation is a practice whereby several crops are grown on same field, such that at maturity, one crop succeeds the other, in a particular, predetermined sequence. The sequence is designed such that line sown crops are succeeded by dense cover crops. A proper rotation of crops not only maintains fertility but also helps in reducing soil erosion. A good rotation should include a cultivated row crop densely planted, small grain and a spreading legume (Sharma. and Singh, 2013).

11. **Cultivation of grasses (ley farming):** This method consists in growing grasses in rotation with agricultural crops. It has greater utility when crops and livestock are grown by the same farmer (Edwards *et al.*, 2019; Lal, 2020). The inherent features of the pasture phase include inputs of organic matter, reduced tillage, less erosion, and little or no fertilizer and herbicide applications (Edwards *et al.*, 2019). This practice improves the fertility of soil and helps in binding the soil, thus preventing soil erosion. This practice ensures that the soil is never left bare, as the grasses can be grown in relatively drier periods when other crops cannot survive.

12. **Afforestation and reforestation:** Trees and shrubs can act as soil stabilizer. If trees are removed, bare soil becomes prone to increased soil detachment by raindrops, splash erosion, crusting, and runoff (Madueke *et al.*, 2019, 2021). This underscores the need for afforestation or reforestation. Afforestation means growing forests in places where there were no forests before. Reforestation means replanting of forests in places where they have been destroyed by uncontrolled forest fires and excessive logging.

13. **Retiring the land:** Areas subjected to heavy soil erosion should be put under thick cover of grasses. Natural fallow system where land is left uncultivated for one or more cropping season, sometimes, up to 20 years, is a form of land retiring (Blanco and Lal, 2008). In the course of land retiring, afforestation is usually used in conjunction with extensive grassing. Such soils should not be built on or used for crop production, to avoid exacerbating an already dire situation. With regards to this, a buffer zone should be provided, amounting to up to 50 m from any active (gully) erosion site, that is not subjected to agricultural, industrial, commercial or habitation purposes.

14. **Avoiding soil compaction:** When machine, animals or people continuously walk over the soil; they press it, consolidating the soil into a hard layer. Since there will be less space between the compact soil particles, infiltration/percolation decreases, resulting in increased runoff, runoff transport capacity and soil erosion (Blanco and Lal, 2008; Zaman *et al.*, 2018). It is necessary to make a way on paving stones or cleared pathways rather than trampling the soil, especially when it is wet (Blanco and Lal, 2008). Adding organic manure, will also by encouraging bioturbation by earthworms.

15. **Vegetative filter strips (VFTs):** It involves planting of suitable grass/fodder species, like vetiver grass, in rows across the land slope to act as barriers to moderate runoff velocity and erosion. The fibrous root system of grass binds the soil and the grass barrier filters the run off, retaining the sediments on the site, while also increasing infiltration (Blanco and Lal, 2008). The fodder can also be used for feeding the livestock, providing an alternative source of income for the farmer.

16. **Mixed cropping/intercropping:** Intercropping is the practice of simultaneously growing more than one crop, interspaced between each other in the same field (Blanco and Lal, 2008; Sharma and Singh, 2013). In this practice there is one main crop and one or two subsidiary crops. Generally, legume is used as one of the crops. This practice gives better cover on the land, good protection to soil from beating action of rain and protection from soil erosion, by binding the soil particles (Sharma. and Singh, 2013). Growing soybean, groundnut, cowpea etc. with maize, is a common practice.

Urban Planning and Allied Measures

Inadequate urban infrastructural development results in extensive land degradation, including soil erosion. If these infrastructures are adequate, land degradation would be largely prevented. In order to achieve this, USDA (2000) recommended the following basic principles of erosion control on construction sites:

a. Divide the project into smaller phases; clearing smaller areas of vegetation.
b. Schedule excavation during low-rainfall periods, where possible.
c. Fit development to the terrain.
d. Excavate just before construction instead of leaving soils exposed for months or years.
e. Cover disturbed soils with vegetation or other materials (mulch) to reduce erosion potential.
f. Divert water from disturbed areas.
g. Control concentrated flow and runoff to reduce the volume and velocity of water from work sites to prevent formation of rills and gullies.
h. Minimize long and steep slopes (e.g., use bench terraces).
i. Prevent off-site sediment movement.
j. Inspect and maintain any structural control measures.
k. Where wind erosion is a concern, plant and install windbreaks.
l. Avoid soil compaction by restricting the use of trucks and heavy equipment to limited areas.
m. Soils compacted by grading need to be broken up or tilled prior to vegetating or placing sod.

Some of these measures are discussed in greater details below:

1. **Source control of runoff flow:** The primary goal of source control during construction is to protect exposed earth surfaces from the erosive energy of rain splash and surface runoff flow. Cover is the most effective erosion control/prevention method. Cover includes top soiling in conjunction with one or more of the following methods: seeding, mulching, hydroseeding, sodding, erosion control blankets, turf reinforcement matting (TRM), riprap, gabion mat, aggregate cover, and paving.
2. **Runoff control during project work:** During the construction of a project, it is not possible to provide surface cover for all disturbed areas. Runoff control methods, such as slope surface modification and slope gradient reduction, are employed to prevent soil erosion.

3. **Improving drainage:** This involves making a channel that allows the water to flow through it to prevent the spread of water all over the land. All structures should have pipes or drainage channels (gutters) that can effectively drain water out of the yard into a water collection system. Places with heavy water runoff may need an installation of underground perforated drainage pipes.
4. **Trenching:** Trenching (usually for installing utility services), often occurs at the end of bulk earthworks. Topsoil and sub-soils should be stockpiled separately adjacent to the trench so that at the completion of the operation these soils can be replaced in the appropriate order and vegetation established.
5. **Minimize disturbance:** The most effective form of erosion control is to minimize the area and extent of disturbance, retaining as much existing vegetation as possible. This is especially important on steep slopes or in the vicinity of water bodies, where no single measure will adequately control erosion and where receiving environments may be highly sensitive. Match land development to land sensitivity. Watch out for and avoid areas that are wet (streams, wetlands, springs), have steep or fragile soils. Analyze all the "limits of disturbance".
   a) **Stage Construction:** Temporary stockpiles, access and utility service installation all need to be considered.
   b) **Protect Steep Slopes:** Steep slopes should be avoided where practicable.
   c) **Protect Water bodies:** All water bodies and proposed drainage patterns should be properly maintained. Map out all water bodies and show limits of disturbance and protection measures.
   d) **Stabilize Exposed Areas Rapidly:** Convert conventional sowing to mulching. Mulching is an effective instant protection measure.
   e) **Install Perimeter Controls:** Perimeter controls above the site keeps clean water runoff out of the worked area. Common controls are diversion drains, silt fences and earth bunds.
   f) **Employ Detention Devices:** Earthworks will still discharge sediment-laden runoff during storms.
   g) **Runoff Diversion Channel/Bund:** This is a non-erodible channel or bund constructed for the conveyance of runoff to a site-specific cross section and grade design. It is done to either protect work areas from upslope runoff, or to divert sediment laden water to an appropriate sediment retention structure.
   h) **Contour Drain:** This is a temporary ridge or excavated channel, or combination of ridge and channel, constructed to convey water across sloping land on a minimal gradient. To periodically break overland flow across disturbed areas in order to limit slope length and thus the erosive power of runoff and to divert sediment laden water to appropriate control or stable outlets.
   i) **Rock Check Dam:** Small temporary dam constructed across a channel (excluding perennial waterbodies), usually in series, to reduce flow velocity. It may also retain coarse sediment. Check dams are constructed in order to reduce the velocity of concentrated flows, thereby reducing erosion of the channel. Rock check dams will trap some sediment, but they are not designed as a sediment retention measure.

Engineering Operations

Engineering methods deal with the physical structure that stops or try to prevent soil erosion. Different engineering methods to control soil erosion are:

1. **Sediment retention pond:** A temporary pond formed by excavation into natural ground or by construction of an embankment and incorporating a device to dewater the pond at a rate that will allow suspended sediment to settle out (Tasman District Council, 2019). To treat sediment-laden runoff and reduce the volume of sediment leaving a site, thus protecting downstream environments from excessive sedimentation and water quality degradation.
2. **Riprap:** These are rock pieces, piled up to create a barrier to water/sediment flow. These include a variety of rock types including limestone and granite, which are used to armor embankments, shorelines, bridge abutments, streambeds and other seaside constructions to prevent soil erosion due to concentrated runoff or other water-related pressures. A limitation of riprap arises when the slopes of the considered area are greater than 2:1; the rubble becomes unstable and is itself prone to erosion. Tang *et al.* (2018) reported that after 12 months of the installation of ripraps, the shear strength of the soil increased by up to 239.1%. Gabion and riprap revetments could increase the river water purity and the ecological biodiversity (Van *et al*., 2018).
3. **Gabions:** Gabions are riprap wrapped in galvanized, steel-wire mesh; they are used to stabilize slopes, stream banks, or shorelines against erosion (Blanco and Lal, 2008). Gabions also promote growth of vegetation, further ameliorating the impacts of soil erosion (Morgan, 2005; Saleem ***et al.***, 2018). Tang *et al.* (2018) reported that, 12 months after construction, the shear strength of the soil behind the gabion increased by up to 162.9%. The durability and lifespan of gabions is a function of their wire frames, and premium ones can last for up to fifty years.
4. **Terraces:** Terraces are mechanical structures such as an earthen ridge or stone walls which divide the slope into short gently sloping sections, reducing slope steepness. They moderate runoff

velocity and soil loss, increasing soil moisture content through improved infiltration. Terraces are more favorable in agricultural land with finer textured soils on steep slopes (16% to 40%) with high erodibility factor (IWRM, 2016). It has been reported that terracing reduced soil erosion up to 99% (Bai *et al*., 2019). Regular inspections of terraces especially after heavy storms, is very essential for sustainable use.

5. **Contour bunds:** Contour bunding are earth or stone embankments of 1–2m width, established on the field contour to reduce runoff velocity. Contour bunds are recommended for gentle to moderate slopes – about 16% slope (Blanco and Lal, 2008; IWRM, 2016). Savadogo *et al.* (2017) reported that contour bunds can reduce soil erosion and increase soil water holding capacity in an intervention area.
6. **Check dam:** A check dam is a small, sometimes temporary dam constructed across a gully, drainage ditch or waterway to counteract erosion by reducing water flow velocity (Zaman *et al.*, 2018). A check dam is designed to control the runoff velocity of water so that the area below is prevented from erosion. A check dam interrupts the flow of water and flattens the gradient of the channel, thereby reducing the runoff velocity and soil erosion.
7. **Anti-erosive ditches/channels:** These are drainage channels constructed to prevent runoff water from upper hill zones from entering arable lands. The water in the channel may either infiltrate of be diverted, depending on the goal of the project. To increase the performance of anti-erosive ditches, protective grasses are planted on ridges along the channels. Like other erosion control structures, regular maintenance is a necessary prerequisite to sustainable use (Kuypers *et al.*, 2005).
8. **Waterways:** Waterways in a conservation system are channels designed to convey runoff at low velocity to a suitable disposal point (Zaman *et al.*, 2018). Artificial waterways are normally protected by grasses like *paspalum* spp., and so are referred to as grassed waterways. Grassed waterways are wide, shallow channels with perennial grass cover, established along the natural drainage pathways to convey runoff at low velocities, usually at slopes of up to 5% (Blanco and Lal, 2008; Zaman *et al.*, 2018). Grassed waterways are more important in filtering by retaining runoff sediments, pollutants and other particulate matter within storm water and their performance will depend on soil permeability within the area. According to the study conducted by Fiener and Auerswald (2003), the runoff and sediments were reduced from 90% to 10% and from 97% to 77% respectively.
9. **Hillside water ponds:** Rainwater harvesting is a system of collecting water through different techniques such as storage of rainwater on surface reservoirs and groundwater recharge for future use. This reduces runoff water and soil erosion. A study conducted in China in 2011 showed that the use of ponds for retaining rainwater reduced soil erosion up to 15.9% (Peng *et al.*, 2011).
10. **Sediment basin or catch basin:** A sediment trap or sediment basin is an earthen embankment constructed across a waterway with a spillway made of stones or aggregates to slow the evacuation of runoff by retaining it for a short period of time which allows the settlement of sediments. Sediment basins remove mainly silts but will not remove fine silts and clay (William, 1997).
11. **Roof runoff cisterns/rainwater harvesting:** Rainwater harvesting is an important erosion prevention measure as it reduces surface runoff, which is the main cause of soil erosion and flooding. Calfoforo *et al*. (2009) reported that the use of roof runoff cisterns reduced soil erosion by up to 98%.
12. **In-situ moisture conservation pits:** These are small pits constructed by excavating the soil to arrest surface runoff and silt and thus leading to storage of runoff and ground water recharge. This is already practiced locally in some parts of Southeastern Nigeria especially, Anambra state. In addition to reducing runoff and soil erosion, the impounded rainwater ensures healthy soil moisture and nutrient status for the plant growth, even during relatively drier periods.

Conclusion

Soil erosion is a complex phenomenon. It may be natural or accelerated. For geologic/natural soil erosion, soil loss is balanced out by soil formation. On the contrary, accelerated soil erosion is influenced extensively by human activities and the soil is lost faster than it is formed.

Given the vast importance of soil to the socio-economic and environmental wellbeing of human societies, soil conservation to prevent or control soil erosion is of utmost importance. This is more so in Southeastern Nigeria, and Anambra state in particular, where soil erosion has reportedly carted away over 10 % of the indigenous soils.

There is no specific best way to control or prevent soil erosion. Several complementary measures can be employed simultaneously, with particular reference to the agronomic and some small-scale engineering measures. When the erosion is allowed to get to the advanced stage, as is the case with most of the gully erosion in Southeastern Nigeria, it becomes much more difficult to manage. Prevention and/or control at the very early stages of soil erosion are the best available option.

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