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Effects of Soil Erosion on Water Resources in Slopy Mountainous Areas of Afghanistan and Soil Attrition Control Strategies

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Abstract
In the research reported here, we have investigated various kinds of soil erosions in the mountain slope areas in certain parts of Afghanistan. Due to arid conditions, soil erosion represents a major issue in terms of groundwater drawdown and soil cover for infiltration countrywide. The main objective of this research is to study different methods for controlling soil erosion. It is well known that Afghanistan is a mountainous country, and there is more soil located in the slopy mountain areas of the bedrock, and all of these soils become bare without vegetation, during precipitation during the rainy seasons, since soils from surfaces (aquifer layers) are leached from the ground surface and are transported to the plain areas. In this case, the bedrock is exposed to the ground surface and precipitation does not infiltrate into the aquifer layers of the bedrock. This poses a serious problem in Afghanistan since there is no vegetation cover and the entire soil is transported by season floods during the rainy seasons. To control this natural calamity, it is necessary to use a variety of methods to prevent soil erosion during natural events. Certain methods, such as terraces, retaining walls, protection walls, turfing, tree and shrub planting, dry stone masonry, crib wall, gabion wall, reinforced earth wall, pile and tie back walls, toe walls, revetment walls, check dam, surface drainage, stone pitching, prop wall and dentition wall, wattle fence, wire net, tree, and grass planting are used, however, it requires a careful assessment that depends upon the terrain, local conditions, and slopes. The report provides a comprehensive review of different methods used to prevent soil erosion to increase vegetation and prevent soil erosion and runoff in the different mountain areas of Afghanistan. Since soil is a blessing to sustain life, this study is critical to protect this natural resource for the society of the country.

Keywords
Soil conservation methods, groundwater, surface water, soil erosion, mountain areas

1. Introduction

Afghanistan is one of the countries it is clime is arid and semi-arid, and all mountains and sloppy areas are covered by very thin layers of soft soil and sediments. During the rainy season, more soil is transported at the different drainage areas of rivers (Niard, 2005), and at first, it makes very small gullies, rain rills, runoff, streams, and rivers (Rasouli et al., 2024). Generally, there are three kinds of courses, one is the upper course, which belongs to the more slopes and the velocity of the river is much higher, their more erosion to the river beds (downcutting), in this river course more transported bigger sizes such as a boulder, cobbled, pebbles, the kind of river flow is turbulent because in this river course having very more friction, and about all materials is transported to the down areas (Rasouli and Vaseashta, 2023a). The second is the middle course in this river course the velocity of flows is a little slower than the upper course (Vaseashta et al., 2021), and there are the slope of the river is medium, and more transported medium sizes such as granules and sands, the kind of river flows is laminar and turbulent, in this area of river more eroded lateral and beds of rivers (Rasouli and Vaseashta, 2023b), but some bigger particles sediment in these river channels, and we can find some bigger sizes (Rasouli, 2021b). The third river course is plain areas in these areas where we can find smaller sizes such as clay, silts, and sands and it's called fine materials from the viewpoint of soil science or pedology. In this area of rivers, we can find more meander structures, viz. caving banks, and deposition banks (Vaseashta, 2015), as well as some vegetation converse (Vaseashta, 2022).

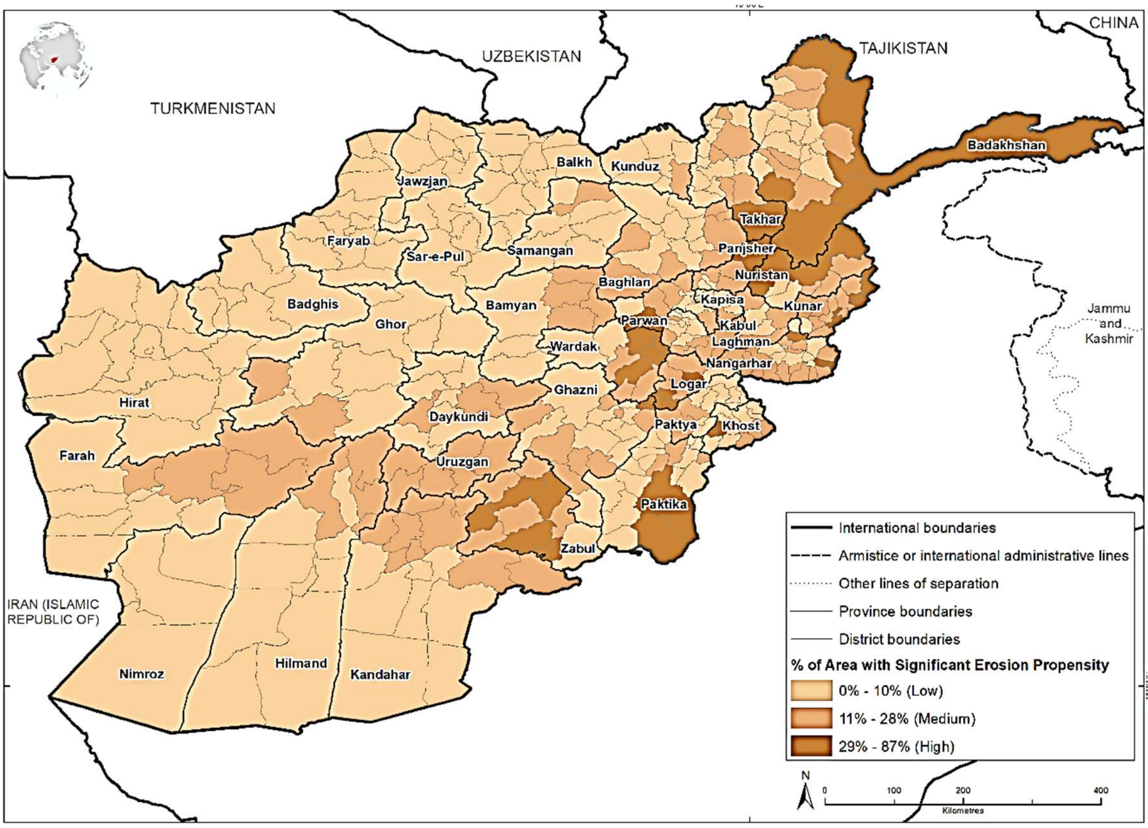


Fig. 1. Soil erosion map of Afghanistan (adopted from WFD, 2025)

It is clear that for the upper and middle courses, we cannot find any vegetation cover and all ground is bare because all soil is transported to the lower and plains areas (Rasouli, 2020). Also, from the viewpoint of groundwater, we cannot find groundwater in the upper slopy mountains areas, because there are all bedrock and aquifage layers (without pores), only we can find groundwater in the lower plain areas (Rasouli et al., 2015). However, it is very important to control soil in the slopy mountains areas by different methods such as terraces, retaining walls, protection walls (Vaseashta et al, 2020), turfing, tree and shrub planting, dry stone masonry, crib walls, gabion wall, reinforced earth wall, pile and tie back wall, the toe wall, revetment wall, check dam, surface drainage, stone pitching, prop and dentition wall, wattle fence, wire net, tree, and grass planting methods, we can controlling soil at the mountains sloppy areas (Rasouli et al., 2021). To implement these methods, support from national and international professional levels persons is necessary to avoid this issue becoming a much larger problem (Rasouli, 2022), such as resulting from landslides or mud run-offs in residential and commercial areas, and on roads.

If these problems are not controlled soon, the groundwater levels will go down gradually, air pollution will be high, and there will not be much vegetation cover in the mountain areas (Rasouli et al., 2023a). In the mountains' skirts, more materials will be eroded by different types of streams, and as a result, the bedrock will become bare at the land surface, which consists of aquifage (impermeable layers) and we will not have the groundwater in the mountains areas (Vaseashta et al., 2023). Generally, in the mountain slopes and skirts, the erosion of soil is causing movement of these bedrocks and boulders and hence there is no storage of groundwater (Arian et al, 2015; Rasouli et al., 2023b).

Since ancient times, the soil has been one of the natural resources of a country, and it plays a vital role in the development of the country (Rasouli and Safi, 2021). With recent advances in soil science, there have been many improvements in soil conservation and related research on its interaction was water (Rasouli and Shamal, 2018). Soil conservation is particularly important in slopy areas and also when the conditions are arid, there is a shortage of ground and surface water, and to avoid soil erosion becomes essential (Rasouli, 2022b). Recently, soil erosion has become a greater vulnerability (Rasouli, 2020a). In areas of uncontrolled gradual soil erosion, it causes not only a shortage of agricultural fertility but also a loss for the filling of the dam which decreases the capacity reservoir of the dam at the sedimentation time (Rasouli, 2020b). In such cases, soil conservation and stewardship are very important for human life. Controlling soil erosion is one of the very important underpinnings of Afghanistan's society (Rasouli, 2019). The report deals with many different approaches for soil conservation, depending upon the terrain, soil type, atmospheric conditions, and other local factors. By having an appropriate type of soil conservation strategy (Kumar, 2024; Hilger et al, 2013), it will be possible to achieve vegetation (Touhami et al, 2024), appropriate soil moisture (Li et al. 2024), drainage, and other conditions favorable to dams.

2. Location Map of Afghanistan

Soil is one of the natural resources of one country, which has a very important role in the development of the country. Afghanistan is a country with arid and semi-arid climates (Biswas and Mukherjee, 1994) and there is a lot of land that is bare without vegetation (Rasouli et a, 2021). During the rainy and snow melting season, more soil is transported and eroded by surface runoff (Fig. 1). More soil is eroded from upper lands and mountains sloppy areas to the plain areas (Urbano et al., 2006). In Afghanistan we have seasonal precipitations during the spring and winter seasons, also sometimes in the summer season, we have flash floods and more soil in Afghanistan gets eroded due to floods because in this season there is no vegetation covered, but just the dry land (Rasouli et al, 2023b).

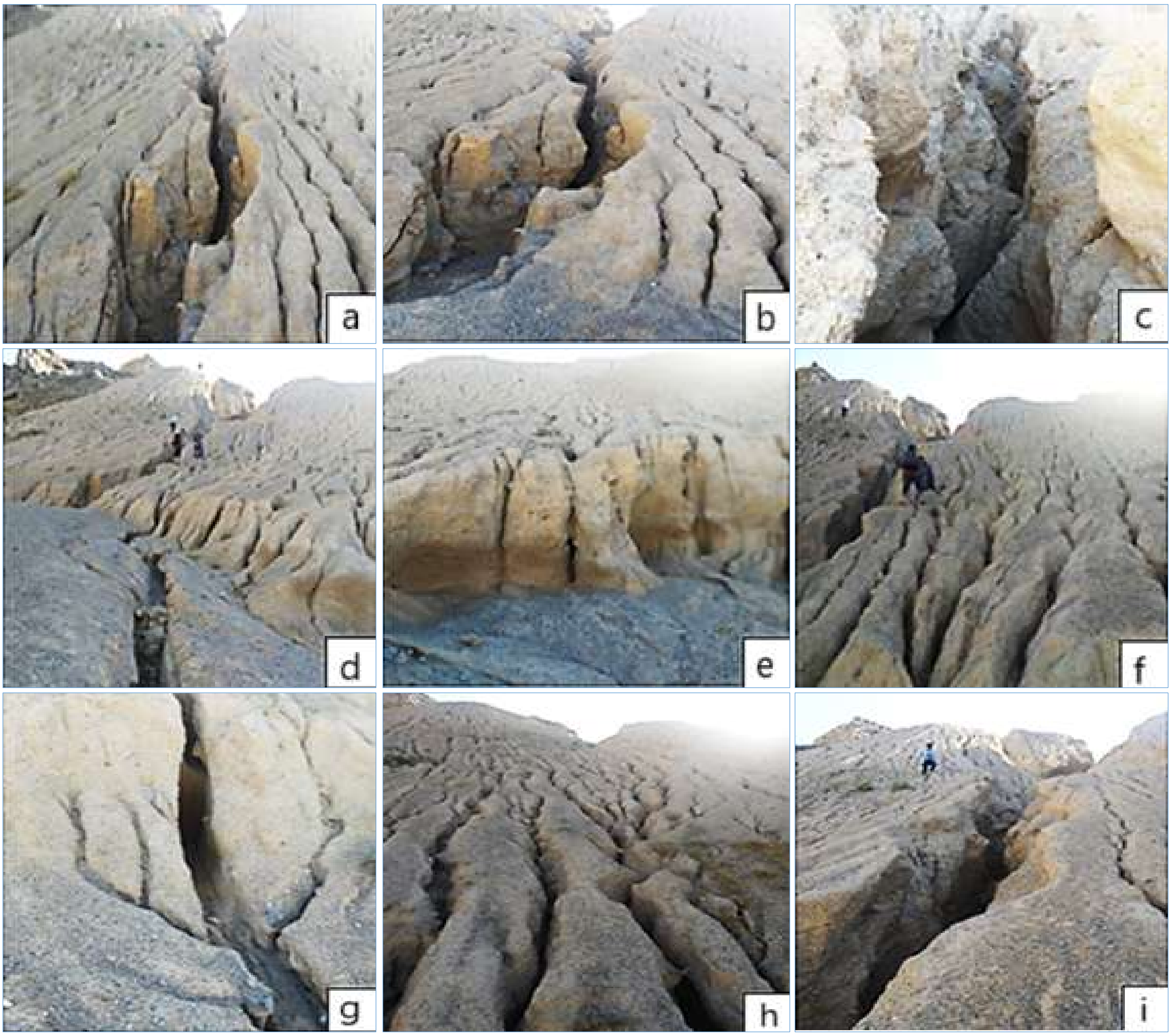


Fig. 2. Different kinds of soil erosion in the mountain's slopy areas. The erosions in (a) – (i) consist of a mix of splash erosion, sheet erosion, rill erosion and gully erosion. In some instances, there is wind erosion, mass erosion, and tunnel erosion

3. Different Structures During Soil Erosion

When precipitation reaches the earth's surface, it is divided into three parts, one part is evapotranspiration in the troposphere which forms different types of clouds, the second one is infiltration in the aquifers' lithosphere layers and goes down in the different types of sediments and continues its vertical movement to that time it reaches the bedrocks aquifage layers and makes groundwater, and the third is making different types of surface streams to make gullies or rain rills. In erosion, we can find different types of structures such as branches (Figs. 2a–d), palmate (Figs. 2e–g), dendritic (Figs. 2h–i), and small valleys. These types of structures belong to the compositions of soil, generally in the gravelly soil the erosion is high but in the clay soil, it is lower. In the smaller sizes, the adsorption force is very high, and every surface of soil particles is much closer to gathers, as well as the specific surface between smaller soil particles is very high, but in the larger sizes it is smaller.

On the other hand, it belongs to the cementation and matrix materials, since those soil particles have carbonated cementation materials consolidated, and the soil has iron oxides and organic materials. Also, the soil has more organic materials and it is unconsolidated than the other soil, as shown in Fig. 2, which shows different types of erosion, viz. splash erosion, sheet erosion, rill erosion, and gully erosion, and in some instances, we can find wind erosion, mass erosion, and tunnel erosion.

The figure above shows a variety of erosions, depending upon a variety of atmospheric conditions, elevation, season, and activities, such as vegetation or animal paths.

4. Soil Erosion Prevention Through Obstacle Formation

To prevent erosion, it is necessary to create different sorts of obstacles in front of the soil erosion sites in the agricultural area. For the slopy areas, the surface of the land is covered by a variety of soil types and in these areas, the soil is more eroded. To decrease the velocity of runoff at the duration of rainfall, we can use different structures of terraces to reduce the downward velocities of surface runoffs (Tünnemeier and George, 2005). In order to do so, we can make prolonged terraces along different horizontal lines, which intersect at the opposite sides of slope areas. These structures are designed to avoid soil erosion and decrease the run-off velocities of rivers. Furthermore, it is collected in the soil that eroded at the upper areas of slopes. For better effects of these structures, other options to make are hill, stone masonry, protection, and retaining walls, check dams, and terraces, to exhibit these kinds of structures. Information about the different structures of dams is for avoiding soil erosion is also one of the very important sections of avoiding soil erosion and according to the locals, it is necessary to pay close attention to this effect and collect different information as to what kind of dams and structures are necessary to avoid soil erosion and surface run-off.

4.1. Wood Dam and Stone Walls

An example of obstacles versus soil erosion are stumps and sliders of trees. The eroded soil accumulates in the behind of them and as a result, it is the leached soil is avoided. These kinds of structures are unconsolidated compared to stone masonry walls. In addition, one can use some grass, pineapple, and other cultivations. In these, we can use the erosion of soil for infiltration into the groundwater, as well as protecting the moisture of the soil. A wood dam is a barrier that stops the flow of surface water. Reservoirs created by wood dams not only suppress floods and soil erosion but also provide activities such as irrigation, agricultural protection, vegetation, and tree growth. This kind of dam can also be used to collect or store water to be evenly distributed between locations. These dams generally serve the primary purpose of rainwater and avoid soil erosions.

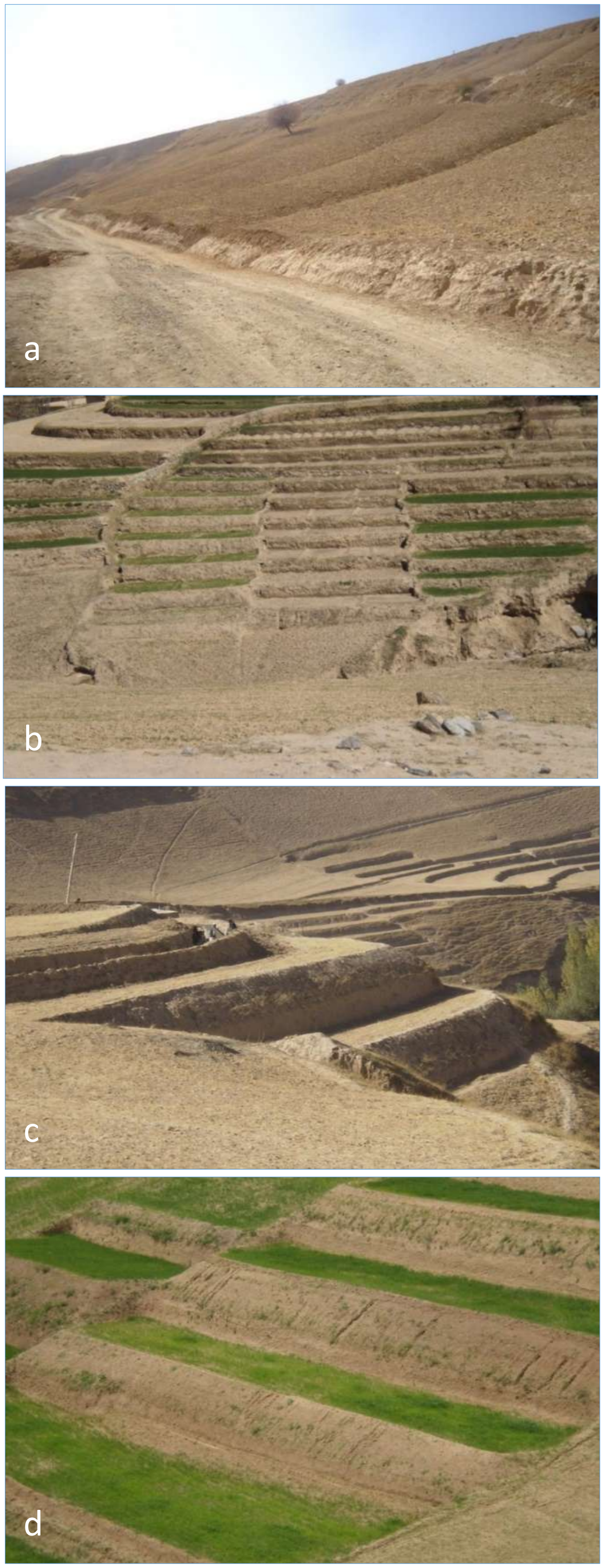


Fig. 3. Different kinds of terraces, as listed in captions. Photos captured by Author's Device. a: Horizontal clayey silt terrace, b: Bench-type terraces made using alluvial sand, c: Terraces made inside of slop terraces with sandy silt soil and d: Terrace made outside of slope terraces

In Afghanistan, it will be beneficial to use these dams along with stone wall construction, mainly due to the mountainous terrains and slopes, the region collects good quality rocks from sedimentary, igneous, and metamorphic formations, and some of these rocks is solid and insoluble providing good solid structures. In conjunction with a variety of woods, such as evergreen, oaks, poplars, wild hazelnuts, almonds, and pistachios, it is possible to form dams with great woods.

4.2. Terrace

The terrace is another structure beside the crest and cannel and across the slopes and it consists of the deformation of the land slope at different surfaces, preparation at the mechanical form (Terracing), and preparation of land for agriculture, to avoid the land from erosion. Terraces are rills at the side of a hill, and they are made at the following techniques protected areas (water and soil), at those places, there is a problem of soil erosion by water, those places need water safety and protection, those places soil and topography one kind and making terraces at the one reason, and those places the water losses are more observed. Terraces are important since they prepare the ground for the division of land and make cultivation more favorable, the organizing of precipitation and decrease soil erosion, and protect soil moisture, keeping agriculture of land, terraces aim to decrease of soil erosion, and avoid from the velocity of soil and the infiltration of water. Figs. 3a–d shows different kinds of armaments (or terraces).

4.2.1. Outside Slope Terraces

This type of terrace is often used in those areas where there are corn cultivations and middle precipitation and it is favorable for dry climates, as shown in Fig. 4.

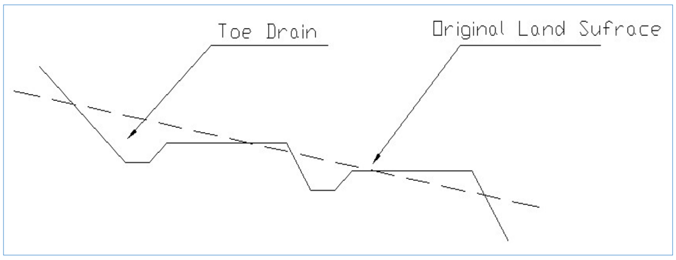


Fig. 4. Schematic diagram of terraces – Outside slope terrace

4.2.2. Sloped Terraces

This kind of reverse (traverse) slope terrace is for diverting water and is used in very high precipitation (under 500 mm) areas with high humidity and temperate conditions, as shown in Fig. 5. A channel/gutter is usually also placed at the base of the terrace. The establishment of the transverse slope, in this case, also depends on the soil texture. Due to generally arid conditions in Afghanistan, these terraces do not experience large quantities of precipitation, hence a transverse slope with the channel option is sufficient for such terraces.

4.2.3. Bench Type Terraces

The bench type of terrace is typically used in high-humidity climates and the kind of soil that requires high infiltration rates and percolations, such as for paddy cultivation areas. An example is shown in Fig. 6.

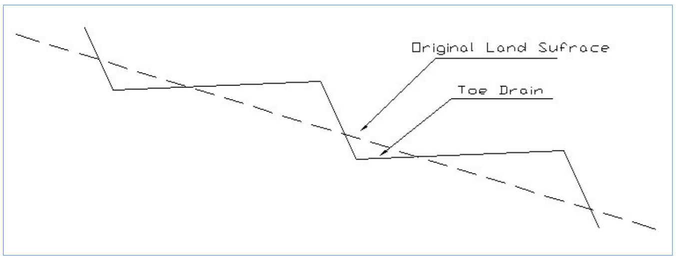


Fig. 5. Schematic diagram of terraces – sloped terrace

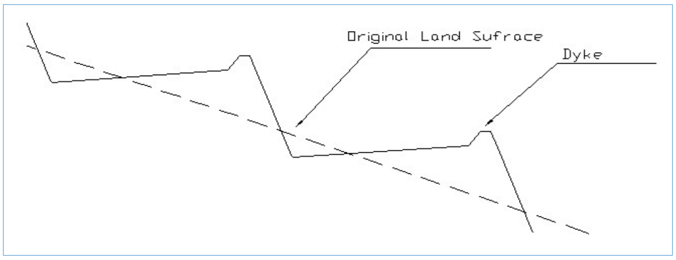


Fig. 6. Schematic diagram of bench type of terraces

4.2.4. Chair-type Protected Terraces

This kind of terrace is for the collection of water in places where the precipitation amounts are medium, and the infiltration rates are high. An example is shown in Fig. 7.

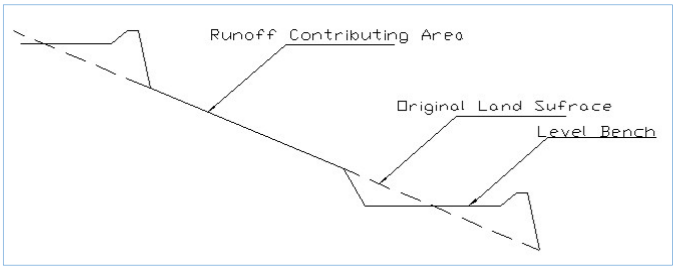


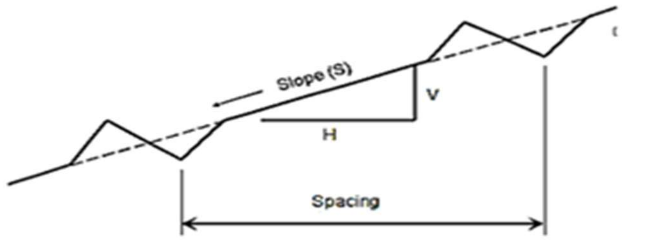
Fig. 7. Schematic diagram of Chair type of terraces

The main point for terraces is that the terraces provide curvature using the slopes on the curved plains. The plains (less or no slope) decrease erosion and pave the ground for infiltration providing moisture for plants to grow. For high precipitation regions, high sloes are necessary to control the amount of water retained by the soil. Typical details of construction are provided below in Table 1 and Fig. 8.

A typical procedure for soil terrace structures consists of terrace compaction by gradual filling. The side and edge of terraces must be higher than the slope to control sediments. The upper of these terraces have less slope than others. The upper and lower parts soil must be mixed thoroughly. Any variation in quality will require different kinds of terraces. In the different parts of terraces, it is necessary to cultivate different kinds of vegetation such as grass, and fodder, and at the edge of terraces, it is better to cultivate different fruit trees. The terraces are usually prepared during appropriate seasons, such as when there is not too much rain or drought. On terraces, the work must be started from the upper side of the slope to the lower side, and lastly, the outer sides of terraces must be consolidated by stones or wood, to avoid soil movement to the down slope.

Table 1. The distances between slopes

Average slope	V:H	Maximum spacing (meters)
12 or less	1V:8H or less	12
12 to 25	1V:8H to 1V:4H	10
25 to 40	1V:4H to 1V:2.5H	8



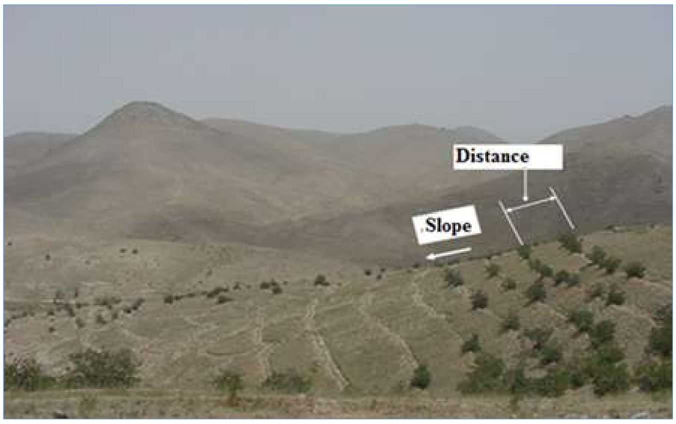


Fig. 8. Schematic diagram of terraces with varying slopes

5. Soil Erosion Prevention

Soil erosion prevention is conservation by preventing the loss of the topmost layer of the soil from erosion or the prevention of reduced fertility caused by overuse, acidification, salinization, or other chemical soil contamination. Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some areas. A consequence of deforestation is typically large-scale erosion, loss of soil nutrients, and sometimes total desertification. In some cases, the grass, trees, and vegetation are cultivated to create areas of relief. Using the terraces described above changes the water flow to reduce the soil erosion. For soil fertility, several types of fertilizers are used such as animal-based fertilizers, and chemicals-based fertilizers to keep nutrients and amount of water in the soil, using these terraces. Decreasing the agricultural areas and changing the infiltration capacity resulting from the slumping and sliding of soil by not selecting the right slope can be harmful to the soil and water capacity.

5.1. Methods of Soil Erosion Prevention

Soil erosion is a major problem as the history of soil erosion is closely tied to the development of human civilization and agriculture. Soil erosion is a natural process, but human activities have accelerated it significantly over time. The challenge lies in mitigating its effects while maintaining agricultural productivity to sustain growing populations. Soil protection is a vital aspect of soil conservation and involves strategies to prevent soil erosion, maintain soil fertility, and promote sustainable land use. There are different methods for preventing soil erosion and these processes are generally known as soil conservation methods, viz. agriculture, agroforestry, water management, soil stabilization, land use planning, soil management, and monitoring technologies.

Fig. 9. Terrace types, viz. horizontal, transverse, diagonal, based on the surface morphology and textures (adopted from open source)

Fig. 10. The sloppy area covered by straw (adopted from open source)

5.1.1. Soil Erosion Prevention for Agriculture

This is done to ensure sustainable crop production and maintain the health of the land. By protecting soil from erosion, degradation, and nutrient loss, farmers can sustain yields, improve resilience to climate change, and preserve the ecosystem. Some of the soil conservation for agriculture methods include tillage for enhanced water retention to reduce erosion and improve soil biodiversity. Crop Management methods include crop rotation, planting crops like clover, rye, or vetch between main crops to prevent bare soil exposure and add organic matter. Another method is intercropping, i.e. growing different crops together to reduce soil exposure. Yet another method is terracing and contour farming. As discussed above, terracing provides flat areas on slopes to reduce water runoff and soil loss, especially in hilly regions. Contour plowing provides natural land contours that slow water movement and minimize erosion on sloped fields.

Agroforestry is yet another method that is to plant crops between rows of trees to reduce wind erosion and stabilize the soil. Other methods include soil cover, mulching, and soil fertility management. In addition to water management, other methods are enhancing soil organic matter, such as the use of microbial inoculants promoting soil fertility and reducing dependence on chemical inputs. Lastly, using plowed ground also avoids soil erosion by reducing compaction for aeration. Plowing the slope areas to avoid soil erosion and pave the ground for infiltration.

5.1.2. Soil Erosion Prevention for Urbanization

Soil conservation in urbanized areas is essential to maintain environmental balance, prevent erosion, and mitigate the negative impacts of construction and development. Urbanization often leads to soil degradation through sealing, compaction, and contamination. Several methods are used for soil conservation for urbanization including green infrastructure development, soil erosion controls, stormwater management, soil sealing mitigation, land use planning, vegetation management, and waste pollution management, as part of community initiatives.

6. Methods of Preventing Soil Erosion

Preventing soil erosion involves implementing various techniques and strategies to protect the soil from being displaced by wind, water, or human activities.

6.1. Turfing

Turfing is a practical and effective method to prevent soil erosion by covering the soil surface with grass or turf (a dense layer of grass and its root system). It stabilizes the soil, reduces runoff, and provides long-term erosion control, especially in areas prone to erosion such as slopes, embankments, and construction sites, as shown in Fig. 10. Generally, this method is used at the soil wall and drainage areas. Turfing is a versatile and sustainable solution for soil erosion prevention. Integrating turf with other soil conservation practices provides effective protection and enhances the ecological value of the area.

6.2. Tree and Shrub Planting

Tree and shrub planting is a highly effective method for soil conservation, particularly in areas prone to erosion, land degradation, and environmental stress. Trees and shrubs stabilize soil, reduce erosion, and contribute to ecosystem health by improving biodiversity and regulating water cycles. In some sites, plants that cannot grow easily from seeding are first sown at the nursery and as seeding is prepared for planting, they are planted at the site. Such planting creates a dense network of roots in the soil. The main engineering functions of trees can also be used for slope support, and they take responsibility for civil engineering structures previously constructed on the top of the slope. Tree and shrub planting can be done on almost any type of slope having a slope angle of less than 30°. Generally, the top of the toe wall or any retaining structures are the best sites for tree and shrub planting (Fig. 11).

6.3. Dry Stone Masonry

This type of wall is very important for the village roads, and this kind of wall is very efficient and can be made at a low cost in sloppy areas. As this type of wall is from dry masonry walls, it can be made at a height of 3- 4 m from the ground surface. But in some places, the height of the wall can be more than 4m. Also, in those places filled with materials earthquakes, and seepage, these types of walls are bigger problems. Dry stone masonry walls are one of the most favored walls in rural roads of Afghanistan (Fig. 12) because they provide good drainage, they are cost-effective, and the chance of failure is low. For slope protection works, dry stone walls are suitable for a height of up to 3 m to 4 m. However, dry stone masonry walls of height greater than 4m are also used in some cases, but it is not the right practice for retaining wall construction. Exceptional lateral pressure in the backfill, seepage pressures, and vibration from vehicle movement as well as from earthquakes provoke the dry-stone masonry wall to fail.

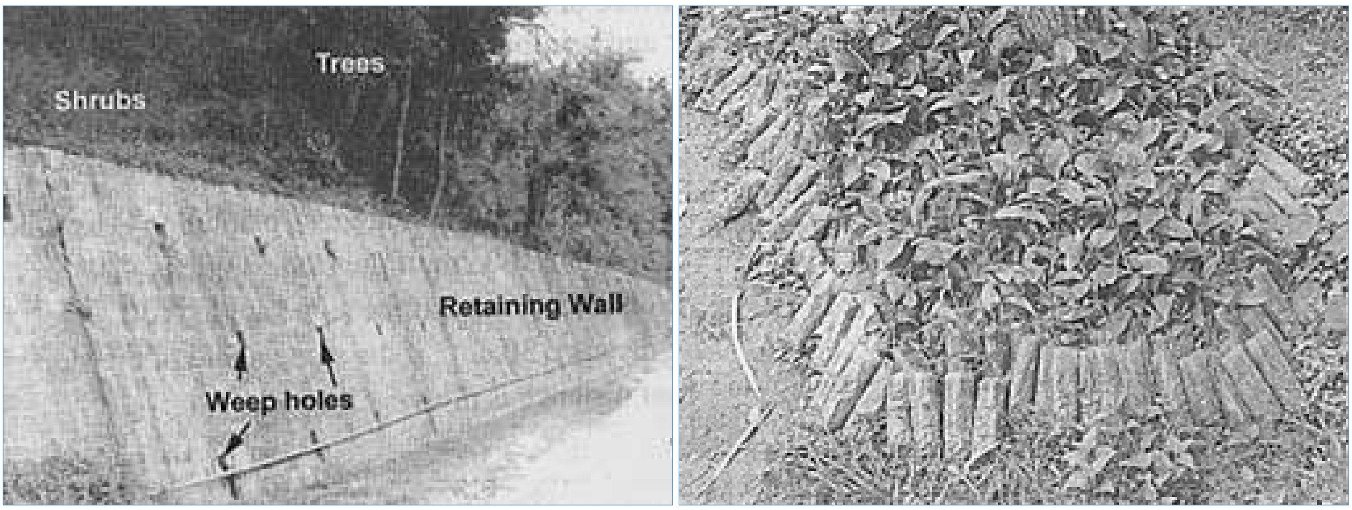


Fig. 11. Planting and shrubs (adopted from open source)

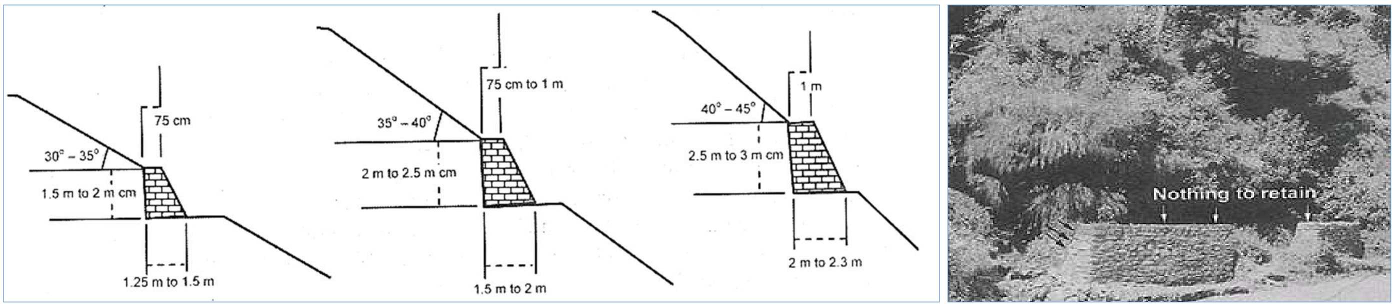


Fig. 12. Dry stone masonry in the sloppy area (adopted from open source)

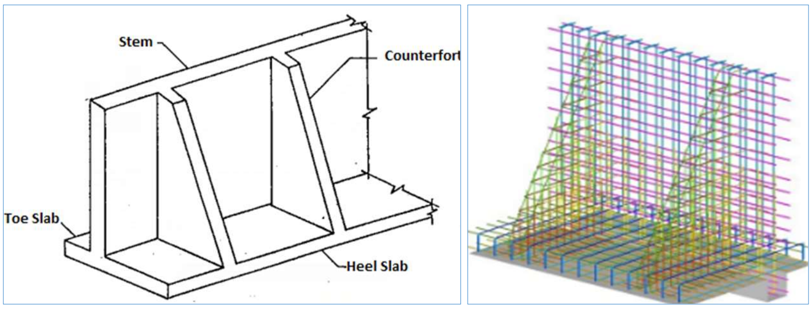


Fig. 13. Cantilever wall

The width-to-height ratio varies from 1:1 to 0.6:1 for wall heights of 1 m to 4m respectively. Skilled workmanship and fresh rock fragments are required for the construction of quality dry stone masonry walls. Sincere care is needed during the packing of stones because improper interlock of the stones reduces the strength and stability of the wall (Fig. 12). Similarly, all stone must be dressed, if it is rounded, into rectangular blocks. If practical, it is better to use big boulders at every 1m interval to tie the wall.

6.4. Cantilever and Counterfort Walls

Cantilever and counterfort walls are built of reinforced concrete. Such walls do not depend only on their own weight but also on the weight of backfill materials. Counterfort walls consist of a relatively thin stem and a base slab. The base is also divided into two parts, the heel and toe (Fig. 13) slabs. The heel is the part of the base under the backfill, while the toe is the other part of the base. These walls can be constructed to great height (max. height usually around 10 m). Most cantilever walls are economical to base connection. For greater heights, counterfort or buttressed walls are used, otherwise, the thickness of the stem of the cantilever wall becomes excessive. Both types of walls are relatively costly and require careful design and framework. These walls can also be precast in a factory or formed on-site. Thus, in Afghanistan, they are not common in bioengineering works.

6.5. Crib Wall

A crib wall is a type of retaining wall often used for soil conservation and stabilization on sloped or eroded land. It consists of interlocking frames or boxes typically made from wood, precast concrete, or steel, which are filled with soil, rock, or other materials to create a sturdy and stable structure, as shown in Fig. 14. Crib walls are usually quite large and can be out of scale and character with the surrounding landscape. Another wall similar to a crib wall is known as a bin wall consisting of steel boxes or bins that are bolted together in modular units and filled to form a wall. The past popularity of crib and bin walls, in particular, lies in the fact that they are both relatively inexpensive and quick to install. Key Features of a Crib Wall are its open design, modular construction, better drainage, and eco-friendly.

Fig. 14. Crib wall at the sloppy different materials (adopted from open source)

6.6. Gabion Wall

A gabion wall is another effective structure for soil conservation and stabilization. It is made of rectangular wire mesh baskets filled with stones, rocks, or other materials. These walls are widely used for controlling erosion, stabilizing slopes, and supporting soil in areas prone to erosion or landslides. Gabion walls mainly work on the shear strength of the rock fill for internal stability, and their mass or weight to resist external, lateral forces. Generally, the gabion walls consist of the sliding of stone and specific weight. The gabion wall is porous and is used in floods and mountain areas. Gabion walls are wire baskets made of course wire mesh. Gabion walls are constructed by sacking and tying wire gages filled with trap rock or native stone on top of one another to form a gravity-type wall (Fig. 15). Gabion depends mainly on the shear strength of the rock fill for internal stability, and their mass or weight to resist external, lateral earth forces. Thus, gabion walls are used in the site where the retaining wall needs to allow high amounts of water to pass through it. It is important to use a filter fabric with the gabion to keep adjacent soil from flowing into or through the cages along with the water. As relatively flexible and well-porous structures, they are useful in situations where movement might be anticipated. They are also easy to erect, and it is a cost-effective retaining structure.

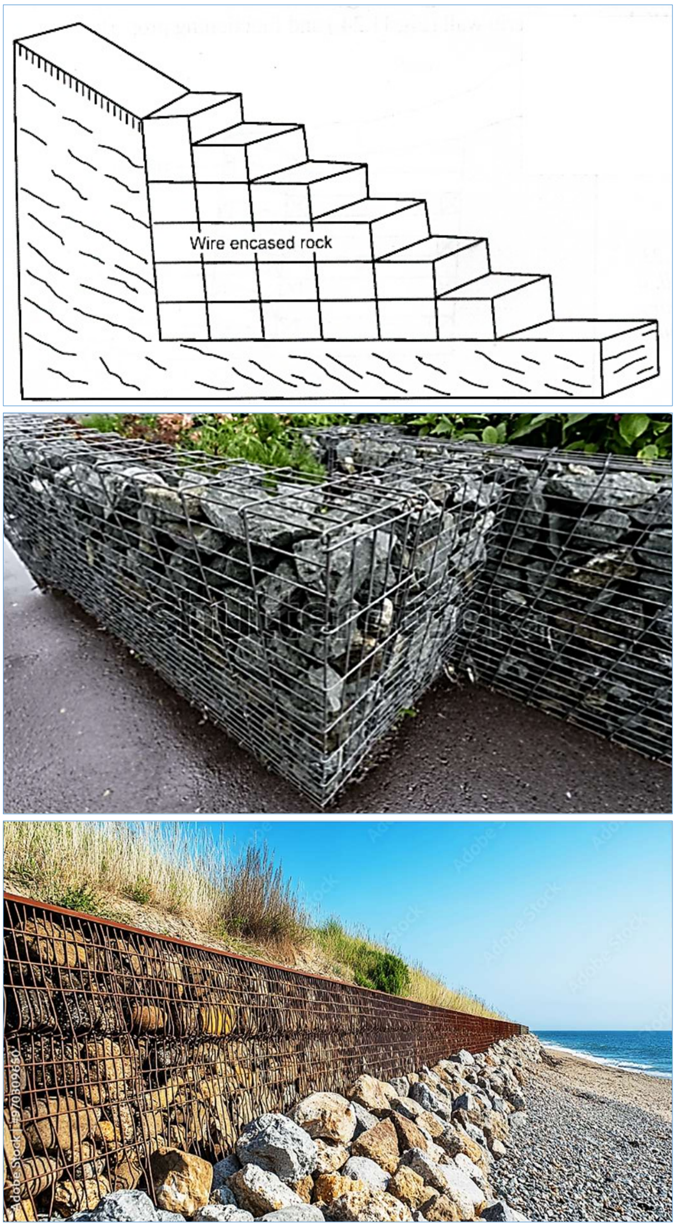


Fig. 15. Gabion walls at the mountain and flood areas (adopted from open source)

6.7. Reinforced Earth Wall

Reinforced Earth Walls (REWs) are engineered structures designed to stabilize soil and prevent erosion. These walls are often used in soil conservation, slope stabilization, retaining wall construction, and infrastructure projects such as roads and railways. Sometimes also called gravitational walls, it is filled with different materials on the backside. The original reinforced earth wall consists of a granular matrix or fill reinforced with successive layers of metal strips. The REW is based on the reinforcement of the earth through metal or plastic intrusion, which provides a simulated cohesion allowing the earth to stand vertically. Shear stresses that develop in the reinforced backfill are transferred via interface friction to tensile resistance in the metal strips. The strips are connected to facing elements – typically thin, precast concrete panels stacked atop one another (Fig. 16). The REW is one of the better solutions that can be used for soil conservation. The example shown below is a reinforced earth wall with hexagonal-shaped panels.

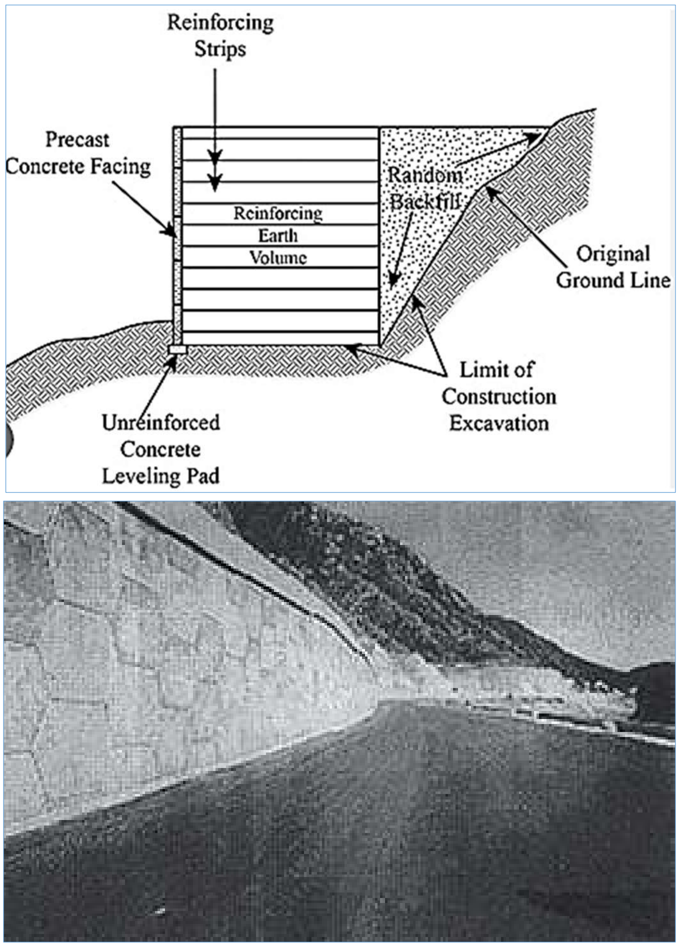


Fig. 16. Reinforced earth wall at the lateral of the road, before slopy areas (adopted from open source)

6.8. Pile and Tie Back Wall

Pile and Tie-Back Walls are another effective solution for soil conservation, particularly in areas with high lateral soil pressures, unstable slopes, or erosion-prone terrains. These walls use piles driven into the ground and tie-back anchors to stabilize the soil and control movement. Pile and tieback walls are non-gravity structures and are rarely used as retaining walls where less space or foundation conditions limit the use of gravity structures. Piles commonly consist of a row of bored, cast-in-place concrete cylinder piles or normally driven steel H- piles, as shown in Fig. 17. Vertical structural elements are made of steel, concrete, or timber and are driven deep into the ground to provide foundational support and resist lateral and vertical forces. The tie-back Anchors are high-strength steel rods or cables anchored into stable soil or rock layers behind the wall, which transfer forces from the wall into stable ground to counteract lateral soil pressure. The structures include perforated pipes or weep holes for drainage to prevent water accumulation behind the wall.

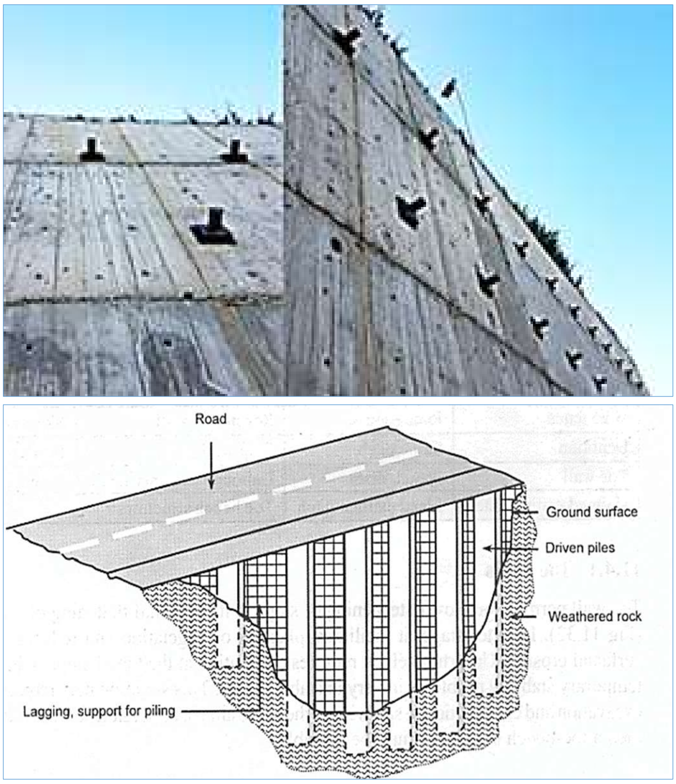


Fig. 17. Pile and tie back wall at the mountains and sloppy areas (adopted from open source)

6.9. Toe Wall

This type of structure is simple but effective and is used for soil conservation and erosion control, particularly at the base (toe) of slopes, embankments, or retaining walls. The primary purpose of a toe wall is to stabilize soil, prevent erosion, and reduce the risk of slope failure by anchoring the base of the slope or structure. The toe wall permits overstepping at its base and flatting of the slope above (Fig. 18). In the latter stage, it facilitates the planting of vegetation which reduces the danger of surficial erosion. Although the wall prevents erosion and provides slope stabilization as a cost-effective solution, the wall is not suitable for very steep or high slopes. It has limited effectiveness in areas with heavy water flow or severe erosion without additional measures like riprap or gabions.

This leads to toe bench structures which are horizontal or near-horizontal platforms created along the slope, usually combined with retaining walls, vegetation, or drainage systems. These structures interrupt the flow of water, reduce its velocity, and allow sediments to settle, thereby reducing erosion and enhancing slope stability. These structures are very similar to the toe wall but different in the amount of excavation required at the toe of the slope and the amount of backfill. Usually, it is constructed far away from the foot of the slope incorporating a level of a very gentle sloping backfill. Vegetation can be readily established on the more or less level bench at the foot of the slope. A toe bench can buttress the base of the slope and catch debris coming rolling down the slope (Fig. 19).

Fig. 18. Toe wall at the agricultural lands (adopted from open source)

Fig. 19. Toe bench structures (using personal device)

6.10. Revetment Wall

A revetment wall is a protective structure used for soil conservation, particularly along slopes, riverbanks, coastal areas, or embankments. It helps prevent soil erosion, stabilize slopes, and protect against the impact of flowing water, waves, or rainfall. These walls are commonly constructed using stones, concrete blocks, or other durable materials, and they are designed to absorb and deflect erosive forces. When erosion at the toe of the slope is expected, revetment walls are built, since the walls are designed for slope protection rather than slope support. In general, these walls are constructed of dry-stone masonry blocks and sometimes strengthened by mortared masonry such as composition stone mortared masonry (Fig. 20). Usually, revetment walls are used when vegetation is not adequate to protect the slope such as on very steep slopes, sharp directional changes in stream flow, and sharp turns in the stream or channel itself, where streams are constricted by bridge or culvert.

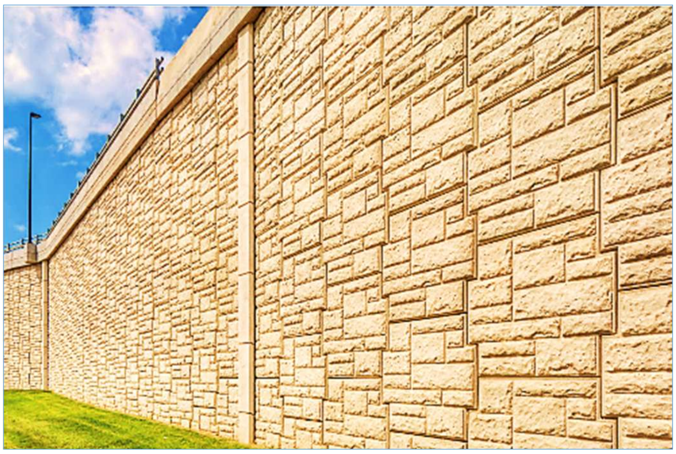


Fig. 20. Revetment wall beside the roads, to avoid soil creeps (using personal device)

Sometimes revenants wall is also called mechanical riprap revetment if the stones are placed on the surface in a single layer just to cover the slope. Nevertheless, revetment always armors the slope against erosion and a high degree of infiltration. In bioengineering works, revetment walls are generally used at the base of the cut slope where seepage erosion creates the slope problem of undercutting. Revetment reinforcement may include geotextiles or geogrids behind the wall for added stability and erosion resistance (Fig. 21). The drainage systems are integrated into the structures to manage water flow and prevent hydrostatic pressure buildup.

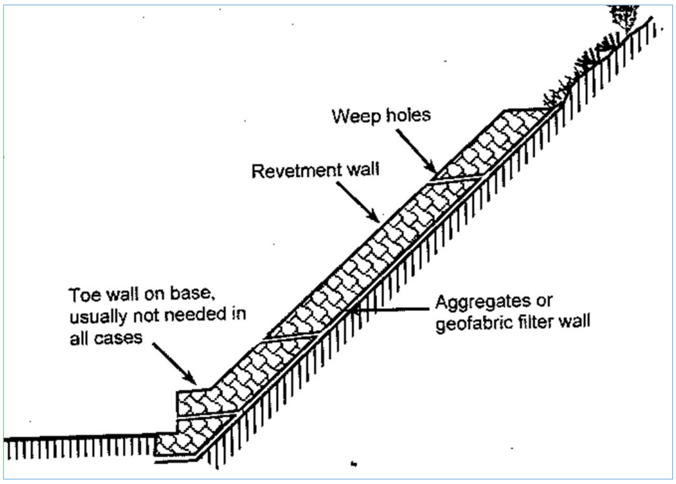


Fig. 21. Prevent wall

6.11. Check Dam

A check dam is a small, temporary, or permanent barrier constructed across a natural or artificial channel to slow down water flow, reduce soil erosion, and promote water conservation. Check dams are commonly used in agricultural fields, degraded lands, and watersheds to trap sediment, increase water infiltration, and improve soil stability. For these structures, the slope of the area is much smaller with different types of trees, vegetation, and shrubs to reduce erosion. Check dams are usually low, temporary barriers erected across a narrow water course (gully) to retard flow, minimize erosion, and promote the deposition of sediments. Check dams are usually placed at critical points along the gully. The critical point is called as Knick point, where a sudden change in gully gradient is detected. Similarly, a check dam is also placed at the gully head, where the gully is active (Fig. 22). These critical locations are easily identified by the help of the longitudinal profile of the gully as well as recent exposure of soil and removal of any vegetation cover. The Knick Point area can be protected by the planting of trees and shrubs as part of bioengineering works around the wing of the check dam. In addition to placing check dams in these critical positions, dams must be constructed to a design spacing that is related to the height of the dam and the gully gradients. Chack dam may be of stone mesh, with an apron of similar construction or timber. The establishment of a thick growth of trees or shrubs along the banks and bed of the channel also retards velocity and scour.

Fig. 22. Chak dam at the front of different streams (using personal device)

6.12. Surface Drainage

This is an essential technique in soil conservation that involves the removal of excess water from the surface of the land. Proper surface drainage prevents waterlogging, reduces soil erosion, and enhances the productivity of the land. It is especially useful in areas with heavy rainfall, poorly drained soil, or slopes prone to runoff and erosion. It is the removal of surface or subsurface water from an area by natural or artificial means. The term surface drainage is normally applied to the removal of excess water by canals, drains, ditches, culverts, and other structures designed to collect and transport water either by gravity or by pumping. There are some good prevention techniques which include reshaping of slope and construction of ditches, cascade, chute, and canals (Figs. 23a–b). So that rainwater cannot get inside the soil and build up the pore water pressure, the schematics show good engineering works and surface drainage for surface erosional control and subsurface failure.

6.13. Prop Walls and Dentition Walls

In engineering, a prop wall is known as a support wall. Both prop walls and dentition walls are engineered structures used for soil conservation and slope stabilization. These walls serve different purposes but are often part of broader strategies to prevent soil erosion, improve slope stability, and manage water flow. Usually prop wall is built on softer strata to support overlying younger strata and bear a load of overhang strata to some extent. Conversely, dentition walls are used to cover the highly weathered softer strata, and they usually do not offer support to the weight of overlying strata. A dentition wall is a series of interlocking or staggered retaining walls, often constructed in stepped formations. The term "dentition" reflects the resemblance of the wall's design to teeth. This structure is designed to retain soil while allowing for the natural drainage of water. This technique is particularly useful in bands of alternating hard and soft rocks, such as in the slope's areas. Voids and ditches are formed on the slope of moderately weathered rocks because of rigorous gully erosion and are also covered by the dentition wall (Fig. 24).

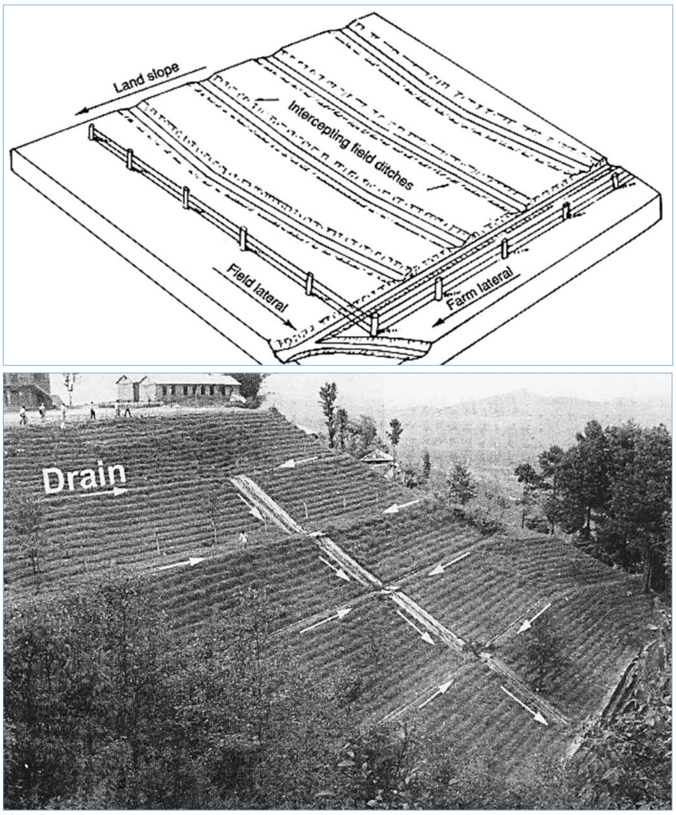


Fig. 23. Surface drainage at a: the waterfall and b: cascade areas (adopted from open source)

6.14. Stone Pitching

Stone pitching is a method of soil conservation that involves covering slopes, embankments, or channels with a layer of stones or rocks. This technique helps protect the soil from erosion caused by water flow, wind, or gravitational forces. Stone pitching is widely used in areas prone to erosion, such as riverbanks, road embankments, and agricultural lands. Stone pitching is one of the easiest and cheapest small-scale civil engineering systems useful to apply for surface armoring functions. It gives a strong covering of the surface and controls surface erosion. It can stand even in strong water currents and is widely used in engineering work mainly for rill and sully erosion control, as shown in Fig. 25. Some plants can be also seeded between the gaps of pitched stone for catch functions, called vegetation stone pitching and is considered as bioengineering system rather than civil engineering structures. This technique is mainly useful on slopes up to 30˚ having a heavy seepage problem. Locally available stones or rocks, sometimes supplemented with mortar or concrete for additional stability.

Fig. 24. Roadside slope protection by wattle fence

Fig. 25. Stone pitching at the face of water stream areas (using personal device)

6.15. Jute Netting

Jute netting is a biodegradable and eco-friendly soil conservation method that involves laying woven jute fabric over the soil surface. It is particularly effective in preventing soil erosion on slopes, embankments, and areas with loose or disturbed soil. Jute netting stabilizes the soil, facilitates vegetation growth, and gradually decomposes to enrich the soil. The term jute is also used for the fiber of two species, viz. *corchorus capsurlaris* and *corchorus oliorius*. A Jute net is generally woven into a wire net to make inert structures (Figs. 26a–b).

Fig. 26. Jute and coir net used for slope cover in bioengineering works

6.16. Wattle Fence

A wattle fence is a traditional soil conservation structure made from woven wooden branches or saplings, which are often planted vertically into the ground and interwoven horizontally to form a barrier. This method is particularly effective in controlling soil erosion, stabilizing slopes, and protecting areas that are prone to water and wind erosion. Wattle fences are simple to construct, eco-friendly, and serve multiple purposes in soil conservation. These fences are typically constructed from locally available materials such as willow, hazel, or other flexible, durable branches and saplings. The branches are cut and woven in a way that forms a strong, flexible barrier, as shown in Fig. 27. When properly maintained, wattle fences can last for many years. Using wattle fences in conjunction with other erosion control methods such as stone pitching, jute netting, or check dams can enhance overall effectiveness.

6.17. Wire Nets for Soil Conservation

Wire netting is a method used for soil conservation, particularly for preventing soil erosion, stabilizing slopes, and protecting vulnerable soil surfaces. It involves using wire mesh or netting made from galvanized steel or other durable materials to support soil, control erosion, and sometimes even promote vegetation growth. Wire netting is commonly employed on steep slopes, embankments, riverbanks, and construction sites. In this kind of structure, boulders, cobbles, and pebbles are commonly used. Wire netting is often used when the slope is highly weathered and or a new slope will weather quickly to unravel from the slope. Usually, gabion wire mesh is used in wire netting as the most effective technique for wire net to drape the mesh on the slope and allow the material to make its way to the base of the slope of the wire net (Fig. 28).

Fig. 27. Wattle fence at the agricultural lands (using personal device)

Wire netting can be used along riverbanks and streambeds to prevent erosion caused by high water flow and bank undercutting. Wire netting can be used in conjunction with other methods like stone pitching, jute netting, or vegetation planting for more effective erosion control. Adding geotextiles beneath the wire mesh can improve soil stability and increase the efficiency of the system by reducing water infiltration. Also, Asing coated or specially treated wire mesh can improve its longevity and resistance to environmental degradation.

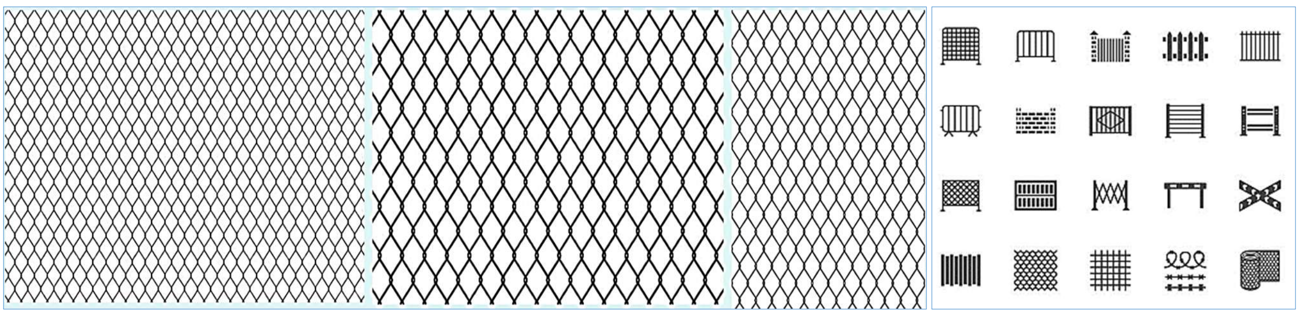


Fig. 28. Wire net at the river's streams

Fig. 29. Horizontal line of grass plantation (using open source and right panel personal device)

6.18. Tree and Grass Planting

Tree and grass planting is a fundamental method of soil conservation that uses vegetation to prevent soil erosion, improve soil structure, and enhance water retention. By strategically planting trees, grasses, and other vegetation, soil conservation efforts can significantly reduce the impact of wind, water, and human activities on the soil surface. This method is widely used in agricultural fields, hilly areas, riverbanks, and other erosion-prone regions. There are definite patterns of grass plantation such as horizontal line of grass planting.

6.18.1. Horizontal Line of Grass Planting

In this pattern, grass slips and clumps from seed are planted in horizontal lines on the slope. The horizontal line of the grass plantation (Fig. 29) provides surface cover, retards surface runoff, and catches surface debris.

6.18.2. Vertical Line of Grass Planting

In this pattern, grass slips and clumps grown from seed are planted in vertical lines on the slope. This system provides surface covers and drains surface water along the vertical plantation line (Fig. 30).

Fig. 30. Vertical Line of grass plantation (using personal device)

6.18.3. The Diagonal Line of Grass Planting

In this pattern, grass slips and clumps grown from seed are planted in diagonal lines on the slope. Any site having a slope of less than 65˚ and fine soil materials is the best site for the diagonal line of grass planting (Fig. 31).

6.18.4. Brush Layering

Brush layering consists of live plant cutting in small terraces excavation into the slope. Terraces can range from 30 cm to 100 cm in width. In general hardwood cutting is inserted horizontally into two layers into soil across the slope (Fig. 32).

Fig. 31. Diagonal line of grass plantation (personal device)

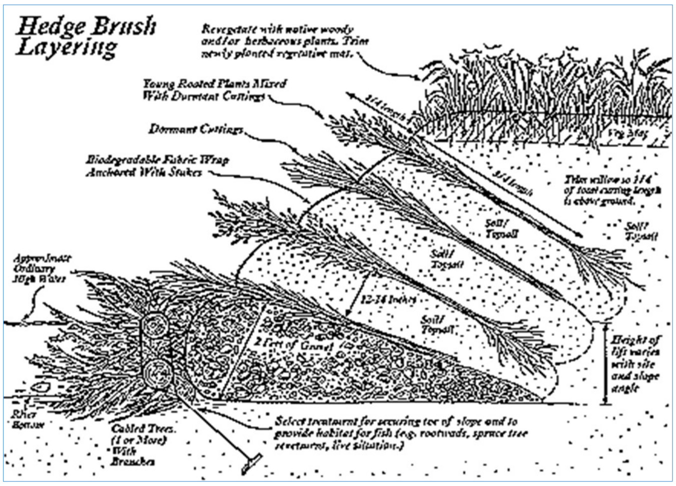


Fig. 32. A schematic view of roadside slope protected by brush layering integrated with other vegetation system and civil engineering structures (Source – open source)

6.18.5. Random Grass Planting

Rotted grass slips, stem cutting, or seeding are planted randomly on a slope but with specific spacing (Fig. 33). This method is suitable for steep slopes having severe problems with surface erosion.

6.18.6. Palisade

When hardwood cutting is inserted vertically in two rows into soil across the slope (Fig. 34), such vegetation structures are called palisades. This system forms a strong barrier and traps the materials rolling down the slope.

Fig. 33. Random of grass plantation (personal device)

Fig. 34. Palisade vegetated system (using personal device)

6.18.7. Live Staking

When, the live, vegetation, and woody cuttings are inserted perpendicular to the slope and single cuttings are approximately 0.25 – 0.4 m in diameter and 0.6 – 0.75 m in length are used then the pattern is called Live staking. Live staking is similar to the palisade but only a single line of cutting is used in a single line of vegetation system. For this purpose, cutting should have a round cut top and slanted bottom. The cutting is installed 60 – 90 cm apart using triangular spacing, which gives a stake density of about 4 per seq m (Fig. 35).

6.18.8. Facines

A bundle of wood or sticks used for bioengineering purposes to line or fill a trench is called fascine (Fig. 36).

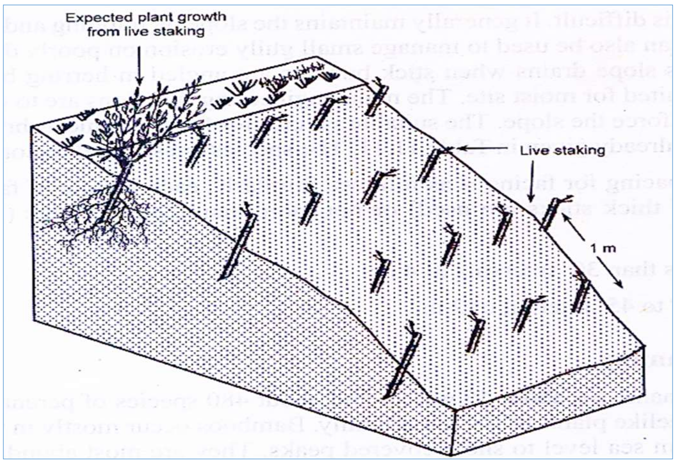


Fig. 35. Block diagram of Live staking

Fig. 36. Fence implemented as a bioengineering system (using personal device)

6.19. Live Check Dam

A live check dam is an innovative method of soil conservation that combines traditional damming techniques with the use of living plants, particularly grasses, shrubs, and trees, to stabilize the structure and enhance its effectiveness. Unlike a conventional check dam, which is made primarily of stone, concrete, or other non-living materials, a live check dam utilizes the natural properties of vegetation to provide long-term stabilization and erosion control (Fig. 37). The basic structure of a live check dam involves creating a barrier or a series of barriers along a stream or riverbed to slow down the flow of water and prevent soil erosion. These barriers can be built with natural materials, such as logs, stone, or branches, combined with live vegetation. The dam is reinforced with the roots of live plants, which grow through or along the structure, providing added strength to the dam and increasing its erosion resistance over time. The combination of water flow restriction and vegetation helps protect soil from being washed away, particularly in areas subject to heavy rainfall or flood events. Live check dams are natural solutions that contribute to ecosystem health and biodiversity, unlike traditional dams made from concrete or stone, which can disrupt natural habitats. Using live plants reduces the cost of construction, as materials like stones or concrete are expensive and require significant labor to install. The plants themselves are inexpensive and easy to obtain. As the plants mature, their root systems help to reinforce the dam, making it more resilient to water flow over time, unlike traditional check dams which can deteriorate due to weathering.

Fig. 37. Live crib wall on toe of slope (using personal device)

6.20. Live Crib Wall

A Live Crab Wall is an innovative method of soil conservation that utilizes the combination of physical barriers and live vegetation to stabilize soil, prevent erosion, and provide ecological benefits. This method draws its name from the crab-shaped or interwoven design of the structure, which mimics the shape of a crab's claws. It typically involves using living plants or trees that grow through the wall, enhancing its strength and sustainability. The technique is especially effective on steep slopes, along riverbanks, and in areas prone to soil erosion. The structure is filled with suitable backfilling materials and live branch cutting, which are packed inside the crib (Fig. 38). It is important to choose an erosion-prone area, such as riverbanks, steep slopes, or areas susceptible to wind and water erosion. Also, it is necessary to assess the soil type, water flow, and the potential for vegetation to thrive in the area. While the physical barrier of a live crab wall may be installed quickly, it can take time for the plants to grow and fully establish their root systems. During the initial phase, the wall may not be as effective at preventing erosion until the plants have matured.

6.21. Branch Packing

Branch packing is a soil conservation technique that involves using branches, twigs, and other plant materials to stabilize soil, control erosion, and improve water retention in areas prone to soil degradation. This technique is particularly useful in areas with steep slopes, gullies, or places that experience high levels of rainfall or runoff. Branch packing helps reduce the velocity of surface water, promote infiltration, and prevent the loss of soil from the surface. The process of branch packing essentially creates a physical barrier that traps soil, reduces water flow, and encourages the establishment of vegetation, which further stabilizes the soil. It is an eco-friendly and cost-effective approach to soil conservation. Branch packing consists of alternating layers of live Branch cutting and compacted backfill to repair small slides, head cuts, and derision in slopes (Fig.39).

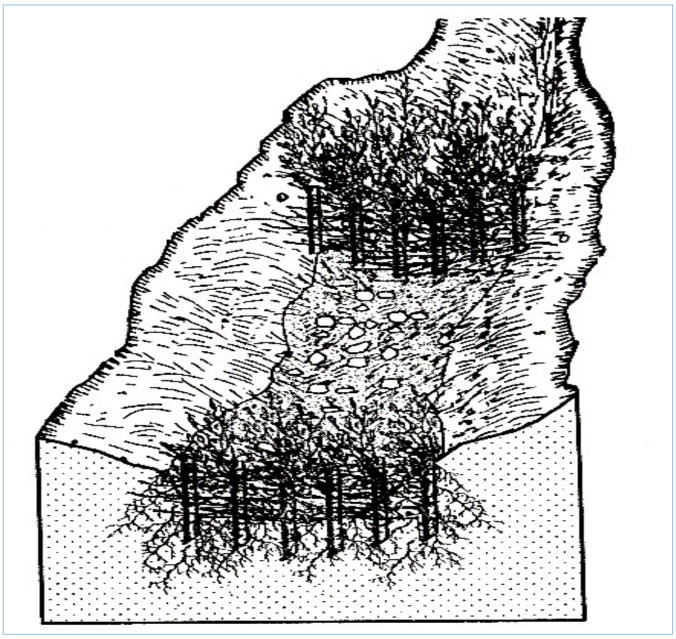


Fig. 38. Live check dam in a gully

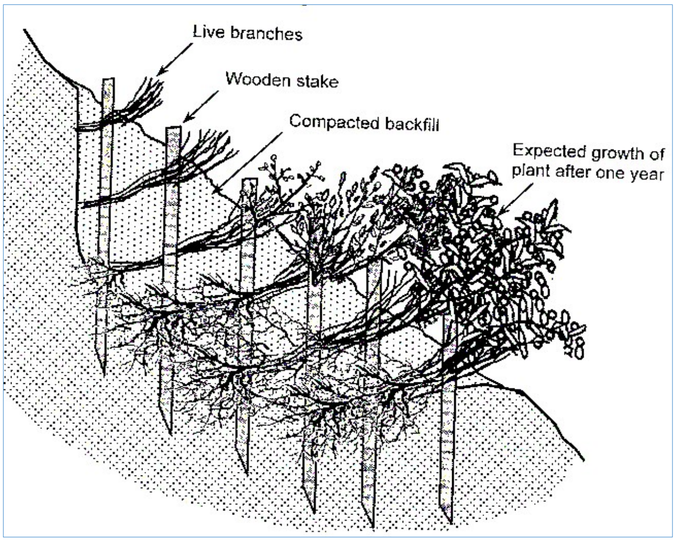


Fig. 39. Schematic diagram of an established growing branch backing installation. (Using open source)

6.22. Vegetation Gabion Wall

As we know, gabions are stiff boxes flexible rolls of close-meshed wire filled with pebbles and cobbles. Between gabion boxes and within them, living branches are introduced to the root in such structures are called vegetation gabion walls (Fig. 40).

6.23. Vegetation Stone Pitching

Vegetated stone pitching involves tamping live cutting of plant materials and seeds of deep-rooted planted into the soil between the joints or open spaces in stones that have been placed on the slope (Fig. 41).

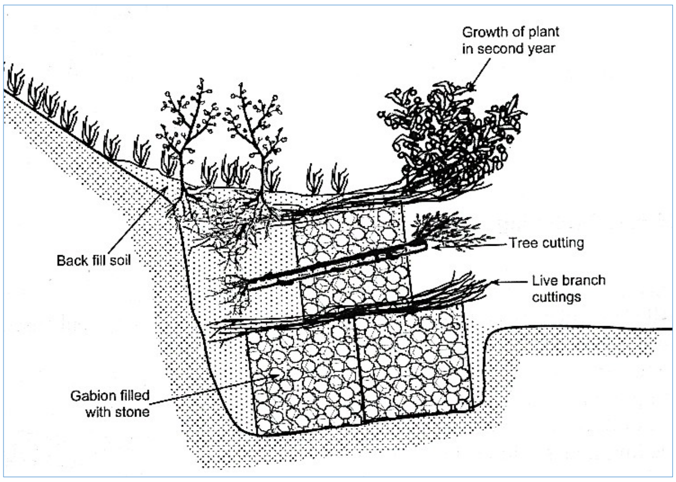


Fig. 40. Vegetated gabion wall

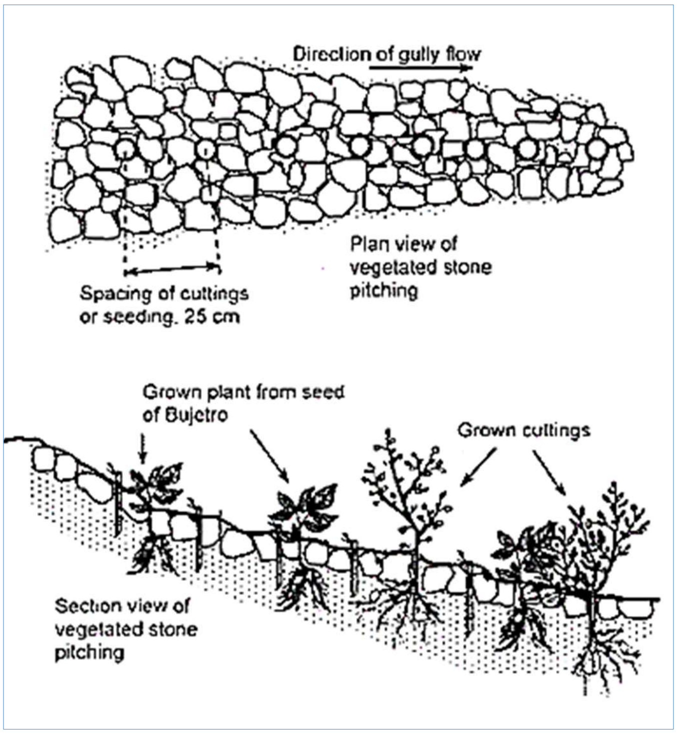


Fig. 41. Vegetated stone pitching

6.24. Mulching

Mulching is a widely used soil conservation technique that involves covering the soil surface with a layer of organic or inorganic material to improve soil health, prevent erosion, conserve moisture, and promote plant growth. It helps create a protective barrier over the soil that shields it from the forces of wind and water, reducing erosion and the loss of valuable topsoil. Mulching is a simple, cost-effective, and sustainable way to improve soil conditions, especially in areas prone to erosion, moisture loss, or temperature fluctuations. Nevertheless, it is temporary systems like grass seeding, and tree seeding (Fig. 42).

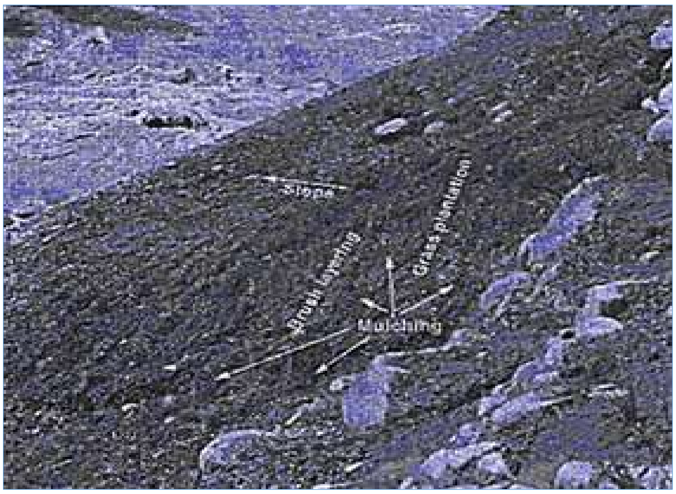


Fig. 42. Mulching on the slope (using open source)

7. Conclusions

In Afghanistan we have seasonal precipitations during the spring and winter seasons. Also, sometimes in the summer season, there are flash floods, as a result, more soil in Afghanistan is eroded because during this season there is no vegetation cover due to soil run-off. Soil erosion is one of the major problems in the world. Historically, more communities have faced this problem and during the last century, most attention to soil erosion has been paid. Thus, soil protection is one of the important tasks and part of global study. There are different methods for avoiding soil erosion and these processes are generally called soil conservations. This review provides a basis for the investigation and a detailed overview of soil conservation methods. Generally, there are three variations. The first has large slopes and the velocity of the river is much higher. There is more erosion in the riverbeds (downcutting) and in this river course, transport of larger sizes such as boulders, cobbles, and pebbles are transported, and the river flow is turbulent because this river experiences more friction. The second variation of the river course is where the velocity of flows is slightly slower than the upper course, and there is the slope of the river is medium. Here there is transport of medium sizes such as granules and sands, and the river flows are laminar and turbulent, and the river is more eroded along lateral paths and beds of rivers. However, we can still find some larger particles of sediment in these river channels. From this, it is clear that in the upper and middle courses, we cannot find any vegetation cover and all ground is bare, because all of the soil is transported to the lower and plains areas. Also, from the viewpoint of groundwater, we cannot find groundwater in the upper sloppy mountain areas, because there are all bedrocks and aquifage layers (without porous), only we can find groundwater in the lower plain areas. But it is very important to control soil in slopy mountain areas by different methods such as terraces, retaining walls, protection walls, turfing, tree and shrub planting, dry stone masonry, crib walls, Gabion walls, reinforced earth walls, pile and tie back wall, the wall, revetment wall, check dam, surface drainage, stone pitching, prop wall and dentition wall, wattle fence, wire net, tree, and grass planting methods. By this, we can control soil at the mountains' sloppy areas. To control the soil using these methods, we need national and International professional expertise to avoid much bigger problems at a later stage. In the mountains, skirts about more materials are eroded by different types of streams, and as a result, the bedrock is bare at the land surface there consists of aquifage (Impermeable layers) and we cannot have groundwater in the mountain areas. Generally, in the mountain slopes and skirts, the erosion of soil is more of the medium course, and we can find more than bedrock and boulders that do not store groundwater.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Data is contained within the article.

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