ECOSYSTEM-BASED DISASTER RISK REDUCTION

A HANDBOOK FOR PRACTITIONERS

KERALA INSTITUTE OF LOCAL ADMINISTRATION
UNITED NATIONS ENVIRONMENT PROGRAMME

JULY 2022

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Ecosystem-based Disaster Risk Reduction
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The handbook has been prepared with the support and cooperation of Dr. Muralee Thummarukkudy, Dr. Karen Sudmeier-Rieux, Ms. Saeeda Gouhari and Ms. Devashree Pillai of the UNEP. We are also grateful to other agencies under the Government of Kerala, namely the Mahatma Gandhi NREGS State Mission - Kerala, the Kerala State Disaster Management Authority, the Kerala State Directorate of Soil Survey and Soil Conservation, the Kerala State Landuse Board, the Haritha Keralam Mission, the Centre for Water Resources Development and Management, the Kerala Forest Research Institute and the Ayyankali Urban Employment Guarantee Scheme Mission for their support.

There are a vast number of experts to whom we are deeply indebted for their insights and inputs which has helped shape this handbook. We believe this handbook will be a ready reckoner of sorts on how to apply interventions under the Mahatma Gandhi National Rural Employment Guarantee Scheme and other similar schemes in a manner so as to reap the benefits of ecosystem-based disaster risk reduction.

ABBREVIATIONS

AUEGS	Ayyankali Urban Employment Guarantee Scheme
CBNRRM	Community-based Natural Resource and Risk Management
CBOs	Community-based organizations
CCA	Climate Change Adaptation
CSR	Corporate Social Responsibility
CRZ	Coastal Regulation Zone
CVCA	Critically Vulnerable Coastal Areas
DRR	Disaster Risk Reduction
EbA	Ecosystem-based Adaptations
Eco-DRR	Ecosystem-based Disaster Risk Reduction
EEZ	Exclusive Economic Zone
EGS	Employment Guarantee Schemes
GAD	Gender and Development
GCMs	General Circulation Models
GIS	Geographic Information System
GPS	Global Positioning System
HTL	High Tide Line
KILA	Kerala Institute of Local Administration
Mahatma Gandhi NREGA	Mahatma Gandhi National Rural Employment Guarantee Act, 2005
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MIS	Management Information System
MoEF	Ministry of Environment and Forests
NBS	Nature-Based Solutions
NCZMA	National Coastal Zone Management Authority
NGOs	Non-Governmental Organizations
NRM	Natural Resource Management
RCM	Regional Climate Model
SCZMA	State Coastal Zone Management Authority
SDGs	Sustainable Development Goals
SHGs	Self-Help Groups
SFDRR	Sendai Framework for Disaster Risk Reduction
TNA	Training Needs Assessment
UNEP	United Nations Environment Programme
UNISDR	United Nations International Strategy for Disaster Reduction

PREFACE

Ecosystem based-Disaster Risk Reduction (Eco-DRR) as a concept emerged in international policy under the aegis of the United Nations Environment Programme in 2013. Whereas nature-based solutions is a much larger canvas that encompasses all manner of nature-related solutions, Eco-DRR is more focused on the natural defences offered by ecosystems against the rising impacts of disasters while keeping communities at the helm. In India, the adoption of the Eco-DRR approach offers an opportunity to dovetail local and traditional knowledge about ecosystems with new age strategies and technologies to develop optimal defenses against increasing natural disasters. But in recent years, the vast destruction of natural ecosystems as a result of the current developmental paradigm has led to loss of ecosystems, ecosystem services as well as the knowledge and relationship with nature. Parallel to this, is the fact that official initiatives to protect and conserve ecosystems have often been exclusionary, placing local communities at odds with the conservation process.

The concept of Eco-DRR alternatively places communities in charge of ecosystem governance. In India today, communities along with local governments are shouldering the challenge of protecting and conserving ecosystems to defend themselves. From across the country, there are numerous case studies and success stories of efforts taken by local groups, government bodies and non-governmental organisations. A close inspection of many of these show that with access to locally available funds and resources, such efforts can definitely be scaled up and mainstreamed to reap more benefits.

This Handbook therefore aims to provide practitioners across the country a foundation on some typical examples of combined civil structures and natural resource management works to help practitioners in standardizing design practices and use of state-of-art technology. It also provides basic guidance on how to leverage funds under the Mahatma Gandhi National Rural Guarantee Employment Scheme (Mahatma Gandhi NREGS) and similar schemes related to Natural Resource Management for implementing Eco-DRR interventions. It This Handbook has been developed by the Kerala Institute of Local Administration (KILA), in partnership with the United Nations Environment Programme (UNEP), with funding from the European Commission.

Dr. Joy Elamon
Director General, KILA

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INTRODUCTION

1 INTRODUCTION

Ecosystems have played a great role in disaster risk reduction (DRR) for centuries. Ecosystem-based Disaster Risk Reduction (Eco-DRR) is now well recognised by communities engaged in disaster-risk mitigation and environmental conservation. Eco-DRR is the use of holistic and sustainable approaches that utilize biodiversity,

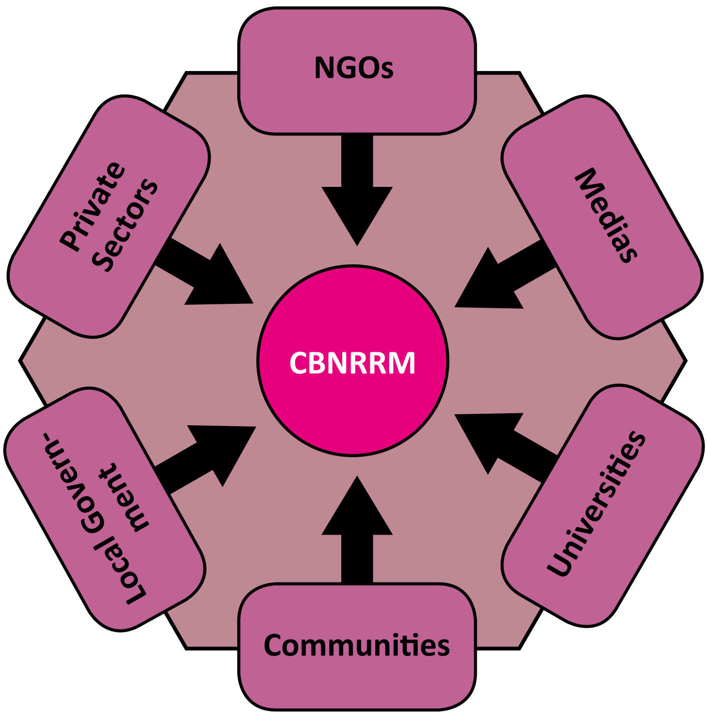


Figure 1.1: Stakeholder in CBNRRM
Source: Sudmeier-Rieux, 2019

ecosystem functions and services to manage the risks of climate-related impacts and disasters, and can be very effective in reducing the impact of various climatic disasters such as landslides, flood protections, coastal hazards, fires, etc (Renaud, 2013). If combined with conventional measures such as retaining walls for slope protection, embankments and dykes for flood risk mitigation or flood walls and bank revetments for sea wave erosion control, these measures are more sustainable, suited to the landscape and contribute additional strength and provide protection from disaster risks.

Eco-DRR addresses both climatic and non-climatic hazards and provides solutions to different types of hazards (e.g., storms, landslides, drought). Eco-DRR is defined by Estrella and Saalismaa as the "sustainable management, conservation and restoration of ecosystems to provide services that reduce disaster risk by mitigating hazards and by increasing livelihood resilience". Therefore, these measures are designed not only to reduce the impacts of the disaster events but to also provide co-benefits in the form of environmental conservation, functioning of ecosystem services, conservation of water resources and alternative livelihood options. The attempt here is to build resilient communities.

Furthermore, Eco-DRR approaches prioritize Community-based Natural Resource and Risk Management (CBNRRM), an approach that combines the sustainable management of natural resources and risks in a given area with community participation. As a participatory process, Eco-DRR helps strengthen local capacity for emergency preparedness and increase the resilience of livelihoods.

There is great scope for leveraging Eco-DRR through the Mahatma Gandhi National Rural Employment Guarantee Scheme. While the programme is supported by the Union government, implementation is undertaken at the local level. The programme has been on-going since 2006 and the project is being implemented in all the states in India.

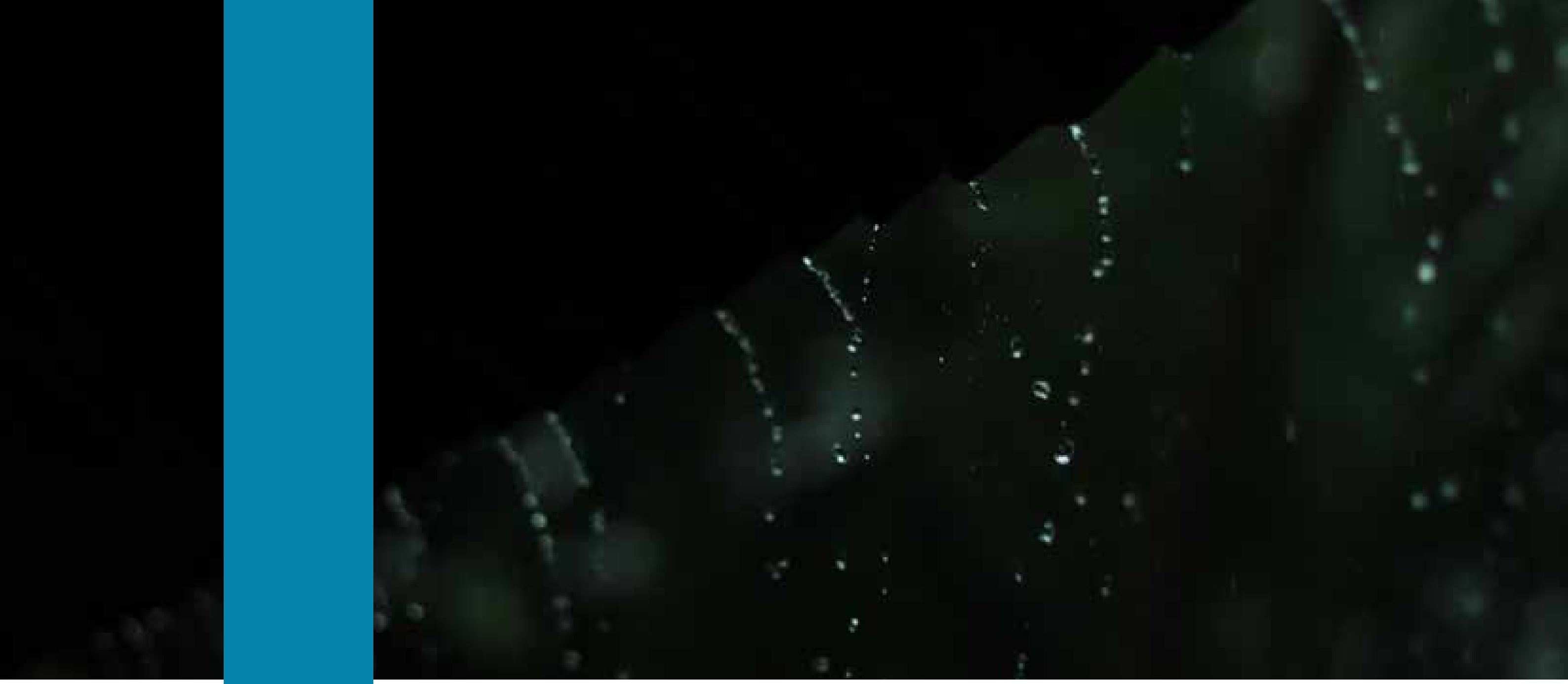
In addition to the mandate of providing employment, the scheme is also mandated to work towards building sustainable community assets and infrastructure, especially with regard to land and water, making it the perfect avenue for leveraging the Eco-DRR approach. Furthermore, the local governments have the flexibility to identify permissible projects which are eligible for support under this scheme including in convergence with other schemes, making it community-oriented and participatory in nature. The potential of MGNREGS's activities to contribute towards the achievement of Sustainable Development Goals (SDGs) has also been recognised by the Union Government, thereby making the works under the Mahatma Gandhi NREGS one of the most dynamic and multi-faceted schemes in the country.

MAINSTREAMING OF ECO-DRR IN MAHATMA GANDHI NREGS

In India, the Mahatma Gandhi NREGS is designed to provide additional income to the low-income groups in rural communities by creating employment opportunities at the local level. The Scheme also has another core objective of building sustainable rural infrastructure. The implementation of activities under the Scheme such as water conservation and water harvesting works, drought proofing, irrigation provisioning and improvement works, and renovation of traditional water bodies have contributed to improved ground water levels, increased water availability for irrigation, increased area irrigated by ground and surface water sources and finally improved drinking water availability for humans and livestock (Esteves, 2013). All of these activities are related to Eco-DRR in multiple ways; however, these activities have been carried out according to the demands of communities and have not necessarily been undertaken to increase resilience in a systematic manner through the mainstreaming of Eco-DRR.

Mainstreaming of Eco-DRR will enhance community resilience by increasing livelihood options whilst addressing climate and disaster risks and providing long term environmental benefits. Being generally low cost, Eco-DRR techniques are recognized as cost-effective, and often do not require high-tech applications and can be implemented by the local community. Conservation of water sources, agroforestry practices for soil erosion control, and planting deep-rooted species on steep slopes are some of the activities that local people have been undertaking traditionally, although these have become even more important today as climate risks are increasing. Utilising their traditional knowledge and experience of land conservation is key to reducing environmental degradation which aggravate disaster risks. Ensuring that local land conservation knowledge is utilised also helps mainstream Eco-DRR into local level developmental works through the Mahatma Gandhi NREGS more effectively.

WATER HARVESTING STRUCTURES



2 WATER HARVESTING STRUCTURES

Rainwater harvesting is a viable solution to addressing the issue of water scarcity in many parts of India. Various water harvesting structures available include traditional ponds, open wells, roof top harvesting units, rain pits, subsurface dykes, percolation tanks, check dams etc. Under the Mahatma Gandhi NREGS, the Local Governments have been undertaking many water harvesting activities in rural and urban areas respectively.

WATER HARVESTING

Water harvesting involves the collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance. The purpose of water harvesting is to collect runoff or groundwater from areas of surplus or where it is not used, store it and make it available when and where water becomes scarce (Studer R. M., 2013).

The basic components of a water harvesting system are a catchment or collection area, the runoff conveyance system, a storage component and an application area. In some cases, the components are next to each other, in other cases they are connected by a conveyance system (Error: Reference source not found1). The storage and application area can also be the same, mostly where water is concentrated in the soil for the direct use of vegetation. Water harvesting can

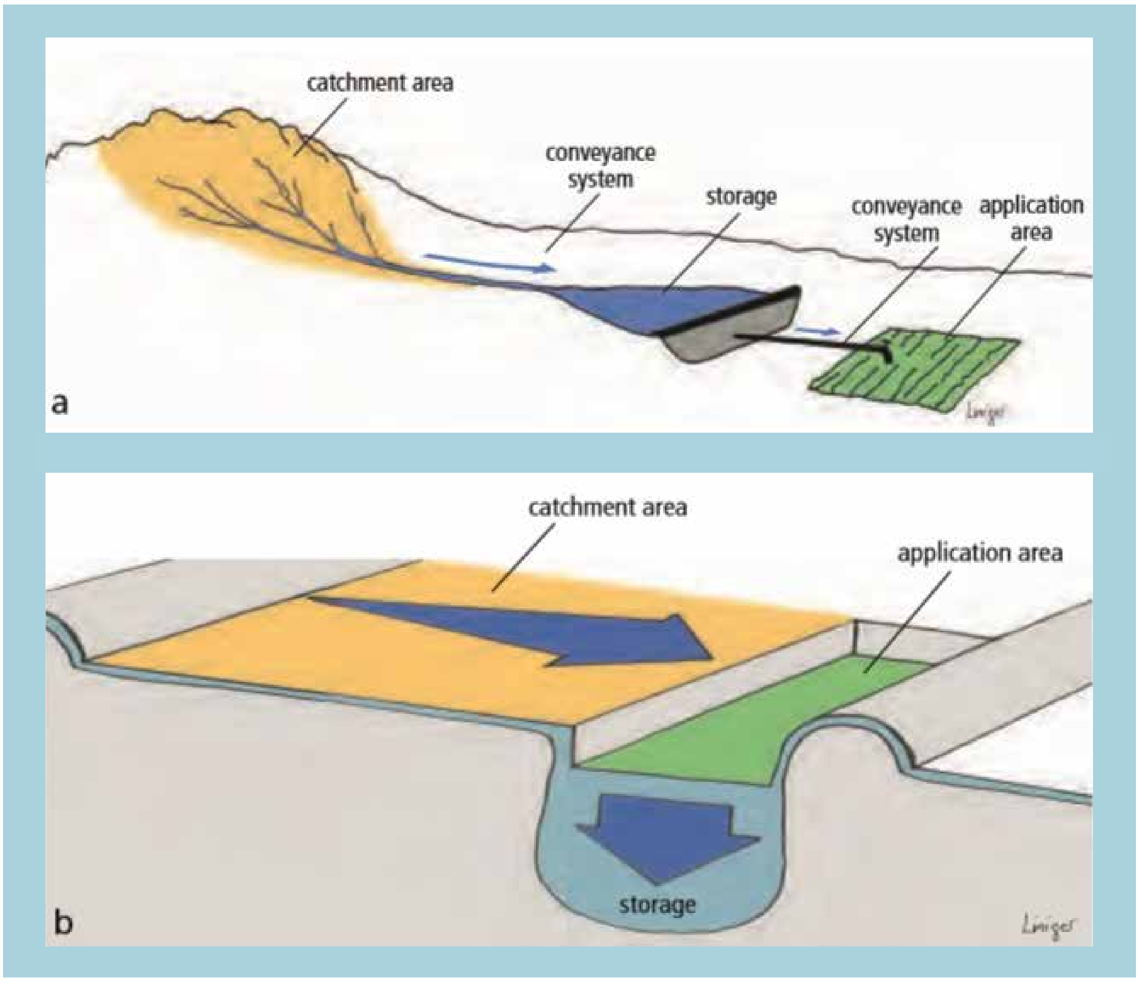


Figure 2.1: Basic components of a water harvesting system
Source: Studer R.M., 2013

even occur naturally, for instance in depressions, or artificially through human interventions (Studer R. M., 2013).

The four main categories or strategies for water harvesting are as follows:

1. Groundwater recharge and storage - This is closed water storage; hence evaporation losses are lesser than open water storage. Water is not directly available; hence wells are needed to access it from the ground. Some examples include earthen dams, infiltration ponds, etc.

2. Soil moisture conservation in the root zone - This is relatively closed as water is stored in the upper part of the soil i.e., the root zone. Part of the water can be used by crops though most water percolates deeper to recharge the groundwater. Some examples include grass strips, conservation agriculture, etc.

3. Closed tank storage – Here the water is stored in a clean manner, near the location where it is used mostly as drinking water. Some examples include rooftop tanks, underground cisterns, etc.

4. Open surface water storage - This method enables storage of larger volumes of water and can be used for agricultural purposes. Some examples include small storage reservoirs, trapezoidal bunds, etc.

Each option has its own strengths and weaknesses, and local conditions typically help define the optimum one for a particular setting. In general, the water harvesting capacity increases from small to large storage, and from surface to soil or groundwater storage (Studer R. M., 2013). The applicability and impact of water harvesting technologies depend on local conditions.

The benefits and constraints associated with water harvesting are listed below:

Table 2.1: Benefits and constraints of water harvesting

BENEFITS	CONSTRAINTS
Increases water availability	Dependent on the amount, seasonal distribution and variability of rainfall
Buffering rainfall variability	Supply can be limited by the storage capacity, design and costs
Reduces pressure on traditional water resources	Structures may take up productive land
Help to cope with extreme events such as flooding, soil erosion etc	Can cause breeding of mosquitoes or become source of water borne diseases
A cheaper alternative to expensive water projects	May deprive downstream ecosystems of water (esp. where flood water is diverted)
Environmental protection	
Socioeconomic advantages	

Source: Studer R.M., 2013

WATER HARVESTING UNDER MAHATMA GANDHI NREGS

The major heads of works as specified under Schedule I of the Mahatma Gandhi NREGS which are directly linked to water harvesting are as below:

Water conservation and water harvesting structures to augment and improve groundwater storage such as underground dykes, earthen dams, stop dams, check dams, with special focus on recharging ground water including drinking water sources;

Watershed management works such as contour trenches, terracing, contour bunds, boulder checks, gabion structures and spring shed development resulting in the comprehensive treatment of a watershed;

Micro and minor irrigation works and creation, renovation and maintenance of irrigation canals and drains;

Renovation of traditional water bodies including desilting of irrigation tanks and ponds and conservation of old stepwells;

Improving productivity of land through land development and by providing suitable infrastructure for irrigation including dug wells, farm ponds and other water harvesting structures.

Under these, 260 types of MGNREGS works/ activities have been identified as permissible works, including 181 types of works that relate to Natural Resource Management (NRM) alone, of which,, 84 are water-related.

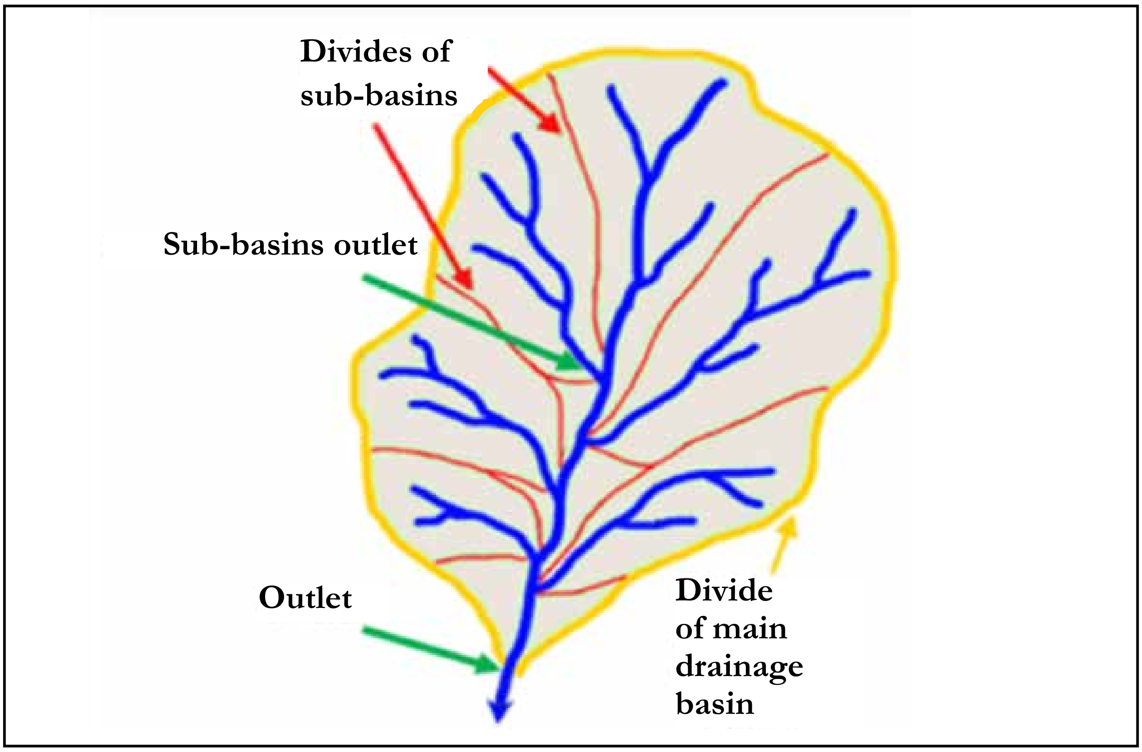


Figure 2.2: Watershed Area
Source: Watershed Hydrology, 2014

PLANNING AND SELECTION OF WORKS

Rain water harvesting should be undertaken considering each watershed as a single unit, as mandated under the Mahatma Gandhi NREGS framework. It should be done carefully with full regard to the ridge-to-valley approach for managing water in a catchment area; both to prevent the fast escape of water, as well as to enable maximum recharge of the groundwater and conserve maximum water in surface storages. This enables the conservation of land, prevents soil erosion and improves the vegetation cover. The Mahatma Gandhi NREGS also stipulates that the activities in the micro watersheds must be managed within the context of adjacent larger watersheds and river basins of which they form integral parts. The conventional ridge-to-valley approach is often not applicable in the lower midlands and coastal regions of Kerala (HKM, 2019). The strategy of a watershed approach should be to restore the existing water resource structures such as ponds and streams, manage catchment areas to conserve more water and implement water harvesting measures. This will contribute to improving the inflow conditions, facilitate maximum ground infiltration to increase groundwater recharge and enhance soil moisture conditions for improving primary productivity of vegetation (Watershed Hydrology, 2014).

Surface spreading techniques can be adopted in rural areas where space for such systems is available in plenty and the quantity of recharged water is also abundant. In urban areas, rain water available from rooftops of buildings and paved and unpaved areas goes unused and can create harmful stormwater problems, leading to flooding and water contamination. If properly harvested, even water in urban areas can be recharged to aquifers and can be utilised usefully at the time of need. It is best that the rain water harvesting systems are designed in such a way that they do not occupy large amounts of land so that there is more effective collection and recharge.

SITE SELECTION

Water harvesting projects are site specific and even the replication of techniques from similar areas are to be suitably modified based on the local hydrogeological and hydrological environments.

The following factors need to be considered while selecting a site for water harvesting:

- Rainfall: amount, intensity, duration, distribution, evapotranspiration rates, runoff generating events;
- Land topography: slope gradients, length of slopes, size and shape of the catchment;
- Soil type: infiltration rate, water holding capacity, fertility, soil depth, texture, structure;
- Collection/catchment area efficiency and runoff coefficient for the generation of runoff;
- Land use for catchment and application area: cultivated, uncultivated or partially cultivated, under pasture or forests etc;
- Alternative water sources and family size (specifically for rooftop and courtyard water harvesting);
- Watershed data;
- Flood hazard risk maps: water harvesting structures can be implemented in upper watershed areas in case there is frequent flooding in lower watersheds.

TYPES OF WATER- HARVESTING STRUCTURES

CONTOUR TRENCHES

Figure 2.3: Contour Trenches

A contour trench is a simple and low-cost solution to slowing down surface run-off in ridge areas of a watershed. Since the trench is dug along a line that is at the same elevation, it increases the chance of holding the runoff water for a longer time within the trench. However, if trenches were not to follow a contour, such digging could actually increase the possibility of soil erosion as there would be a rise in the velocity of runoff due to increase in the slope of the land (Ministry of Rural Development, 2017).

Contour trenches are of two types: Continuous & Staggered. While Continuous trenches are mostly done in low rainfall areas, Staggered trenches are preferred in high rainfall areas like Kerala.

1. Continuous Trenches

- Trapezoid shaped pit dug across the slope along the contour line; ideal size of trench can be 30x30 cms/45x45cms
- Soil taken over from the trenches is deposited on the downstream side to form a bund slowing down surface runoff and reducing soil erosion.
- Land slopes (10 to 25%)
- Ideal in plantation areas
- Planting of grass down for stabilization

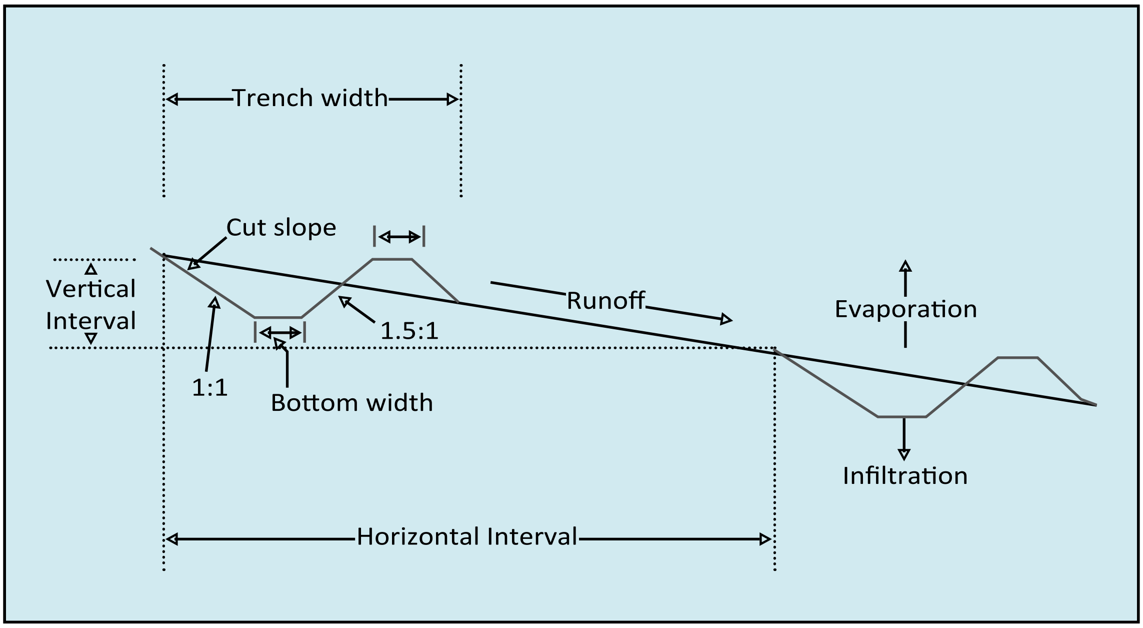


Figure 2.4: Definition sketch of contour trenches
Source: Soil & Water Conservation Structures, 2014

2. Staggered Contour Trenches

- Short (2-3 m long) and arranged in rows along the contour with space between them;. ideal for Kerala conditions
- Maximum number should be limited to 200-250/Ha depending on site conditions & standing crops
- Depth should be 50-60 cms

Figure 2.5: Staggered Contour Trench

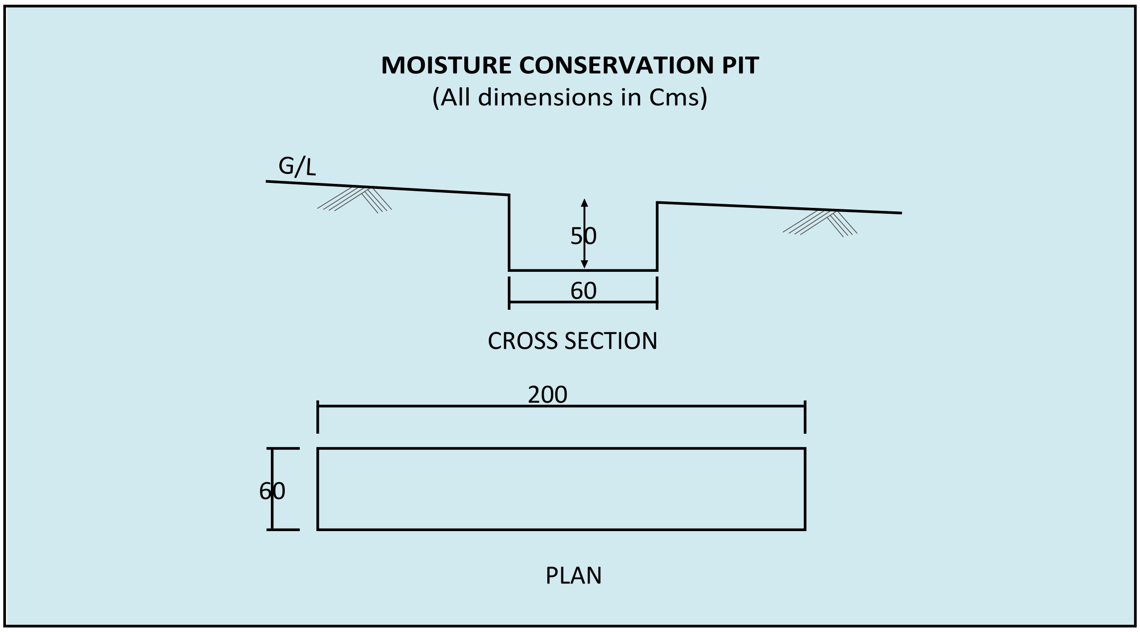


Figure 2.6: Definition sketch of staggered contour trenches
Source: Department of Soil Survey and Soil Conservation, 2016

STONE PITCHED CONTOUR BUND

Bunding is the construction of small embankments or bunds across the slope of land. They can be adopted on land which has up to 35% slope. It is to be constructed along a contour line. This increases the chances of containing runoff for a longer period of time within the bund. Like contour trenches, contour bunds also collect the rainwater that falls in the ridge area of a watershed thereby reducing soil erosion and improving soil moisture. It is important to combine contour bunds with suitable vegetative measures as eroded fertile topsoil also will get deposited in the bund along with the water. They should have a top width of 40-60 cm for enabling planting of suitable grass species (Ministry of Rural Development, 2017).

In high rainfall areas, particularly those which are susceptible to landslides and land slips, the bunds are to be constructed as graded bunds with a grade of 0.2 to 0.8%. Earthen bunds also serve the same function of stone-pitched bunds.

Figure 2.7: Stone-pitched contour bund

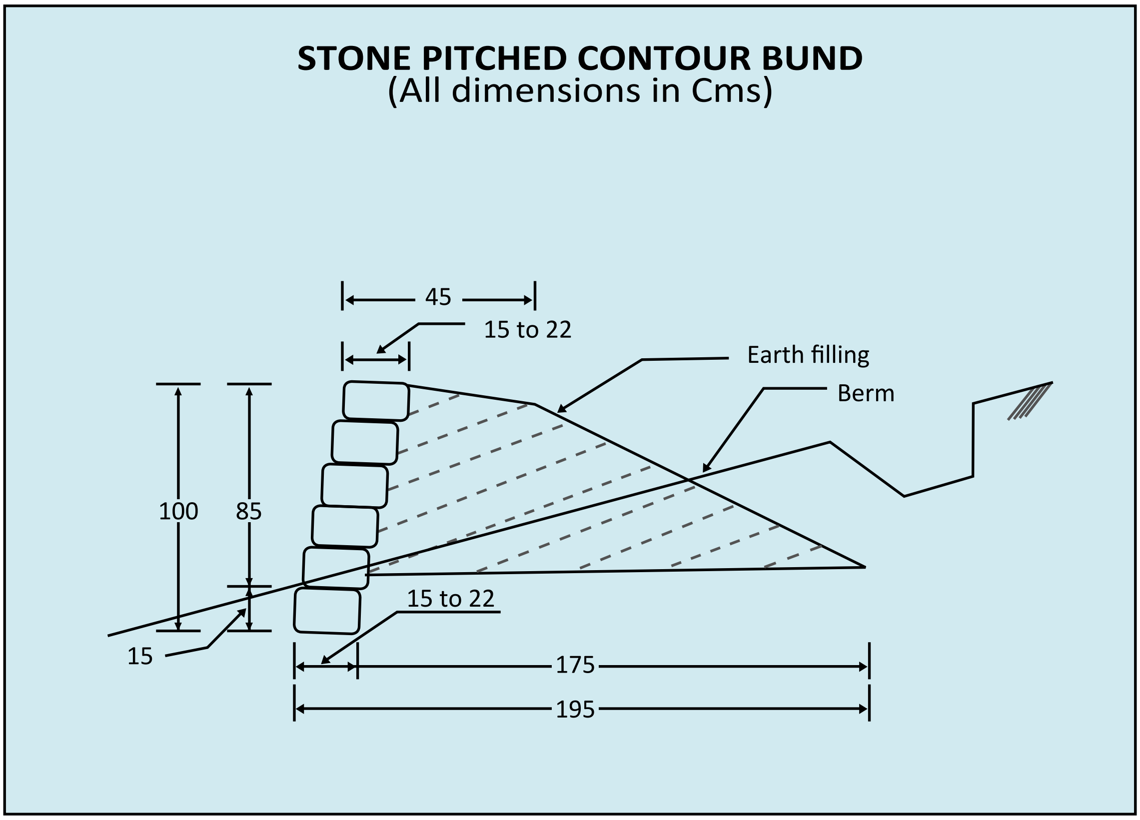


Figure 2.8: Earthen bund
Source: Department of Soil Survey and Soil Conservation, 2016

Figure 2.9: Earthen bund

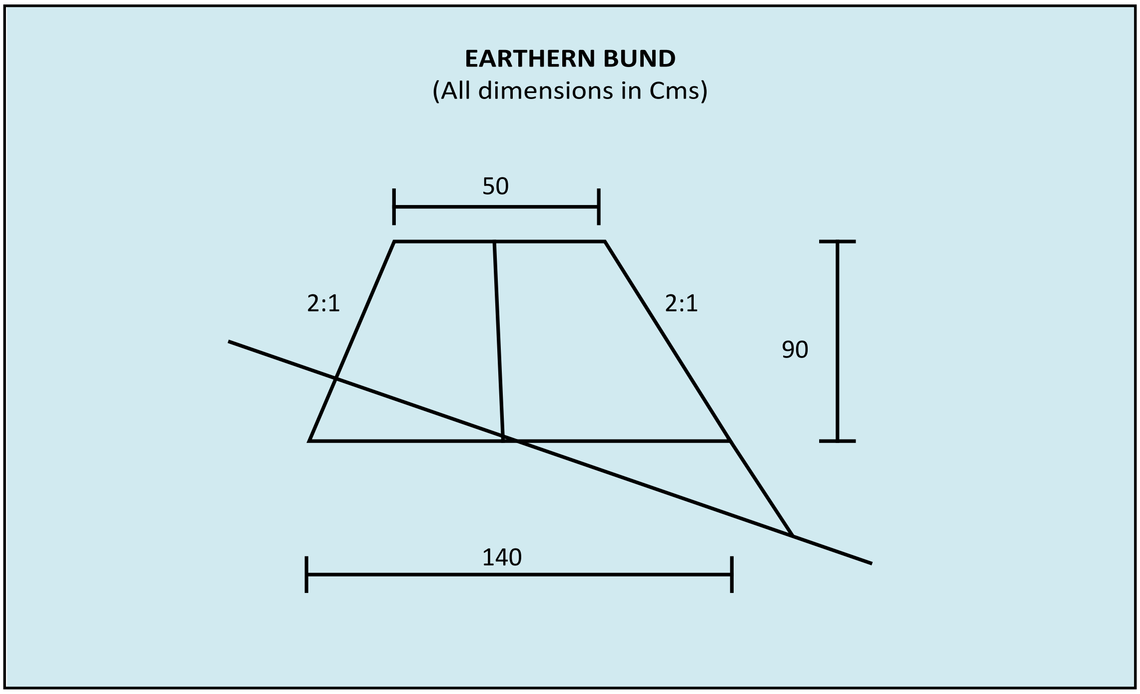


Figure 2.10: Earthen bund
Source: Department of Soil Survey and Soil Conservation, 2016

RECHARGE PITS

A recharge pit allows rainwater to recharge groundwater thereby improving the sustainability of the source of water. It can be made to recharge a borewell/dug well or just to improve the infiltration of water in an area (Ministry of Rural Development, 2017). Recharge pits are generally excavated pits, which are adequately deep so as to penetrate the low-permeability layers overlying the unconfined aquifers. Recharge pits are made over the land surface to arrest excess surface runoff and silting, thereby ensuring ground water recharge.

Figure 2.11: Recharge pit

BENCH TERRACING

Bench terracing comprises the leveling of sloping lands and is suitable for slopes of up to 50% having adequate soil depth. It helps in soil conservation and holding runoff water on the terraced area for longer periods, leading to enhanced infiltration and groundwater re charge.

The width of the terrace should be adequate, so that convenient and economic agriculture operations are enabled. The vertical slope of the benches should be planted with deep-rooted grass species such as Vetiver grass (Chrysopogon zizanioides) that reduces soil erosion and promotes ground recharge though the long roots system (Ministry of Rural Development, 2017).

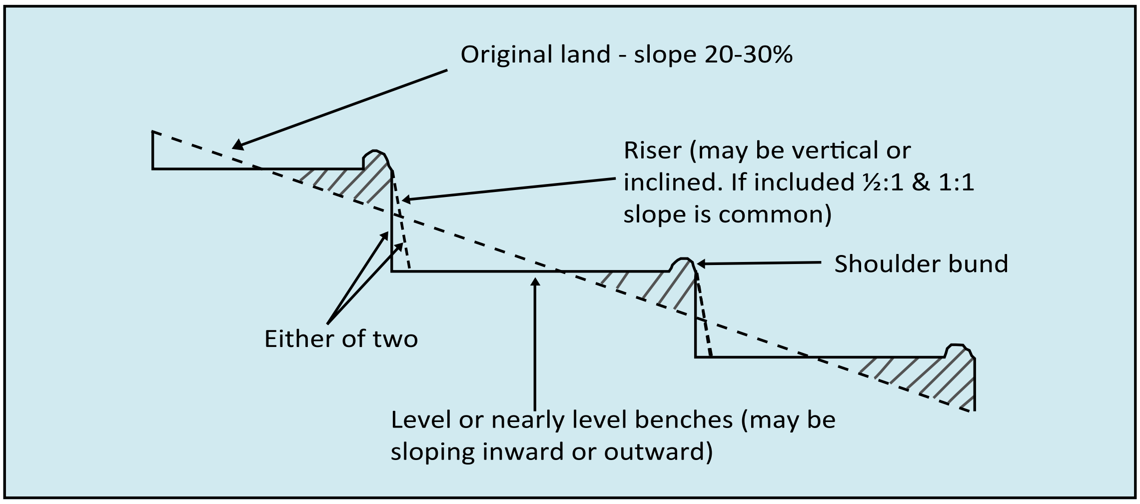


Figure 2.12: Bench terrace and its different components
Source: Soil & Water Conservation Engineering, 2013

Figure 2.13: Bench Terracing

GULLY PLUGS AND CHECK DAMS

Gully plugs and check dams are structures built across gullies and streams to check the flow of surface water in the stream channel and to retain water for a longer period in the previous soil or rock surface. Gully plugs are usually built across first order streams while check dams are built across bigger streams and in areas having gentler slopes. Check dams can be temporary structures such as brushwood check-dams, vegetative check dams, gabion check dams, woven wire dams constructed with locally available material or loose/dry stone masonry check dams. They can also be permanent structures constructed using stones, brick and cement.

Gully plugs are constructed using local stones, clay and bushes across small gullies and streams flowing down the hill slopes carrying runoff to small catchments during the rainy season. While constructing gully plugs, if plant species are used as live check dams to form a barrier across the drainage line, it also helps in the conservation of soil and moisture.

The gully bed slope should be less than 10% and the depth of the gully less than 2 m. The site selected for the check dam should have sufficient thickness of permeable soils or weathered material to enable recharge of stored water within a short period of time. The water stored in these structures is generally confined to the stream course and the height is usually less than 2 m.

If the bed slope is more than 25%, it is not advisable to construct brushwood/ loose boulder check dam. The relief and depth of a stream is used to fix an approximate number of check dams in a stream. The minimum vertical interval between two successive check dams should be equal to the height of the structure and the length of the apron should be 1.5 to 2 times the height of the structure.

Figure 2.14: Gully Plug

GABION STRUCTURES

Gabion structures are rock and wire dams built across drainage lines to reduce the velocity of water flowing through it. They usually have a catchment area of 50-500 ha. By reducing the velocity of runoff, gabion structures aid in reducing soil erosion, trapping silt and thereby reducing the rate of siltation in water harvesting structures in the lower reaches of the watershed, increasing groundwater recharge and increasing the duration of flow in the drainage line. Consequently, the capacity of the water harvesting structures constructed downstream on the drainage line is utilised more abundantly as they get many more refills (Ministry of Rural Development, 2017).

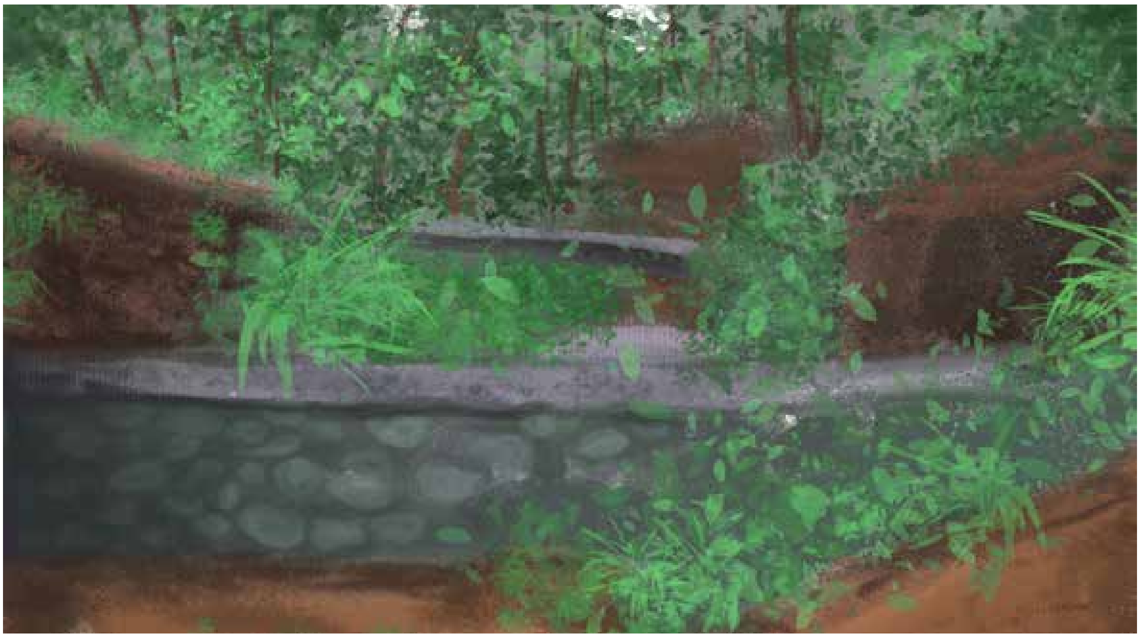
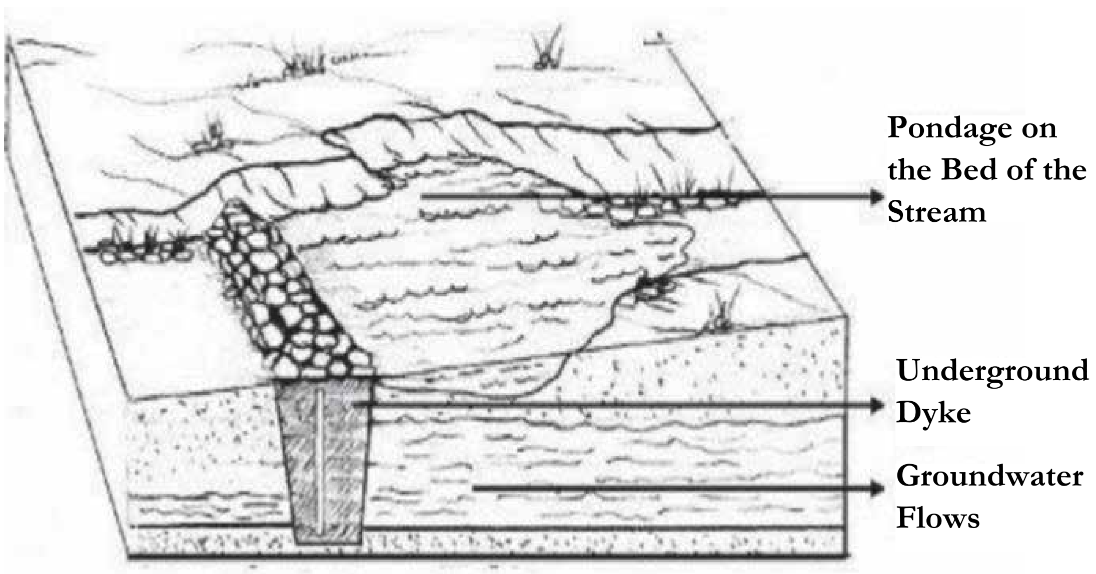


Figure 2.15: Gabion Structure

UNDERGROUND DYKES

Underground dykes are earthen dams that block the flow of sub-surface water and divert them to nearby wells and tubewells. The water blocked by them is not exposed to evaporation and they do not submerge any land.

Underground dykes are more suitable in areas where the soil required to fill up the dyke is fairly easily available and in hard rock areas where impermeable strata are frequently found at shallow depths below the surface. The main aim of constructing underground dykes is to obstruct the flow of subsurface water and make it accessible in the watershed for a longer period. By redirecting the subsurface water to nearby wells and tubewells they increase the water level in wells. Also, they make surface flows in the drainage line available for a longer period (Ministry of Rural Development, 2017).



An underground dyke also creates pondage on the bed of the drainage line

Figure 2.16: Cross Section of Underground dyke
Source: Ministry of Rural Development, 2017

EARTHEN DAMS

Earthen dams are built on the main stream of a watershed. They are especially important in areas which are poor in groundwater resources and do not have access to canal irrigation. Earthen dams can also be built as percolation structures, to augment the rate of groundwater recharge. Such percolation structures are generally built on the upper part of the catchment area. Water stored here percolates to wells and tubewells situated in the lower part of the catchment. They can also be constructed in the immediate upstream portion of wells and tubewells (Ministry of Rural Development, 2017).

DUG-OUT FARM PONDS

Dug-out farm ponds (DOPs) are constructed on private land to harvest runoff from very small local catchments. The main purpose of constructing a DOP is to collect rainwater, which would otherwise have flowed out of the field. Unlike earthen dams, DOPs are comparatively free of topographical limitations. On flatter land, streams are not very deep, and they do not have high embankments. Hence, it becomes difficult to construct water harvesting structures like earthen dams. In such flat lands, DOPs are the most effective water harvesting measure. Farm ponds should be made on a cluster basis so that the overall soil moisture regime of the area is improved, and water is accessible for an extended period of time. If there is a well on the farm, the DOP should be constructed upstream of it so that the well may be recharged from the pond. Usually, the area of a pond varies from 5 to 10% of the command area as per the water requirement.

A DOP of top area 20 m x 20 m, bottom area 14 m x 14 m and 3 m depth can store 880 cms of water in one refill and will be able to irrigate 0.176 ha or 0.352 ha in two refills (Ministry of Rural Development, 2017).

Figure 2.17: Dug-out Farm Ponds

ROOFTOP RAINWATER HARVESTING AND WELL RECHARGING

Rooftop Rainwater Harvesting is the practice through which rainwater is collected from roof catchments and stored in reservoirs. Hence, the common components of a rainwater harvesting system are catchment, coarse mesh, gutters and conduits, first flush device, filter and storage tank (Centre for Science and Environment, 2019).

Open dug wells are the main source of drinking water for households in Kerala. However due to improper water management, the majority of these wells do not have adequate water to cater to the domestic necessities of a household. Capturing rainwater from roof tops of households and diverting the same to wells after proper filtration will help in recharging wells. Further recharge through construction of pits near wells would also help in increased well recharging. Existing and abandoned dug wells and tube/bore wells can be utilised as recharge wells after cleaning and desilting the same, as and when source water becomes available (Central Ground Water Board, Manual on Artificial Recharge of Ground Water, 2007).

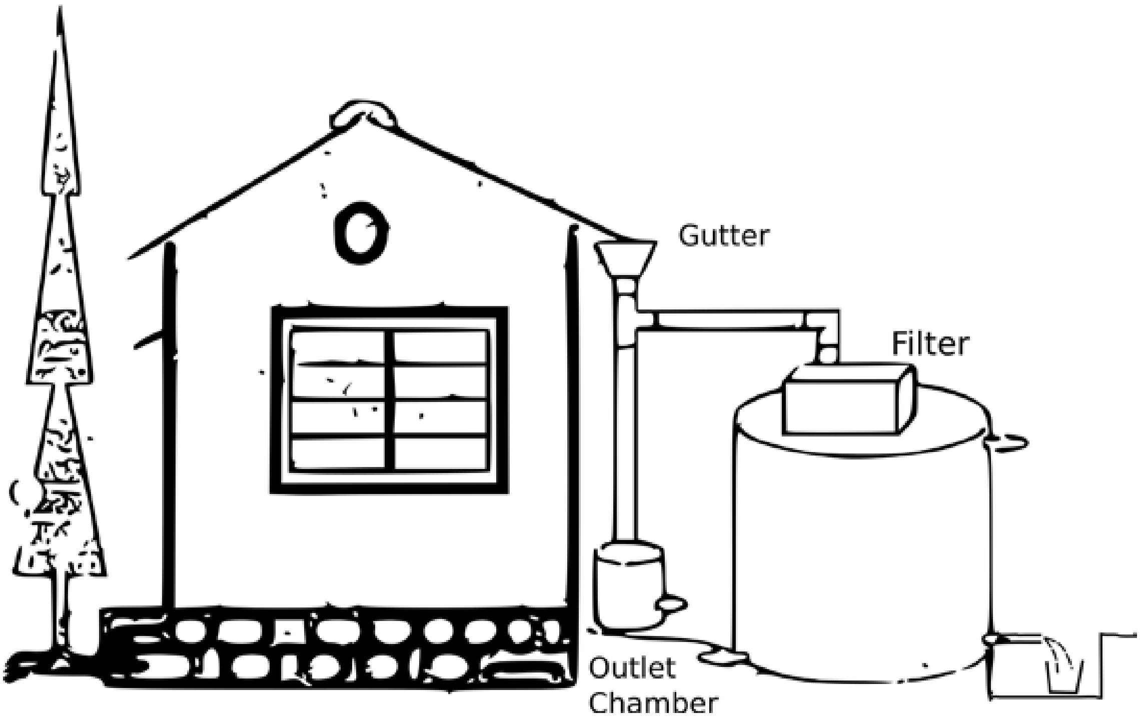


Figure 2.18: Schematic diagram of rooftop water harvesting system

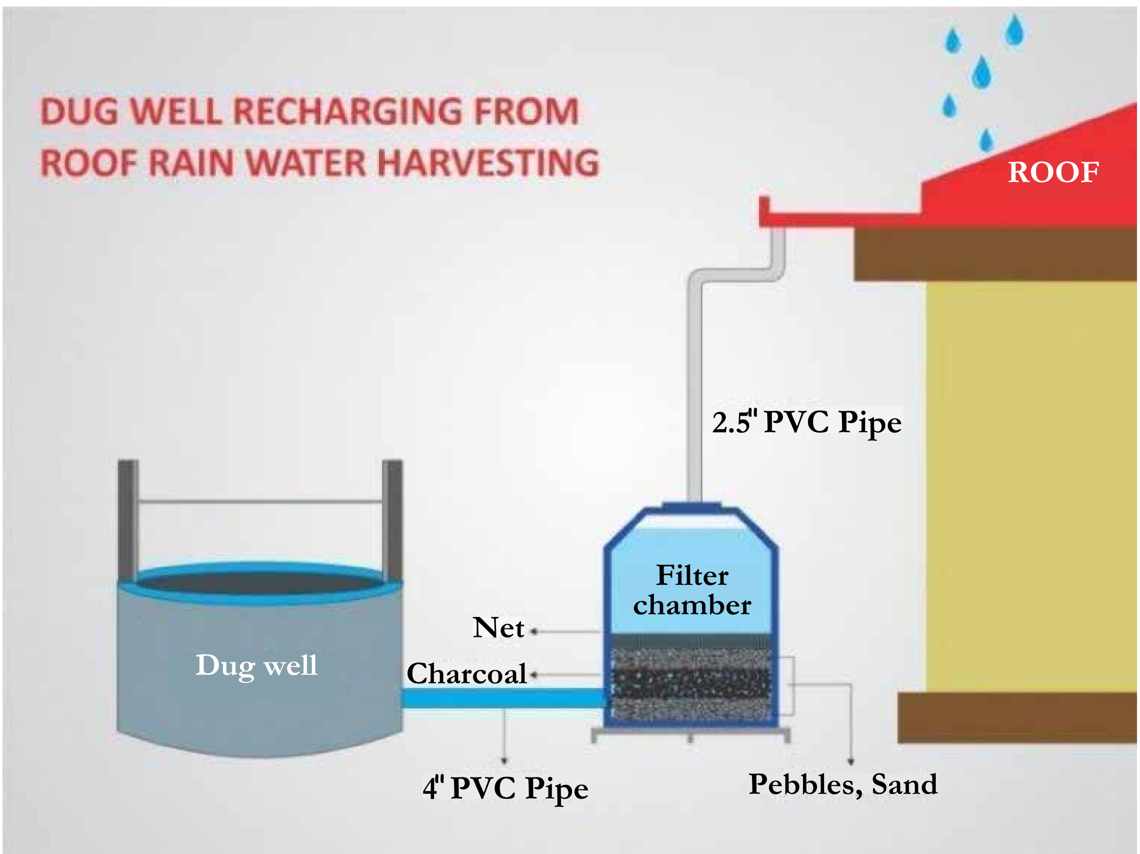


Figure 2.19: Dug well recharging from rooftop rain water harvesting
Source: Mazhapolima, 2014

Table 2.2: Different site parameters for planning water harvesting structures on arable land

SL. NO.	STRUCTURE		LOCATION	SLOPE	CATCH-MENT AREA	SOIL CONDITION	RAINFALL
1	Contour Trench	Continuous	Ridge to Valley (Upper & Middle reaches)	Up to 25%		Soil thickness - medium to deep	Medium rainfall areas (Continuous)
		Staggered		Up to 25%			High Rainfall (Staggered)
2	Bund	Earthen Contour Bund		Up to 8%		Not possible in shallow soil Permeable Soil areas	Low annual rainfall (Below 600 mm)
		Stone-Pitched Contour Bund		Up to 35%		Permeable Soil areas	High or medium annual rainfall (Above 800 mm)
		Graded Bund		Up to 35%		Relatively less permeable soil areas, 0.2 to 0.8% grade	High or medium annual rainfall (Above 800 mm)
3	Terracing	Inward Sloping Terrace	Plantation crops	Up to 50%		Soil thickness - medium to deep	High rainfall areas
		Strip Terrace	Areas of rubber Plantations/ Horticultural plants				
4	Farm Pond			Less than 4%	Not more than 5 ha	Water table lies within 1.5m to 2m Should have an impermeable underground stratum up to a depth of 3m	
5	Rain Pit		Ridge-to-Valley (Upper & Middle reaches)	Up to 25%		Permeable soil Not possible in sandy or gravelly soil Max of 200 pits per Hectare or 8 pits in 10 cents) Soil thickness - medium to deep	

Table 2.3: Different site parameters for planning water harvesting structures in the drainage line

SL. NO.	STRUCTURE	LOCATION	SLOPE	CATCHMENT AREA	SOIL CONDITION
1	Gully Plugs	Seasonal Gullies & first order streams	Bed slope less than 10%	Upper catchment areas Not more than 1-2 ha	Bed of drainage line should not be completely impermeable
2	Brushwood Checks	First and second order streams	Bed slope above 20%		Bed of drainage line should not be completely impermeable
3	Loose Boulder Checks	2nd and 3rd order streams (medium width)	Bed slope between 5 -20%	Less than 50 ha	Bed of drainage line should not be completely impermeable
5	Gabion Structures	2nd and 3rd order streams (Higher width)	Flat bed slope	50-500 ha Minimum independent catchment area is 5 ha	Bed of drainage line should not be completely impermeable
6	VCB	3rd order streams and above	Flat bed slope	Above 500 ha	Bed of drainage line should not be completely impermeable

Table 2.4: Other structures

SL. NO.	STRUCTURE	SLOPE	CATCHMENT AREA	SOIL CONDITION
1	Underground Dyke	Bed slope of drainage line should not be very high	Large catchment area	Hard rock, black cotton soil Impermeable strata at shallow depth
2	Earthen Dam	Bed slope not more than 5%	Should not be too high or too low. Based on its storage capacity	Natural embankments, impermeable Water spread area permeable or impermeable depending on the use

RIVER RESTORATION ACTIVITIES

3 RIVER RESTORATION ACTIVITIES

River restoration is the process of managing rivers to restore degraded riverine environment by reviving the natural river ecosystem and landscape, thereby improving flood plain management through cultivation, development of recreational areas and protection of developmental works. To explore the possibilities of Eco-DRR for the restoration of a degraded riverine environment, fundamental details of the river basin, probable causes of its alterations, etc. need to be understood.

Rivers are probably the most vibrant of all waterscapes on this living planet. Nowadays, there is a growing concern about the threats to water sources like rivers, lakes, ponds and others, of which many are facing near extin ction. Therefore, river restoration is of utmost importance in conserving ecosystem services.

In India, a vast number of issues plague our rivers, including flood plain occupation, water quality deterioration, and indiscriminate mining of river bed deposits. Excessive extraction of riverine materials have caused several direct and indirect impacts such as erosion, river bank under cutting and collapsing, lowering of river channels, changes in shape, increase in turbidity, salt water intrusion in the lower reaches, and drop in water table, all of it resulting in large alterations in river systems and functions.

RIVERINE ECOSYSTEMS

The two types of alterations of a river are hydrologic and physiographic alterations, both of which lead to the degradation of the riverine ecosystem. The impact of these alterations depends on several factors. There may be alteration of a stream or a river as a result of an extreme climatic event such as a flood. A river drying up due to substantial water diversion upstream is an example of an anthropogenic alteration.

Hydrologic alterations in the stream flow may occur due to various reasons such as construction of a check dam or a regulator; a barrage or a large dam would also alter the stream flow. Diversion by pumping can make hydrologic alterations in the flows, as does climate variability. Physical features such as silting, riverbank failure etc. can also cause hydrologic alterations. Other alterations include growth of thick water weeds which arrest water flows and cause contamination. There may also be physiographic alterations, including changes in river flow course, length and gradient of a stream or a river which can occur due to various natural (e.g. soil erosion, sedimentation) and anthropogenic reasons (e.g. encroachment, sand mining).

RIVER RESTORATION THROUGH MGNREGS

Under the Mahatma Gandhi NREGS, Local Governments have been trying to address the issue of degradation of natural resources, through its integration with community upliftment works. This includes watershed management works in both rural and urban areas.

Water harvesting and water resource management works at the watershed level have already been detailed in the first Chapter. Due to issues arising from the management of bigger rivers and riverine ecosystems by different Departments and stakeholders on the ground, the type of works that have been traditionally carried out in rivers under the Mahatma Gandhi NREGS have been limited. However, there are possibilities which can be explored. Under the Mahatma Gandhi NREGS, construction, repair and maintenance of bunds, canals, channels, check dams, culverts, storm/grey water drains, gully plugs, etc are works that are already being done at the watershed level. Watershed management works such as contour trenches, terracing, contour bunds, boulder checks, gabion structures and springshed development are also being done. This chapter elaborates certain other works that can be done directly in the river channel itself and which can be brought under the ambit of the Scheme.

SITE SELECTION

In order to implement Eco-DRR for river restoration and bank protection, first the chosen river should be mapped. The land use map of the micro and macro watersheds must also be considered in the location identification process, and marking the flood and drought affected areas with GPS coordinates is especially important. Flood risk mapping is also important in the location identification process.

It is necessary to understand the causes of degradation of a river in order to select the optimal approach for river rejuvenation. Maintaining E-flows, particularly, is of utmost importance to preserving basic river functionality. The primary focus of any intervention on the river must be to maintain the hydrological system required to sustain freshwater and estuarine ecosystems, as well as the human livelihoods and well-being that depend on them.

RESTORING RIPARIAN VEGETATION

The restoration of characteristic riparian vegetation can increase the shade so as to reduce water temperatures, bring back wooded wildlife corridors and reduce river-bank erosion by reinforcing banks with roots. Planting of native trees, grasses and shrubs can be used to reinstate characteristic riparian vegetation communities. (e.g. Anjili, Eetti, Bamboo, Kudampuli, Attupongu, Karimaram etc., in the case of Kerala)

BANK PROTECTION

Bank stabilisation can be most effectively addressed through a combination of both structures and vegetation (e.g. vegetative revetment of gabions, vegetative embankment, etc.). There are various types of protruding streambank stabilisation structures, including stream barbs, vanes, bend-way weirs, spur dikes, and log jams. Construction of these structures could be incorporated within the MGNREGS/AUEGS work plans. A short explanation of these structures is given below.

STREAM BARBS

These are low dike structures with top surfaces that slope from the bank into the channel and extend from the bank no more than 1/3rd of the channel width. They are typically angled into the oncoming flow, which diverts the flow away from the bank as it passes over the structure. Barbs can be made of graded riprap (solid) or arrangement of individual boulders (porous).

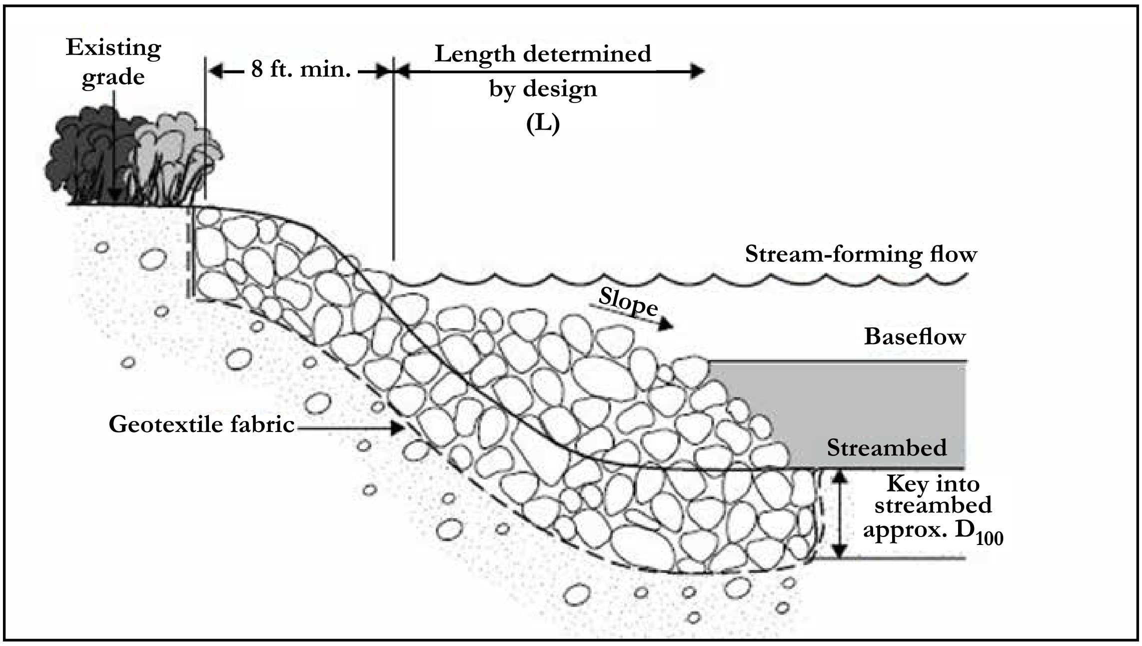


Figure 3.1: Stream Barbs
Source: United States Department of Agriculture, 1996

VANES

Vanes are a subcategory of barbs. Vanes are implemented with an upstream orientation of 20 to 30 degrees from the tangent to the bank line, have a crest elevation at or just below the full level of the bank, and slope at 2 to 7 degrees dip towards the tip. Dip angle increases with increasing stream slope and bed material size. Vanes can be constructed of either rock or logs, or a combination of these.

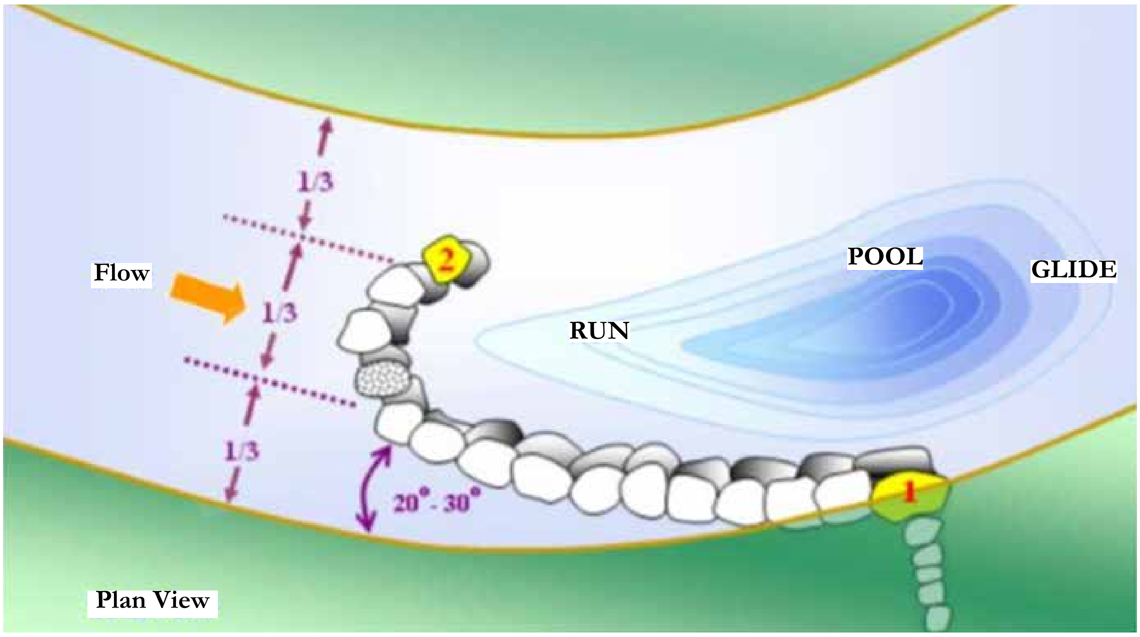


Figure 3.2: Hook Vane
Source: Yochum, 2018

BENDWAY WEIRS

Bendway weirs are rock structures with flat to slightly sloped surfaces (from the bank towards the thalweg or lowest point) that generally extend from 25% to 50% of the channel width from the bank into the channel. Since these structures project further into the channel than barbs, their spacing tends to be further apart. Due to their greater lengths, they are less appropriate than barbs in small radius bends.

Figure 3.3: Bendway weirs

SPUR DIKES

A spur dike is a protruding feature from the stream bank out into the channel, with a horizontal top surface that is typically above the high-flow water level. It is usually oriented perpendicular to the bank but can also be angled either upstream or downstream.

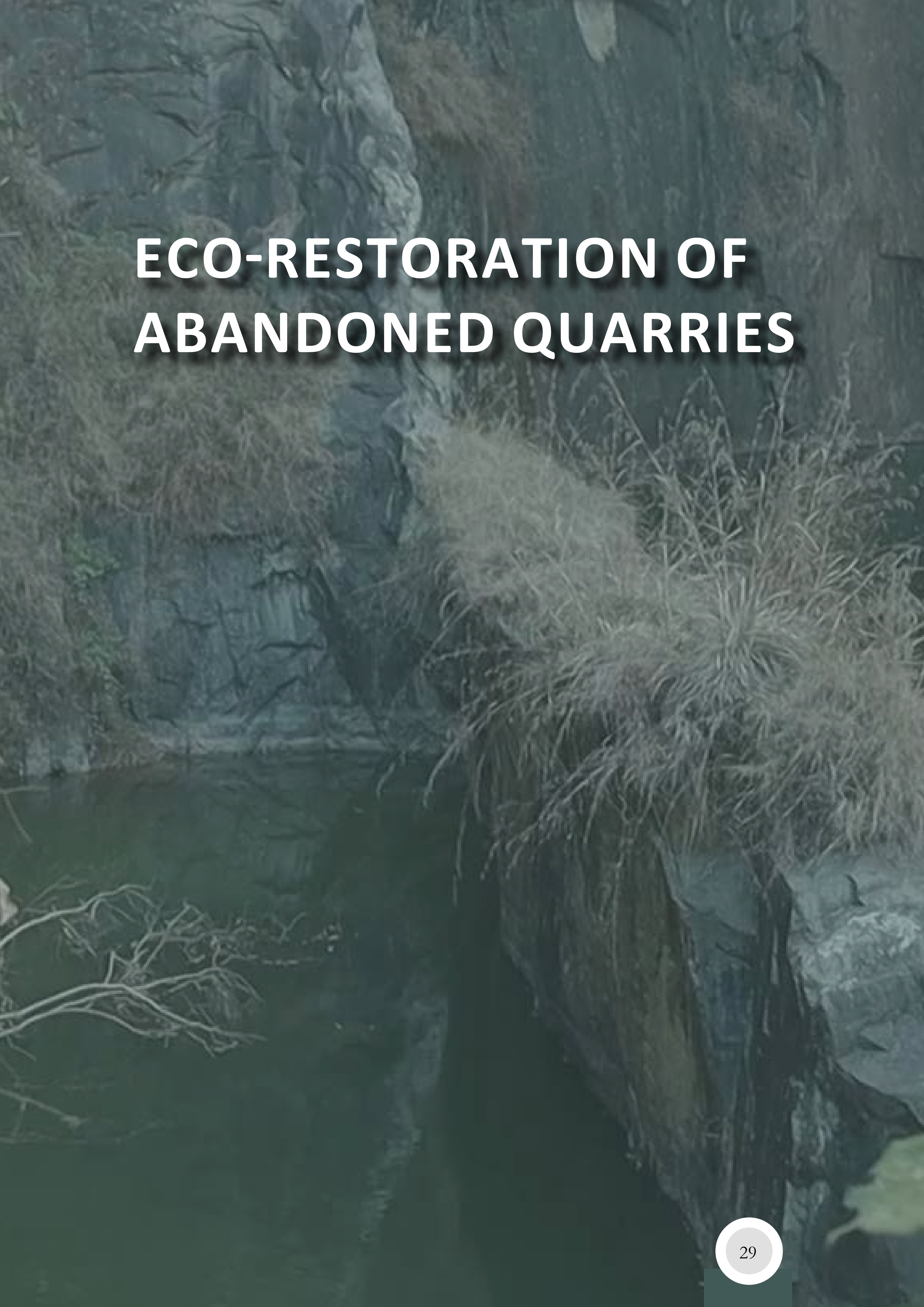
STREAM BANK SOIL BIOENGINEERING

This makes use of engineering practices combined with ecological principles to evaluate, design, construct, and maintain living vegetative systems. A related methodology that uses similar approaches to stabilisation is Induced Meandering, which provides riparian restoration techniques for addressing incised stream channels.

LOG JAMS

These are structures that deflect erosive flows, increase flow resistance, and promote sediment deposition. These structures also provide habitats for aquatic organisms and compensate for stream reaches that are deficient of instream wood due to past unsustainable practices (Yochum, 2018) (Central Water Commission, 2012).

ECO-RESTORATION OF ABANDONED QUARRIES



4 ECO-RESTORATION OF ABANDONED QUARRIES

Many quarries in the country are left unattended and abandoned once their lease period is over, thus presenting indelible eyesores and scars on otherwise pristine landscape and greenery. They sometimes also pose other dangers including rockfall and accidental deaths from drowning where a quarry is filled with water. In such situations, it would be prudent to take up restoration of abandoned quarries and mine pits to minimise hazardous impacts directly and indirectly affecting the populace dwelling in their close proximity and to transform these locations into positive outputs beneficial to society.

There are many options to choose from, when it comes to restoration-based interventions at an abandoned quarry site. While it may be possible to just cordon off quarries for safety reasons and leave them, the best option may be to restore them for community use. But to arrive at an optimal restoration option, the most important task is to identify the type of quarry , the nature of the soil conditions in the area and the biodiversity in the surrounding landscape.

ECO-RESTORATION OF QUARRIES

Quarries represent extreme cases of ecological degradation characterised by the complete removal of vegetation cover and intense landform modifications. Quarrying activities can intensely modify pre-existing ecosystems by perturbing the biogeochemical cycles and hydrological-regimes, altering soil characteristics, landscape patterns and integrity, destroying natural habitats, and interrupting the natural dynamics and genetic flows of various species. By the end of the excavation operations, and in the absence of any restoration, quarries are left to undergo sustained degradation towards increased ecosystem deterioration, accelerated erosion, surface runoff and reduced natural recharge (International Union for Conservation of Nature, 2014).

While planning the eco-restoration of quarries, the following points should be considered:

- The characteristics of the quarry and its surroundings will decide the type of restoration activities that can be carried out.
- The surrounding areas and the communities living close by if any are also relevant from the perspecive of livelihoods management.
- The stability of the walls or slopes as well as the shoulders of the abandoned quarry/ pit should be considered.
- Physical methods should be adopted to reclaim the area, such as easing of slopes, terracing, leveling, construction of retaining walls etc to make it conducive to interventions for restoration (Chandramohana Kumar, 2011).
- Peripheral drainage channels should be developed for safe disposal of collected water to prevent erosion and sedimentation.
- The quality of the collected water should be tested to understand whether it can be used for irrigation or household purposes without treatment.
- The soil type should be identified alongwith other constraints, if any, examined for seed germination and cultivation
- The topsoil removed from the abandoned quarryshould be replaced for further cultivation
- Suitable legumes, forage trees etc should be screened for nitrogen enrichment, nutritional and microbial constraints of spoils/overburden with a view towards re-establishment of species.
- Biodiversity and eco-restoration activities should be undertaken keeping in the mind the surrounding landscape.
- Soil amendments/ameliorants should be used and suitable mulches and practices for in-situ moisture conservation should be identified (Chandra Mohan Kumar, et al., 2011).
- The residential areas in the vicinity and their livelihood activities should be mapped so as to integrate the quarry restoration activities with them.

A variety of objectives could be satisfied by quarry restoration, and an important part of any restoration project is to decide which of these are most important to pursue. In order to take up cultivation and other livelihood support activities in abandoned quarries, some preliminary steps may be undertaken in isolation or in combination to prepare the land. Thereafter, the land can be utilised for economic benefits and livelihood support.

MULCHING

Mulching can be done to improve the quality of the soil as well as to improve the soil moisture content. Overburden should be leveled and structures developed. The surface should then be stabilised by application of organic mulches such as straw, composted coir waste, saw mill dust and biodegradable town waste which will help in growing grasses. This will improve water holding capacity, aeration, drainage, and the development of topsoil with good structure. This method can be adopted in pits used for raising seedlings.

CARPETING WITH GEOTEXTILES

Spreading of geotextiles on the surface of dumps will improve infiltration, drainage, and prevent surface erosion. It ensures stability and reinforcement of slopes, amelioration of site conditions and establishment of vegetation. Seeds or nursery raised seedlings can thereafter be used as planting material.

USE OF ORGANIC WASTES AND COMPOST FOR REMEDIATION AND RESTORATION

In abandoned quarries where greening/agriculture is an option for restoration, composting of organic wastes is a prerequisite. Composted coir pith waste or biodegradable organic town waste can be utilised. Large scale composting yards with windrows for composting the waste can be planned. The compost when mixed with the available material in the site such as sub soils, quarry fines and waste dump materials will form an excellent planting medium. It will provide a balance of nutrients, organic matter, high water retention capacity, aeration, drainage, good structure development and an ideal condition for the establishment of plant species.

SEED MIXTURES OF GRASS AND LEGUME

Grass and legume mixtures of native vegetation can play an important part in the restoration The grass should be local perennial species with fibrous roots, preferably a forage. Legume is a good nitrogen fixer. These seeds with a mixture of fertilizer, aerator, soil can be sown directly on the safe slopes.

VETIVER SYSTEM

Vetiver System is the technique of planting Vetiver (Chrysopogon Zizanioides) grass to restoredegraded land or to stabilize unstable soil slopes. Vetiver (Ramacham) grass grows well in landfills and quarries. It resists prolonged dry spells or waterlogged situations and is an ideal species for quarry restoration programmes. This technique can be used for eco-restoration of vertical quarry walls as well as in the locations where the spoils are dumped which are an eyesore in the natural landscape.

The vetiver technique can also be used for stabilising vertical walls of abandoned quarries. It consists of puncturing holes on the quarry face along the contour using pneumatic drills. The orientation of the holes should be at an angle of 450. Hardened galvanised stakes protruding 60-80 cms on the quarry face are fixed, and toughened plastic/PVC planks placed over them to form a triangular trough for filling soil/planting medium.

BLOCK PLANTING OF TREE SAPLINGS

Indigenous tree seedlings can be planted in the cracks or voids of rocky areas with the help of a covering block of about 1m x 1m x 1m made up of locally available small rocks and pebbles. The boxes can then be filled with sand, soil, and fertilizer mixture and saplings planted in them.

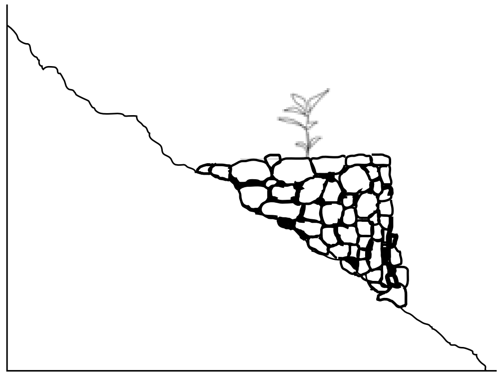


Figure 4.1: Block Planting

HIGH DENSITY TREE PLANTING /AFFORESTATION

High density tree planting is another method which can be adopted to make use of small areas which have good quality earth. In this method the saplings are planted close to each other with a spacing of less than 50 cm. For this, 0.5 to 1.2 m depth of the soil can be dug out and thereafter 60% of the bottom layer can be filled with the dug earth and the remaining with a mix of good earth, fertilizer, saw dust/coir pith compost in a ratio of 4:3:3.

RAINWATER HARVESTING STRUCTURES

Abandoned quarry pits can be used for harvesting rainwater and also for recharging the groundwater reservoir in an area. The options are:

1. Use of water in abandoned quarry pits for irrigation

The water collected in the abandoned pits can be used for irrigating garden lands in adjacent areas. Both rainwater falling directly into the pit and seepage into the pit from surrounding areas can be collected and used. A fence should be constructed around all such pits to prevent accidents due to drowning.

2. Recharge of aquifers

Water collected in quarry pits could be pumped or siphoned to large recharge pits located in nearby areas where there is a sufficient thickness to the weathered zone. The bottom of the recharge pit should be at least 2 to 3 ms above the shallowest water table at that site. The recharge pit may be about 5 to 10 m2 and 2 ms deep, depending upon availability of land, quantity of water collected in the quarry pit and local hydro geological conditions. Where a quarry pit is suitably located on a hill slope, water collecting in the pit can be siphoned off to ponds in nearby valleys without using electrical energy.

3. Drinking water supply

Where conditions permit, water accumulating in quarry pits, after pre-treatment, can be used as drinking water for small communities. In places with minimum chances of pollution, collection of surface runoff in the pit can also be considered for this purpose if a facility for proper treatment of the water is provided.

4. Quarry Pits into Man-made Aquifers

Small abandoned quarries with impermeable walls and floors can be rebuilt as man-made aquifers by partially filling with suitable granular materials such as coarse aggregates and sand, especially in regions facing acute drinking water scarcity. The pit may initially be filled with coarse aggregate and the top one meter filled with sand to act as a filtering medium. Interception of rainwater by the pit will saturate this artificial aquifer and water can be drawn using hand pumps. The potential of such aquifers can be improved by directing surface runoff into the quarries. This requires a thicker filling of aggregates in the pit for storing the additional recharge and also construction of settling ponds for removing suspended matter in the runoff before it enters the aquifer. The top few centimeters of sand acting as filter in the pit will have to be washed seasonally to remove the fine material clogging the pores. This type of reuse may be viable only in cases of extreme drinking water scarcity.

PISCICULTURE

After suitable physical reclamation to ease slopes and depth, the quarries can be utilised for pisciculture. It is ideal if the side-slopes of such pits have gentle slopes, which can be aesthetically afforested with tree species.

AQUACULTURE OF FLOWERING WATER PLANTS

Cultivation of aquatic flowering plants like Lotus, Water Lilies etc. in small and/or large quarry pits can be a remunerative alternative.

DEVELOPMENT OF COMPOSITE NURSERIES

Subject to availability of water and site attributes, abandoned L-shaped quarries and laterite pits can be potential sites for starting composite nurseries of grasses, shrubs, multipurpose trees for fuel, fodder, timber, fruit crops, and medicinal plants.

BIOMASS AND BIO-ENERGY DEVELOPMENT

Since most of the abandoned quarries are located in non-arable land with hostile environments, voluntary community participation may be requested for developing common property resource pools for fuel, multipurpose trees, community grazing lands, and low-cost solar devices for shared use by the local people.

FARMING SYSTEMS APPROACH

Farming systems approach is highly suited to laterite pits in less hostile environments, where soils are more responsive to management. A judicious blending of farming systems with components of agroforestry, horticulture, livestock, pisciculture, pasture and fodder would be suitable measures. The components of the system and type of crops to be raised should be based on site conditions and local needs. Failure of any component can be offset by other components of the system.

MOUNTAIN HAZARD MITIGATION

5 MOUNTAIN HAZARD MITIGATION

Mountain ecosystems are both a fragile physiographic unit and a natural repository, rich with natural resources and services. In India, mountainous and hilly terrains account for 0.42 million square kilometres, approximately 12.6% of the land. The Himalayas form an arc north of the Indo-Gangetic Plain, forming the boundary between the Indian sub-continent and the Tibetan Plateau. This mighty mountain system is seismically active and geologically young. It is a system that is still changing due to the continuous subduction of tectonic plates. The Western and Eastern Ghats run along the western and eastern borders of peninsular India and are old and comparatively stable mountain systems. The Himalayan and the Peninsular systems are the sources of diverse geological, fluvial, and geo-morphological systems with aesthetic and cultural underpinnings.

Exposure to several natural hazards such as landslides, snow avalanches, Glacial Lake Outburst Flood (GLOF), forest fires, cloud bursts, and earthquakes adds to the fragility of these areas. Landslides triggered by heavy rain, tectonic activity, and snow avalanches can impact mountainous regions.

The landslide vulnerabilities of these regions have escalated due to human interventions—unscientific and unregulated modification of slopes, excessive mono cultivation practices resulting in soil degradation and eventually soil erosion, unsustainable infrastructure development, and deforestation. In recent years, several such landslide-induced events have occurred in the mountainous and hilly regions of the country.

ECO DRR IN MOUNTAIN HAZARD MITIGATION

Mountain regions are susceptible to human pressures and climate change degradation. One of the causes of mountain hazards is the ecosystem degradation in mountain environments due to human activities that hamper the soil stability and the slope. Land-cover and land-use changes include deforestation, agriculture expansion and mining. Unsustainable infrastructure development, such as road construction and hydropower projects, is among the biggest drivers of the degradation of fragile mountain environments. These changes increase hazards, such as avalanches, landslides, and flooding, especially in mountainous areas. Landslides, one of the most prevalent natural hazards, are caused by slope stability issues resulting from slope modifications, changes in water saturation, or loss of heterogeneous vegetation. These have become more frequent because of human-driven interventions.

Ecosystem-based measures constitute a critical strategy for mitigating the hazards referred to earlier. Ecological restoration of degraded mountain environments, protecting fragile mountain ecosystems, and adopting minimally invasive bioengineering solutions in unstable mountain slopes are major Eco DRR initiatives to address mountain hazards risk.

Ecological restoration is undoubtedly an essential factor in mitigating the effects of mountain hazards such as landslides and rockfalls. Restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (Bertrand, N., 2021). It recovers lost ecosystem functioning and addresses the risks of mountain hazards. Healthy ecosystems can reduce physical exposure to natural hazards by acting as buffers and providing protective barriers, thereby reducing vulnerability. For example, protected forest cover in a mountain environment can conserve soil, safeguard from accelerated water flows, and ensure stabler slopes, mitigating landslide risk.

Bioengineering methods are the most widely accepted strategies for unstable and degraded mountain environments. Bioengineering techniques combined with civil and social engineering measures can considerably reduce the overall cost of landslide mitigation (Singh, 2010). It offers environmentally friendly, cost-effective solutions to slope instability problems in mountainous and hilly terrains. Bioengineering constitutes vegetation-based techniques that use engineering practices integrated with ecological principles that help slope stability of the mountain areas and maintain environmental balance.

Eco-DRR measures in the mountains offer protection from sliding and slippage of surface material such as rock, soil and water mixtures (McGillivray, 2011). Frequently used Eco-DRR measures include various types of vegetation cover, ranging from forests to shrubs and grasses, green infrastructure (GI) and ecological or biological (bio-) engineering measures. These approaches support biodiversity conservation, improve the livelihood security of the local communities while reducing the risk of natural hazards, and are cost-effective.

Arguably the best example of Eco-DRR in mountainous regions is vegetation that protects people, settlements and infrastructure against landslides (Bathurst et al., 2010; Schwarz et al., 2010).

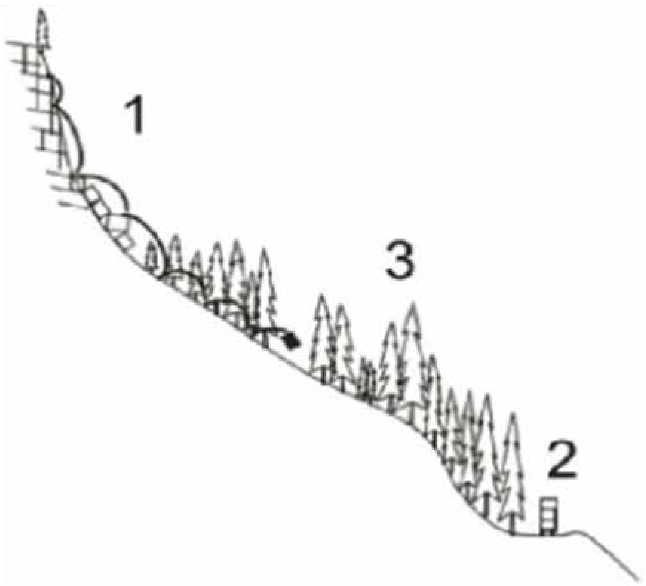


Figure 5.1: Protection of the forest system from mountain hazards. The forest (3) protects exposed assets (2) from the hazard (1); eg. landslides, rockfalls or debris flow
source: Brang et al., 2001

Vegetation, through hydrological and mechanical effects, influences the probability of onset and intensity of landslides (Bathurst et al., 2010; Kim et al., 2013; Schwarz et al., 2013). Trees regulate the water balance through rainfall interception, evapotranspiration and soil water storage, reducing pore water pressure or decreasing soil suction stress, thus lowering the probability of slope failure (Dhakal and Sidle, 2003; Keim and Skaugset, 2003). The hydrological effect of forests is considered relevant for hillslopes with large catchment areas but less for smaller hillslopes where landslides are triggered by short-intense rainfall (Sidle and Bogaard, 2016).

The main mechanical effect of forests is root reinforcement, including basal root reinforcement along a potential slip surface, lateral root reinforcement at the margins of the landslides, and stiffening effects of soil under tension and compression (Cohen and Schwarz, 2017; Schwarz et al., 2015). Vegetation reduces the propagation probability of shallow landslides due to their barrier effect that adds friction to the slope surface. Trees may considerably slow down the movement of slipping soil masses and deflect their flow paths (Lancaster et al., 2003; PEDRR, 2010).

Generally, landslide mitigation by using vegetation is known as soil bioengineering stabilization. This method relies mainly on plant parts—roots, stems, and branches—that serve as the main structural or mechanical elements in the slope protection system. In addition, soil bioengineering systems are environmentally compatible during the construction process because they generally require minimal access to equipment and only local workers and cause a relatively minor disturbance. Vegetation can stabilize the soil to prevent excessive erosion and mitigate the effect of landslides.

Erosion is often a problem when there is not enough protective cover on steep slopes. Vegetation is ideal for erosion control because it is relatively inexpensive to establish and maintain and is aesthetically appealing as well. Vegetative turfing has proved to be, by and large, the most economical and simple means of protecting slopes of hills and embankments against erosion. This method can be adopted only in areas where the soil has enough nutrients and the environmental conditions are conducive to promoting vegetation growth. The method consists of preparing the slope area into seedbeds by grading the slope to the maximum extent possible and subsequently planting the seeds or saplings/plant roots of promising types of suitable, locally available plants. If the slope has pockets of enriched and poor soils, sowing seeds in isolated pockets of specially enriched soil will encourage plantation. The rest of the hill can be treated using other techniques.

Shallow superficial slides constitute a significant proportion of landslides in areas with moderate rainfall intensity and medium cohesive soil cover. Most of these superficial landslides occur due to loss of vegetation cover on soil slopes due to cuts made for road construction. Superficial slides extend to only a shallow depth below the slope surface and originate from erosion due to flowing water.

Vegetative turfing is one of the most effective corrective measures in such cases. Vegetative turfing is essential, even as a preventive measure in a freshly exposed cutting made for road construction. In the case of deep-seated slides, however, vegetative turfing is only one of the several corrective measures which should be adopted, and as such, it can prove to be effective only when implemented along with other corrective measures (Recommended Practices for Treatment of Embankment and Roadside Slopes for Erosion Control, 2011).

Vetiver is a particular type of grass which can be grown in a wide variety of soils such as clayey, sandy, silty, and gravely types; that is, from least erodible to highly erodible soils. This type of grass does not require any special maintenance. Vetiver can grow in a wide range of climates ranging from 300 mm annual rainfall to over 6000 mm annual rainfall and from -14°C to more than 50°C of soil temperature. Moreover, it can withstand prolonged and sustained droughts for more than six months.

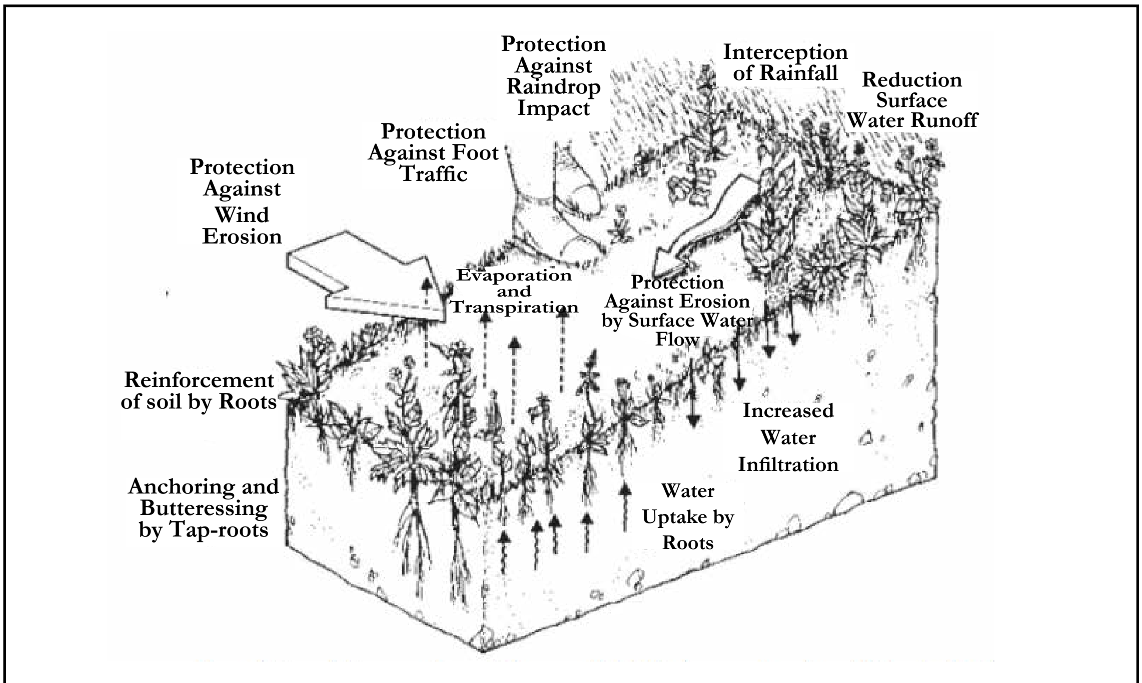


Figure 5.2: Influences of vegetation on soil stability
source: Coppin and Richards, 1990

The stabilisation and protection of slopes by vetiver grass is effective, efficient and low-cost vis-a-vis other traditional erosion control methods like stone rip-rap. Vetiver grass penetrates vertically below, going to considerable depths into the sub-soil. Its roots have significant strength and thereby improve the shear strength of sub-soil at a depth of 0.5 m by as much as 40 per cent. For best results, the vetiver root divisions, or slips, should be planted in a double or triple line to form parallel hedges across the erosion-prone slope. Distance between consecutive hedge rows can be kept between 30 to 50 cm. The slips should be planted at the beginning of the rainy season to ensure they benefit from the soil moisture. Once the hedge has been established on the slope, the only care needed is annual trimming, if required. (Recommended Practices for Treatment of Embankment and Roadside Slopes for Erosion Control, 2011).

In tropical and subtropical areas, Vetiver grass hedgerows (VGHR) for stabilization are ideal because this grass grows fast and has deep root penetration. However, as the roots of the vetiver grass is much in demand for medicinal purposes, and it is seen that vetiver grass planted for slope stabilisation are pulled out of the ground increasing the erodibility of slopes.

The primary function of vegetation on unstable slopes is to bind soil particles together, minimize slippage and movement of loose particles and unstable soil sections, and facilitate water runoff without compromising the safety of the slopes. There are several ways in which vegetation performs these essential functions. These are summarized below:

- **Reinforcing**: The level of reinforcement depends on the nature of the roots. The dense network of coarse and fine roots from vegetation can work as a reinforcement mechanism on the slope by binding and stabilizing loose materials. The dense root network also adds to the shear strength of a slope and thus reduces the risk of landslides and debris flow.
- **Supporting**: Lateral earth pressure results in the lateral and outward movement of unstable slopes. Large and mature plants can provide support and prevent this movement.
- **Catching**: Loose materials tend to roll down a slope because of gravity and erosion, which can be controlled by planting vegetation. The stems and roots can catch and hold loose material.
- **Armouring**: Some slopes are very water sensitive. They start moving and are easily liquefied when water falls on them. Vegetation can protect the surface from water infiltration and erosion by rain splash.
- **Anchoring**: The deep-rooted vegetation can connect the topsoil layer with the underlying stable bedrock layer, with the root tensile strength acting as an anchor.
- **Draining**: Water is the most common triggering factor for slope instability. Surface water drains away more efficiently in areas with dense rooted vegetation. Thus draining can be managed by planting small and dense rooted vegetation.
- **Interception**: Tree canopies are a shield for intercepting raindrops during heavy rainfall. This protects the soil from erosion caused by rain splashes.
- **Restraint**: The dense root network of coarse and fine vegetation physically binds and restrains soil particles, rendering the slope more stable. Also, it protects the

soil from splash effects and reduces runoff velocity, while the roots bind the soil particles, thus hindering surface erosion.

- **Absorption**: Roots absorb surface and underground water, lowering soil saturation and, as a result, the risk of slope failure.
- **Surface runoff reduction**: Vegetation can be used to reduce runoff in several ways, including trapping moisture in leaves.

SCOPE OF ECO DRR THROUGH EGS IN MOUNTAIN HAZARDS

Generally, mountain areas are socially, economically, and environmentally among the most vulnerable physiographic region. The Mahatma Gandhi NREGS incorporates several key policy strategies that have the potential to provide support to the vulnerable remote and rural populations in the mountain environments in terms of employment; this could be utilised to take up works oriented at disaster risk reduction in the mountain regions. Many eco-driven interventions such as soil protection, water, and biodiversity conservation, discharging springs (groundwater discharge), arresting land degradation, increasing tree cover through afforestation programs, and construction of boulder barriers, among others, can enhance stability in the mountain environments, reduce exposure to mountain hazards, and help reduce the risk in mountainous areas. Many road construction activities fall within the ambit of Mahatma Gandhi NREGS. These are targeted at providing all-weather access to villages and include the construction of roads and culverts within village boundaries. Thus, Mahatma Gandhi NREGS can play an essential role in addressing the inherent vulnerability in mountain environments, including remote and inaccessible terrain that is highly vulnerable to landslides and other mountain hazards.

IDENTIFICATION OF LANDSLIDE LOCATIONS

An essential aspect of landslide mitigation in mountainous terrain is the identification of landslide hazard-prone zones at the macro and local levels. Landslide hazard zone maps mark large swathes on the map as being at risk. These broad zones are made up of innumerable slide zones of varying degrees of severity that depends on a host of conditions, some of which are listed below.

- Historic landslide locations.
- Areas of mountainous slopes with small streams or natural drainage paths.
- Areas adjacent to a base or top of a cut or fill slope.
- Areas adjacent to the base of rock mass showing joints.
- Areas at the base of steep slopes with many detached boulders.
- Steep slopes or faces of hard bedrock that have not moved in the past but have a few visible joints, fissures or narrow cracks
- At the top or along the ridges adjacent to steep high slopes.
- Steep slope areas with thick soil masses devoid of vegetation.

- Areas where slope angle changes abruptly and variations occur in the thickness of soil as a result of construction activities
- Relatively flat areas with thick soil mass and frequent water leakage through a porous surface.

In addition to the conditions listed above, various causative factors, such as slope, aspect, rainfall, lineament, lithology, geomorphology, land use, and soil, trigger landslides.

Landslide vulnerability mapping is essential in landslide investigation and risk management. The processes and analysis are done on a GIS platform where the causative factors are combined, considering their relative importance, to form the landslide susceptibility map. The method finally identifies the land areas best suited for development by examining the potential risk of landslides and serves as a decision-making tool for mitigating landslides to inform planning and development processes.

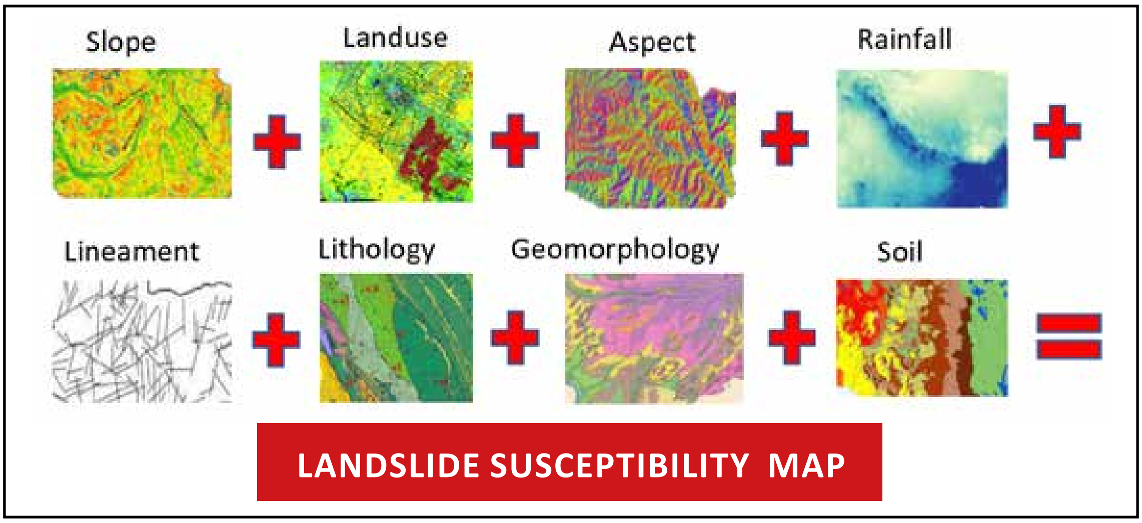


Figure 5.3: Landslide Susceptibility Mapping

MEASURES FOR ECOSYSTEM-BASED DISASTER RISK REDUCTION (ECO-DRR)

Several Eco-DRR measures can be used to reduce landslide-induced hazards in mountainous terrain. These are discussed in the following section.

HYDROSEEDING

Hydroseeding is mixing seed, mulch, fertilizer, and soil nutrients with water to form a thick slurry and applying it to the surface with pressure to promote seed germination and turf creation. Hydro-mulch machinery uses a mixture of wood fibre, seeds, fertilizer, and a stabilizing emulsion to exposed soils to protect them from water and wind erosion. Hydroseeding is a good option for regions that need interim protection until permanent stability is achieved, especially on hillsides and slopes. Site conditions, site topography and exposure to sun and wind, vegetation type, season and climate, water availability, and plans for permanent vegetation should all be considered in the preliminary evaluation of site conditions for selecting appropriate seed mixtures. Hydroseeding is the simplest and quickest method for establishing grass on edges, on large slopes, and in other difficult-to-access areas to cover slopes.

Figure 5.4: Hydroseeding

TURFING

This method uses grass or local vegetation with developed root systems for direct application to the slope surfaces as ground cover to protect the slopes against erosion. Once the roots of this vegetation penetrate the soil, it quickly grows and spreads its roots deeper into the soil, resulting in a firmer overall surface. Turfing can help protect regions with high flow concentrations, such as channels and drains. As grass has a better capability for binding soil than other plants, turf is preferred for decreasing runoff velocity and containing rain splash erosion. Turfing provides instant surface protection and gives complete instant surface cover.

Figure 5.5: Turfing a sloped surface

TREE BUSHES PLANTING (LIVE TRANSPLANTING)

This technique refers to planting vegetation such as shrubs, plants, and trees along slopes. The primary objectives of live planting are to reduce soil erosion and reinforce the soil. This strategy provides instant erosion control. A detailed study of site characteristics and the surrounding environment is required to determine the type of plants and the density of pits along the slope for optimal vegetation development. This method is suitable for gradients with a high degree of steepness. It can be used in combination with the hydroseeding of grass.

Figure 5.6: Bushes planting

GEOTEXTILES

Figure 5.7: Slopes stabilized with biodegradable geotextiles in Hong Kong

Geotextiles are permeable blankets used to cover the soil surface and decrease erosion caused by rainfall. Geotextiles help enhance the surface microclimate by preserving soil moisture and encouraging seed germination and plant development. They are also applied to protect seeds in the early stages of vegetation growth along slopes. This technique is suited for slopes with a high risk of erosion covered with dormant or sluggish vegetation as they instantly control rain splash and runoff. They also protect against erosion in damaged places where vegetation takes a long time to develop. Synthetic mats can be used to add tensile strength to a soil section. Geotextiles are also suitable for steep slopes or high-flow slope channels.

BAMBOO FENCING

Bamboo fences can minimize soil creep or surface erosion on a slope, prevent gully expansion, especially in seasonal water channels, and regulate flood waves along a river's edge. The primary poles might be bamboo pegs to ensure the entire structure is rooted. On the upper side of the fence, shrubs and grasses are planted to collect tiny soil particles. The primary goal is to trap loose sediments on the slope, enhance the growth conditions for plants, and minimize the rate of surface runoff. It must be maintained regularly to preserve the fence, and any damaged sections should be replaced immediately.

Figure 5.8:Bamboo fencing on a slope

JUTE NETTING

Jute netting is a technique to stabilize steep slopes of 35–80 degrees where it is challenging to develop vegetation. This method involves laying jute netting firmly on the prepared slope after sowing seeds of suitable vegetation. Before laying the jute netting, the slopes which are being treated are demarcated, graded and fertilised. The area must be levelled so that when the netting is laid it can cover the entire area flush to the ground ensuring that the runoff would flow over the nettings.

The slope is armoured with locally available woven jute net, and low-growing grass is seeded in the gaps. Jute netting is frequently employed to prevent landslides along highways. The purpose of preserving soil moisture and enhancing infiltration is to protect bare slopes from rain splash erosion, improve the condition of the site, and allow vegetation to develop. Regular observation and maintenance are required till the grass is firmly established.

USE OF COIR NETTING

Coir netting (also known as 'Coir Bhoovastra') is another type of biodegradable material which can be effectively used, like jute netting. Coir netting degrades much more slowly than jute netting. Its expected field life is about 2 to 3 years, providing protection to the slopes for a longer time than jute netting. Coir is also resistant to saline water and provides an ecological niche for rapidly re-establishing the vegetation cover. Coir resembles natural soil in its capacity to absorb solar radiation. This also means there is no risk of excessive heating, as it sometimes happens in synthetic netting materials. Like jute netting, coir netting also breaks up runoff from heavy rains and dissipates the energy of flowing water. Coir promotes the growth of new vegetation by absorbing moisture and preventing the top soil from drying out. However, compared to jute nettings, coir netting is less drapable and has lower water absorption capability. Coir nettings are available in densities varying from 400 to 1400 gm/m2. The higher density means a tighter mesh and less open area in the netting. The length of the rolls would be 50 m, and width can be between 1 to 4 m (Recommended Practices for Treatment of Embankment and Roadside Slopes for Erosion Control, 2011).

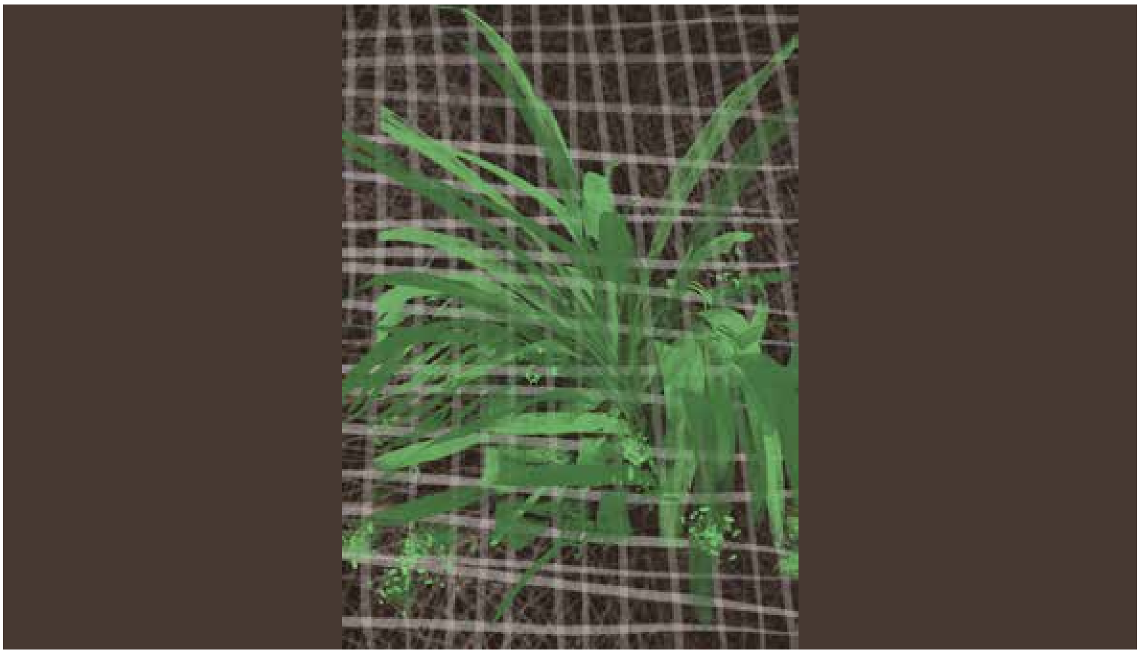


Figure 5.9: Jute netting on a cut slope

LIVE CRIB WALL

A crib wall is a box composed of interlocking struts (logs or precast structures made of concrete, recycled polymers, or other material) and boulders. They are primarily used to support steep slopes and prevent them from undercutting, such as a stream bank or the side of a road cutting, and they are also an excellent way to stabilise the toe of a slope. They are, however, only efficient when the amount of soil to be stabilised is minimal. Live branches and well-rooted plants are inserted between interconnecting logs in a live crib wall, where they may grow and form a root network that reinforces the barrier even more. Nails, bolts, and cross logs can be used for additional security and system protection. Vegetated crib walls provide instant protection, and as the plant develops, their efficacy improves. Crib walls should be constructed at a 10–15° inclination to the slope to promote stability.

Figure 5.10: Timber crib wall with quick-set live cuttings

PALISADES

A palisade is a barrier or wall made of wooden posts, tree trunks, or bamboo posts. These palisade barriers are planted across a slope following the contour to trap debris travelling down the hill, armour and reinforce the slope, and accelerate the infiltration rate. Palisades

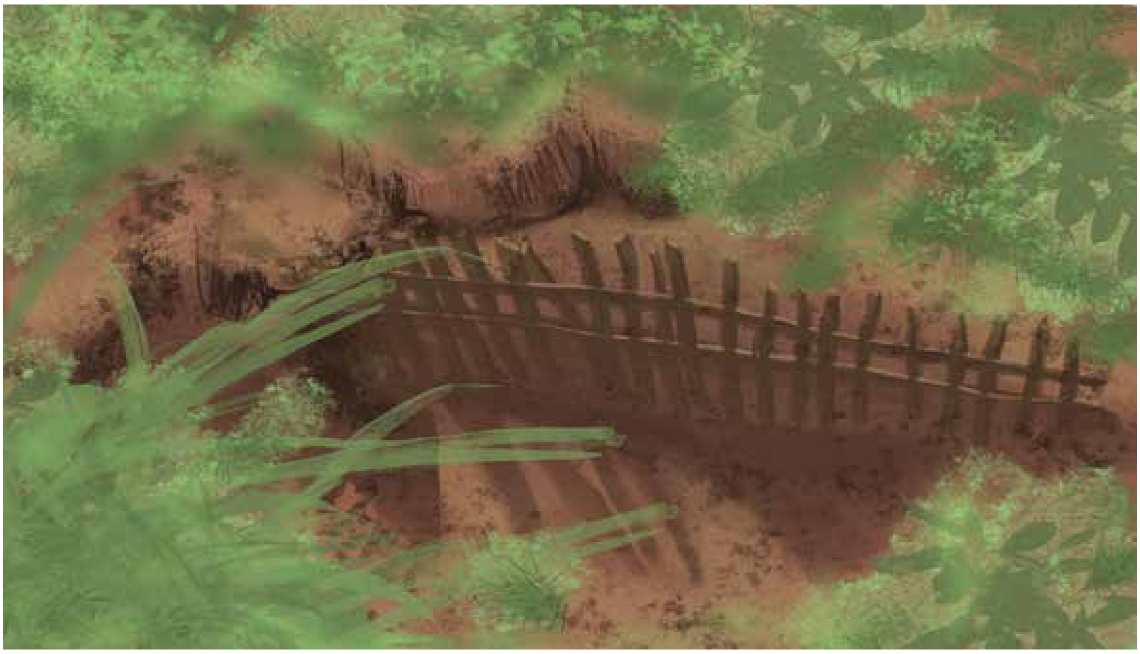


Figure 5.11(a): Palisades

Figure 5.11(b): Palisades

stabilize the gully floor and prevent the creation of deep, narrow gullies and the erosion of V-shaped rills. Palisades require regular inspection, and broken or damaged stakes should be repaired and reinforced to support the growth of plants.

SOFT GABION RETAINING WALL

Figure 5.12:Vegetated soft gabion wall

Empty discarded bags of synthetic fibre or jute, commonly accessible on the market at low prices, are utilized to create this retaining structure. The rubble removed from the landslide's toe is used to fill the bags that construct "soft" gabion barriers. The sealed bags are used as retaining wall building blocks, similar to bricks. The soil from the upslope is scraped and compacted appropriately to fill the gap behind the bags. Thick vegetation is established at the toe of the landslide after roots and sprouting. When the synthetic bags decay, the plant has taken root, and the slope has been permanently stabilized. Using vegetation cover, this method helps protect and armour the slope from erosion caused by runoff or rain splashes.

SODDING

In the sod technique, the indigenous grasses are extracted from pastures with their soil and root systems intact. The grass sods are laid in shallow trenches along the contour or in a checkerboard pattern on the slopes. The sods are arranged, so their top section is elevated above the slope surface. At the same time, the roots are adequately pressed to keep them in contact with the soil below, allowing the root system to penetrate easily into the existing soil. There is no risk of the sods failing because they are already established wild grasses. As with previous bioengineering structures, the sod treatment functions as a living mechanical barrier.

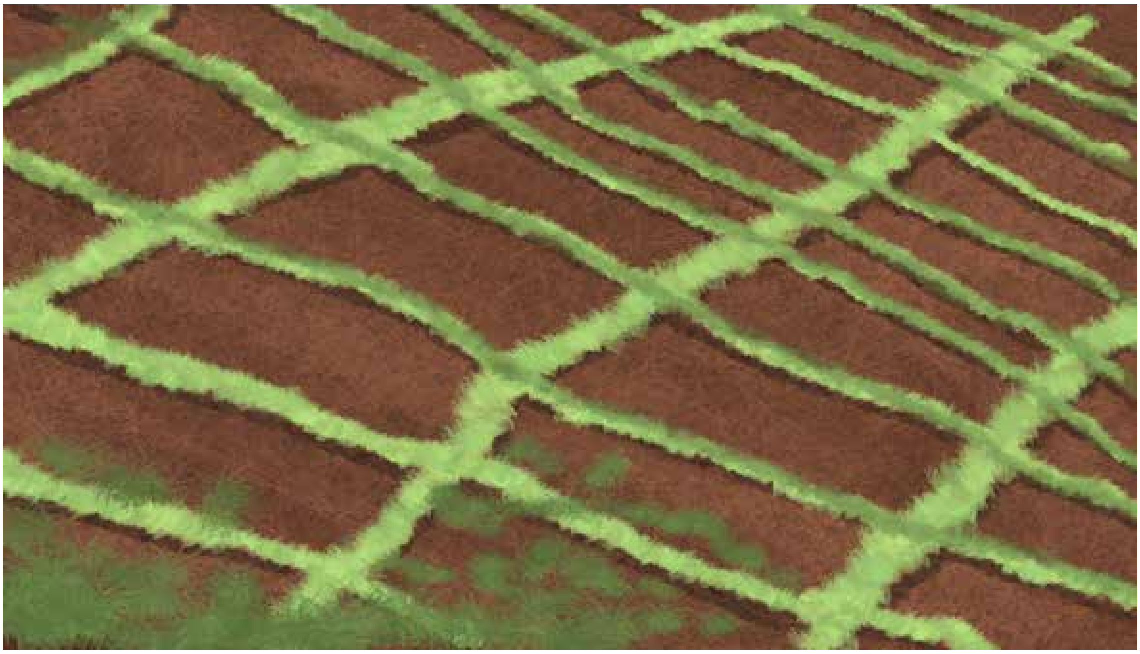


Figure 5.13: Sodding

ENGINEERING ASPECTS

Most hillslopes are naturally concave or convex and are generally stable. Human modification of these natural slopes without proper safeguards renders slopes unstable, which, in turn, causes landslides.

In disaster studies, landslides are perceived as "engineering problems" requiring "engineering solutions" involving structural interventions. Most slope engineering techniques require a detailed analysis of soil properties and a sound knowledge of the underlying soil and rock mechanics. Generally, landslide engineering mitigation measures are arranged in four groups: modification of slope geometry, drainage, retaining structures, and internal slope reinforcement. Selection of an appropriate remedial action depends on: a) engineering feasibility, b) economic feasibility, c) legal/regulatory compliance, d) social acceptability, and e) environmental acceptability. Structural solutions can be very effective when adequately designed and constructed, especially in areas with high potential loss or restricted sites.

Table 5.1: Major types of engineering landslide mitigation measures

MODIFICATION OF SLOPE	DRAINAGE TECHNIQUES	RETAINING STRUCTURES	INTERNAL SLOPE REINFORCEMENT
• Removing material from the area driving the landslide (with possible substitution by lightweight fill) • Adding material to the area to maintain stability (counterweight berm or fill) • Reducing general slope angle	• Surface drains to divert water from flowing onto the slide area (collecting ditches and pipes) • Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics) • Buttress of counterforts of coarse-grained materials • Vertical (small diameter) boreholes with pumping or self-draining • Vertical (large diameter) wells with gravity draining • Subhorizontal or sub-vertical boreholes Drainage tunnels, galleries or adits • Vacuum dewatering • Drainage by siphoning • Electroosmotic dewatering • Vegetation planting	• Gravity retaining walls • Crib-block walls • Gabion walls • Passive piles, piers and caissons • Cast-in situ reinforced concrete walls • Reinforced earth retaining structures with strip metallic reinforcement elements • Buttress counterforts of coarse-grained material • (mechanical effect) • Retention nets for rock slope faces • Rockfall attenuation or stopping systems (rock trap ditches, benches, fences and walls) • Protective rock/concrete blocks against erosion	• Rock bolts • Micropiles • Soil nailing • Anchors (prestressed/regular) • Grouting • Stone or lime/cement columns

SIGNIFICANT TYPES OF STRUCTURAL LANDSLIDE MITIGATION MEASURES

MODIFICATION OF SLOPE GEOMETRY

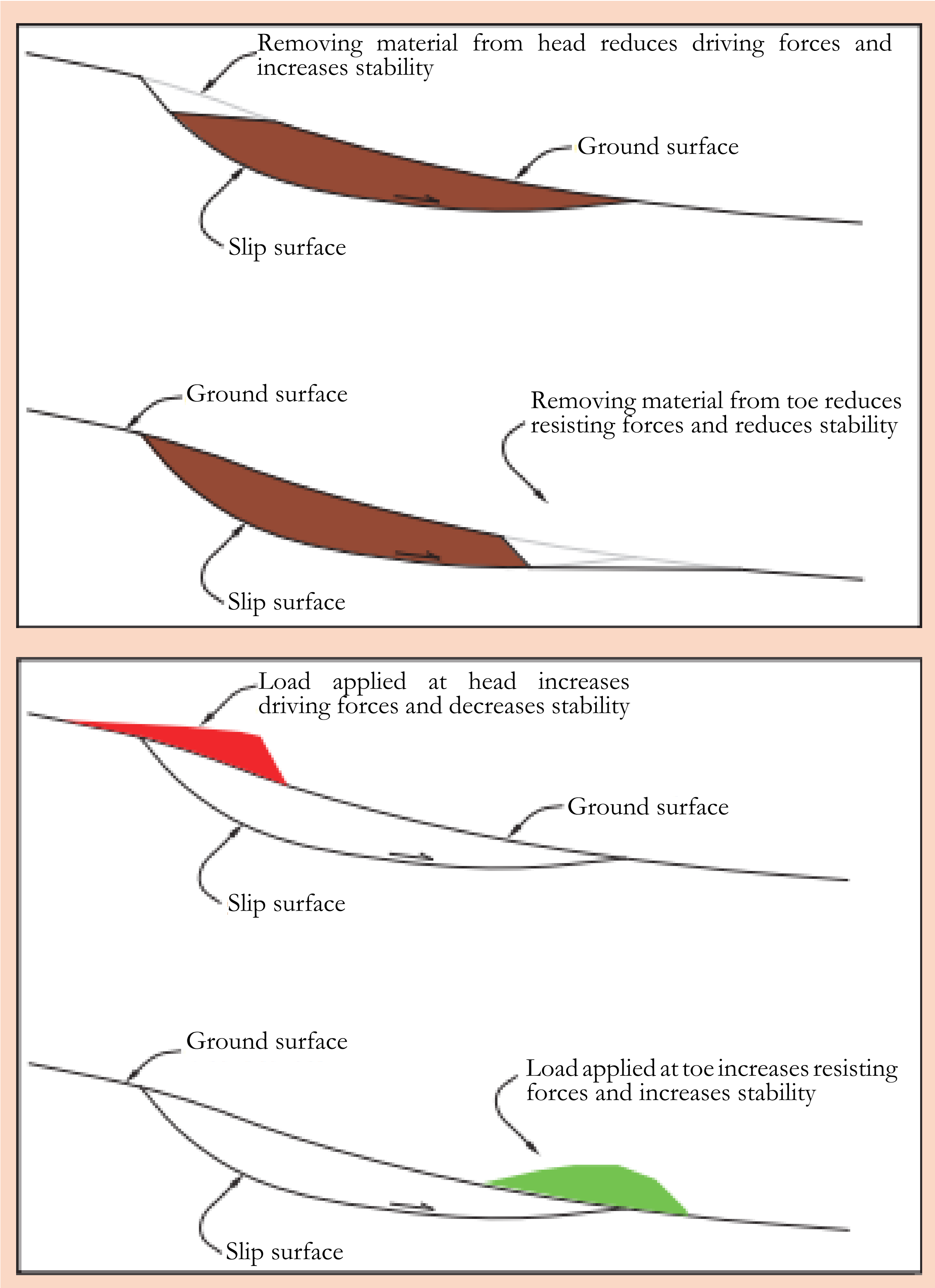


Figure 5.14:Modification of slope geometry

Removal of soil from the head of a slide is a standard method that reduces the driving force of landslides and improves the stability of landslide-prone areas. Also, reducing the height of a slope reduces the driving force on the failure plane by decreasing the weight of the soil mass. This method is only moderately efficient in increasing stability, and a complete solution may involve additional land modification. A simple approach to enhance the stability of a landslide-prone slope is to reinforce the base or toe of the hill with different material and structural elements that can act as a counterforce to resist slope failure. Dumping the removed material from the head and the other part of the slope at the toe will enhance the stability of the slope.

Broken rock or riprap may be preferred because these offer greater frictional resistance to shear forces and do not impede groundwater flow. Another method is the construction of benches, a series of "steps" cut into a deep soil or rock face to reduce the driving forces, effectively reducing the incidence of shallow failures. Benches help protect structures beneath rockfall-prone cliffs, controlling surface drainage or providing a work area for installing drainpipes or other systems.

DRAINAGE TECHNIQUES

Adequate water drainage is the most crucial element of slope stabilization for both existing and potential landslide zones. Drainage is often an essential remedial measure due to the critical role played by pore-water pressure in reducing shear strength. Drainage measures can be either surface or subsurface drainage interventions. Surface drainage measures require minimal design and costs and have substantial stability benefits. Subsurface drainage is also adequate but can be relatively expensive and is recommended on any potential or existing slide zone.

Surface drainage can be either surface ditches or shallow subsurface drains. Surface drainage is best employed at the head of the slide, where a system of cut-off gutters is constructed. The ditches cross the headwall of the fall, and lateral drains along the edges of the slide zone divert the runoff.

The simplest type of subsurface drain is the lateral trench constructed above an unstable slope. Surface water is diverted from unstable slopes by ditches and pipes. Also, drainage of the shallow groundwater is usually achieved by networks of trench drains. The trenches should be excavated to the shallow soil base to intercept any groundwater flow along the failure plane. They are backfilled with coarse gravel to prevent sloughing of the ditch sidewalls. An improvement is to use a drainpipe and then backfill the area with coarse gravel. A horizontal drainpipe is a widely used device for landslide prevention in highway construction. It is most effective when installed during initial excavation. Also, smoothing the topography of the slide surface can prevent surface water from ponding or connecting with the groundwater, enhancing slope stability. Any depressions on the slope that might retain standing water must be removed. Infilling and sealing large cracks in the soil surface by grading the soil mass are beneficial and prevent surface water from reaching the failure plane.

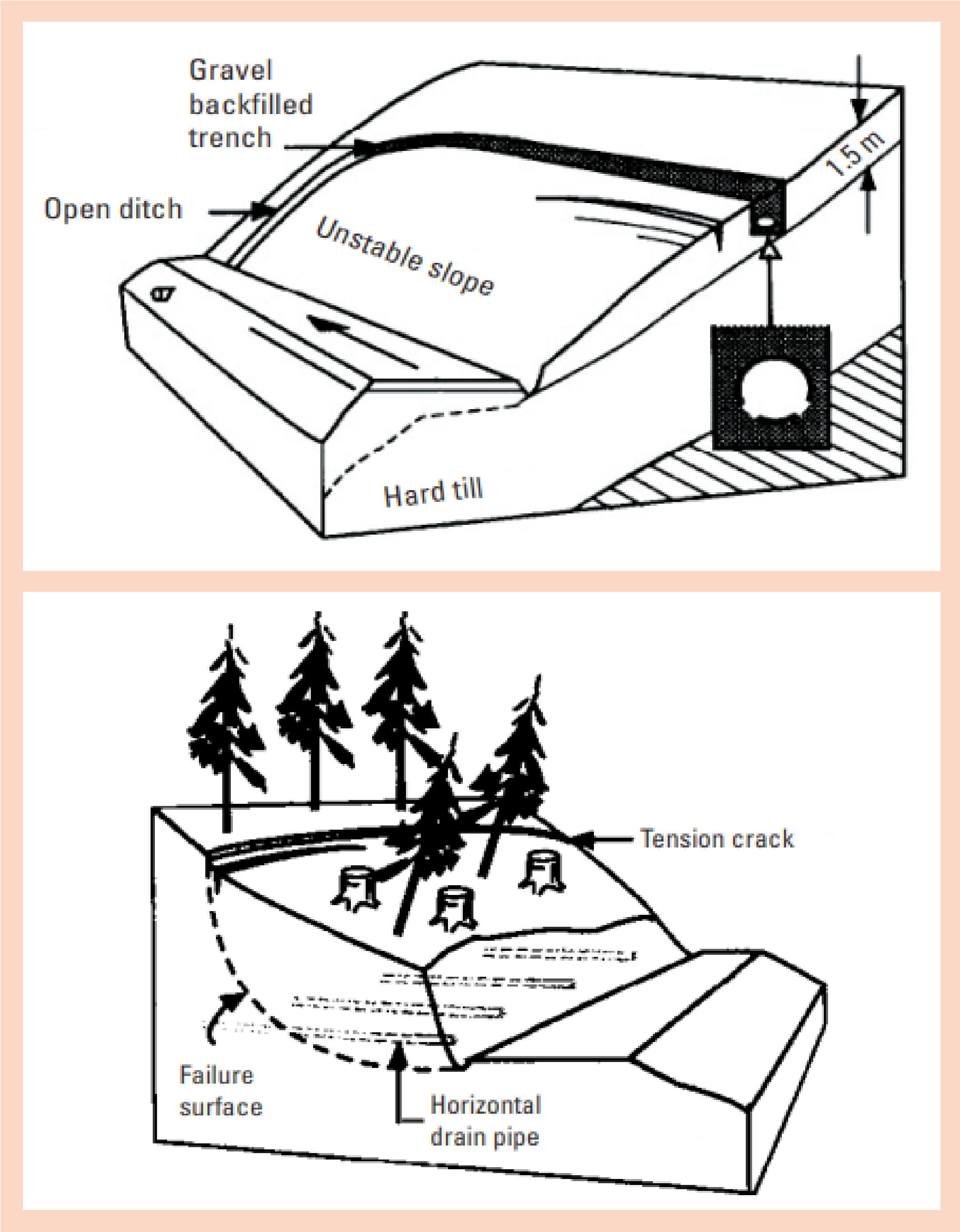


Figure 5.15:Drainage Techniques

RETAINING STRUCTURES

Retaining structures are solid and robust barriers utilized to support soil laterally on an unstable slope and permanently support a soil mass. These structures are designed to harness soil to a slope that would otherwise naturally move down or slide, which may cause a landslide. So these structures are used for slope stabilization and can mitigate landslides. The most common retaining structures are timber cribs, gabion walls, piles, cantilevers, sheet piles, plastic mesh, and reinforced earth.

SLOPE REINFORCEMENT

Reinforcement is the process of strengthening that improves shear strength and minimizes sliding motions along the slip surface with many different types of structures. This standard reinforcement method includes metal pieces to increase the shear strength of the rock and lower the stress released when the bedrock is cut. Metal rock nails or anchors are used as reinforcement measures. Examples include retaining walls, dowels or structural wells, micro piles, tied-back micropile sheet walls, active anchors, and soil nailing.

ROADS

Roads constitute critical infrastructure in hilly areas and are lifelines for post-disaster response measures. Storm-induced roadside mass-movement and slope failures are common in many tropical and subtropical climates (Nirmala Vasudevan, 2015). Failures are also often due to the faulty construction of the roads, such as unusually vertical hillside excavation and unmaintained local drainages. The underlying geology and geotechnical properties of the earth are other causes of roadside slope failure. In addition, unprotected roadside slopes and unmaintained road right of way are some other causes of soil slips and mass movements.

Eco-DRR for roadside slope protection gives primary importance to the ecosystem and is based on the mechanical and hydrological properties of the species which can be planted at a particular site. Adding roots on the slope increases the factor of safety of any sloping surface, where the plant roots provide additional strength to the soil in the form of root cohesion while deeper and larger roots anchor the soil through a process known as soil nailing.

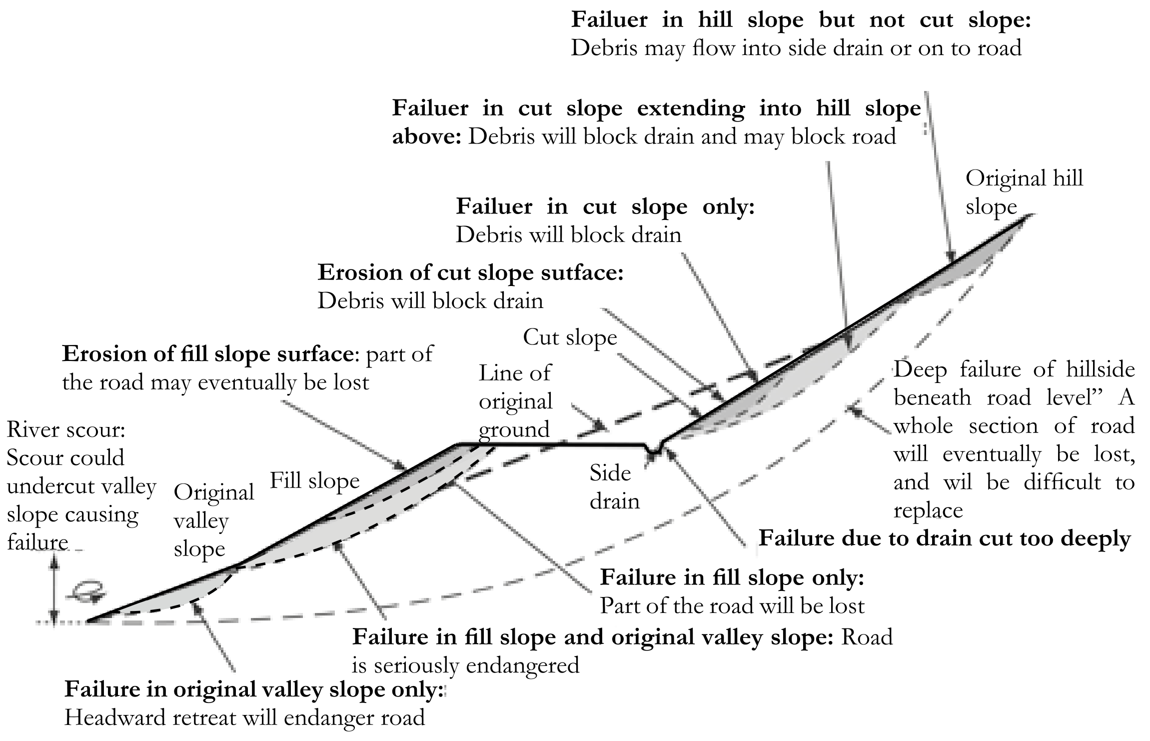


Figure 5.16: Possible slope failure mechanisms in road construction

Under the Eco-DRR approach, planting of vegetative species is often combined with simple and conventional civil engineering structures, also called hybrid construction or grey-green construction such as toe walls that provide immediate support to slopes, discussed in the following section.

In order to design better Eco-DRR measures for roads in hilly terrain, the road should be designed and constructed following standard design guidelines and engineering principles. The chosen road alignment should first be mapped, marking landslide susceptibility and unstable slopes with GPS coordinates, land use, condition of roadside drainage, cross drainages, nearby water sources, water availability, type and depth of soil, exposure of bedrock and its kind etc. In addition, the orientation and location of the road on the hill slope should also be noted.

Along with ground information related to soil, climate, landslides and landslide susceptibility, a map of the given road corridor should be prepared to understand potential roadside failure locations better. This susceptibility map needs to be verified thoroughly to select suitable sites for implementing Eco-DRR measures. It is important to note that Eco-DRR is more effective where the landslide is shallow or the potential failure depth is shallow (< 2 m) and the slope is around 30-40 degrees. Steeper roadside slopes (>40 degrees) may need other modifications to reduce the gradient.

HYBRID INFRASTRUCTURE-GREEN GREY SOLUTIONS

Hybrid solutions are conventional engineering solutions combined with nature-based solutions using appropriate vegetation (Nature-Based Landslide Risk Management Project, 2020). Compared to the costs of using structural measures alone, hybrid solutions are cheaper. Nature-Based Interventions are cost-effective, and they gain more confidence in their deployment as a stand-alone practice or in combination with other engineering techniques. This technique is suitable in susceptible areas where emergency landslide treatment has to

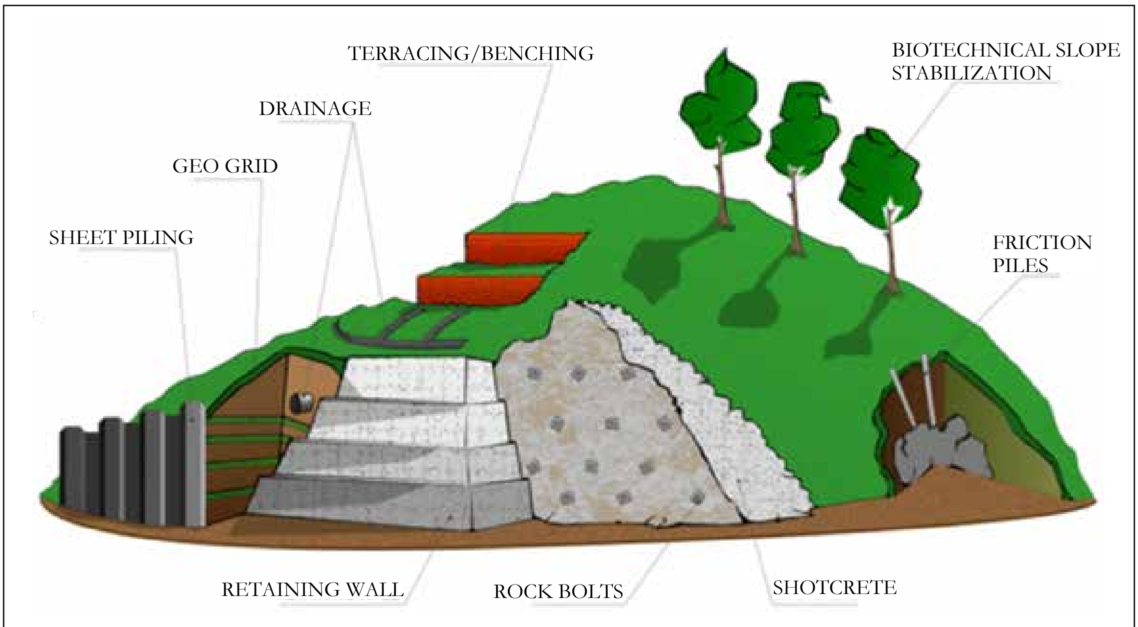


Figure 5.17: A hybrid method of slope stabilization
Source: Pilebuck, 2020

be done with minimal cost. The engineering and nature-based approaches contribute to sustainable development by improving aesthetics and reducing the ecological consequences of construction, maintenance, and operations. Some examples include retaining walls with bamboos, french drains and angled grass lines, the combination of anchors and trees, and Jute netting with planted grass (Figure 23).

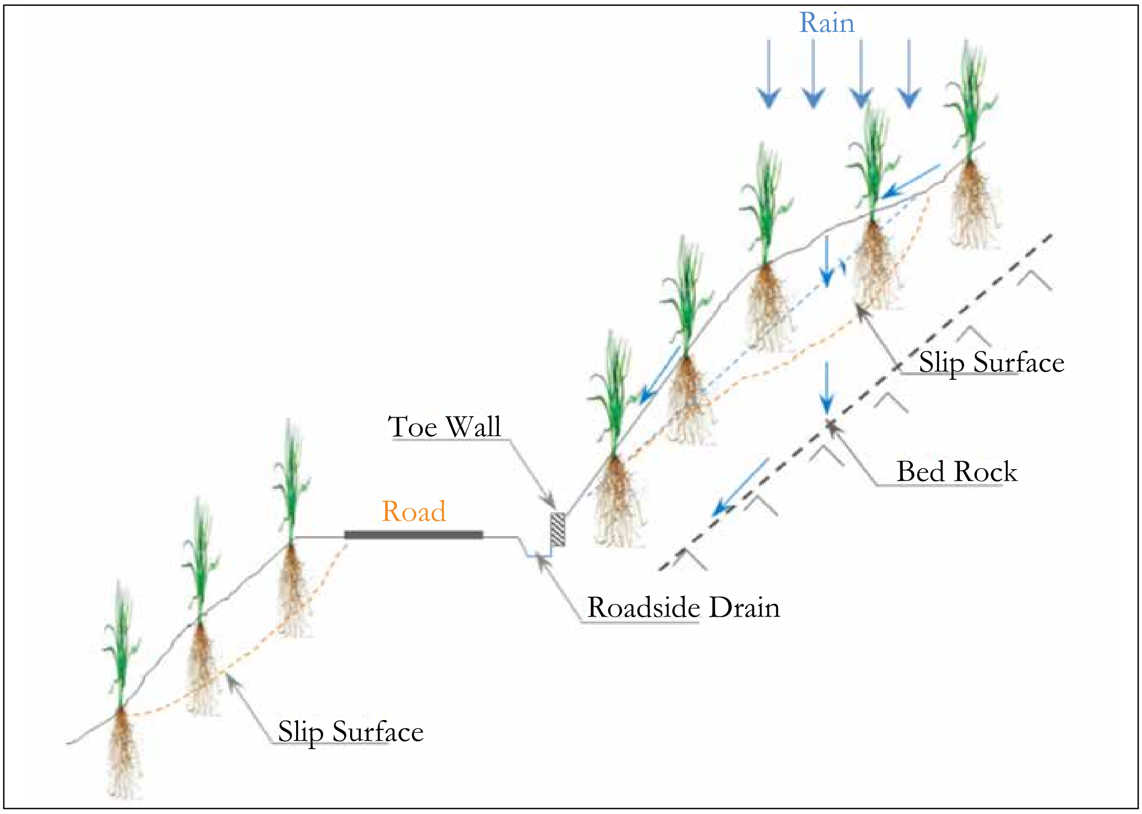


Figure 5.18: Roadside slope protection applying toe-wall, roadside drainage and appropriate plant species

FOREST FIRE MANAGEMENT

6 FOREST FIRE MANAGEMENT

Forest fires occur in nearly all the states of India and around half of the country's 647 districts every year. Forest fires increase carbon dioxide levels in the atmosphere, contributing to climate change and greenhouse effect. In addition to this, it destroys the natural structure of the soil, eroding it, and alters water quality as well. It can also temporarily or permanently destroy forest ecosystems which house a vast variety of flora and fauna. Typically, forest fires are caused either by natural or anthropogenic factors (e.g unattended campfires, negligent discarding of cigarettes, accidents, arson, burning of debris, lighting, fireworks). A warming planet also brings more chances of drought and with it, increased chances of intense forest fires over larger areas.

While small and limited forest fires are an essential part of the forest ecosystem and help in shaping the vegetation patterns and wildlife distribution in forests, large fires severely damage forests in numerous ways because of their uncontrollable nature, and greater intensity and frequency. Sustainable forestry can successfully prevent and help manage forest fires in the long run. Eco-DRR measures can be adopted beforehand and after to ensure that the impacts of a forest fire are mitigated. Other associated steps such as improvement of accessibility including strategic access roads, dirt roads, creation of water points etc can also help in fire suppression.

FOREST FIRE MANAGEMENT

Fire is the naturally occurring companion of energy released in the form of heat and light, when oxygen combines with a combustible or burnable material at a suitable high temperature. There are basically three components i.e., fuel, heat and oxygen that are required in the right combination to produce fire. A combination of these components produces the “fire triangle”. By nature, a triangle needs three sides, if any side is missing, it will collapse the triangle. The same is true for fire. If any of the three components of fire is missing - fuel, heat or oxygen, the fire will cease.

Two out of three necessary components of the fire triangle, i.e., fuel and oxygen, naturally exist in forests. It is the third component i.e., heat that really initiates fire in the forest. Heat may be supplied by either natural or anthropogenic reasons. Depending upon the source of the heat, the reasons for forest fire may be categorized as natural or anthropogenic. Lightning, volcanic explosions, friction produced by rolling stones etc., are the natural reasons for forest fire; the artificial reasons are either deliberate causes and unintentional or accidental causes. Removing any one of these three essential components from the fire triangle will help suppress the fire (Satendra, 2014).

ECO-DRR INTERVENTIONS FOR FOREST FIRE MANAGEMENT

While taking a Eco-DRR approach in Forest Fire Management, it is important to prioritise fire-prone areas, which will help in fine-tuning the fire suppression measures in protected areas. The prioritisation of fire risk zones is a practical concept and an aid to fire management and planning. Fire risk zones are points where there is a greater likelihood of fires starting and also spreading to other areas. Remote sensing has opened up opportunities for qualitative analyses of forests and other ecosystems at all geographical and spatial scales. For any area to be fire-prone depends on many factors such as vegetation type/density, humidity of the area, proximity to settlements, distances from roads etc.

Such vulnerability mapping should also identify existing fire lines and other facilities such as roads, transmission lines, and rail lines that may function as fire breaks. Creating fire lines by selectively removing trees in prioritised areas for more effective fire management is one of the traditional methods for forest fire prevention. Under the Mahatma Gandhi NREGS, destructive activities such as felling of trees is not permitted; but there are other allied activities which can be taken up under the Scheme which will vastly help in forest fire suppression.

CONSTRUCTION OF FARM PONDS

Dugout farm ponds (DOPs) can be constructed in forest areas to collect rainwater which can help retain moisture in the soil, as well as act as water points during fire suppression activities. Other water harvesting structures including earthen dams can also be constructed in order to retain moisture in the soil and regulate water flow, but unlike earthen dams, DOPs are easier to construct. DOPs should be constructed on a cluster basis so that the overall soil moisture regime of the area is improved, and water is accessible for an extended period of time.

Usually, the area of a DOP varies from 5 to 10% of the command area as per the water requirement. A DOP of top area 20 m x 20 m, bottom area 14 m x 14 m and 3 m depth can store 880 cm of water in one refill. This can also act as a water source for wildlife. As a preparatory measure, there should also be regular maintenance and desilting of existing natural water sources in the forest.

AFFORESTATION ACTIVITIES

Different trees have different levels of fire tolerance. Trees and shrubs with low flammability rates can be used as barriers and fire deterrents in forests, in accordance with the geographical location of the forest. Scientific revegetation of forest areas destroyed due to uncontrolled burning can be conducted under the Mahatma Gandhi NREGS. Also, since undergrowth is one of the main reasons for forest fires, the scientific management of forest floor biomass is important. Moisture and water conservation also helps in forest fire mitigation.

CREATION OF ROADS FOR CONNECTIVITY

Roads can be built within forest areas for ensuring connectivity between water sources and fire-prone areas. These roads can be developed under the Mahatma Gandhi NREGS and in convergence with other schemes at the local level.

COASTAL PROTECTION BY MANGROVES

7 COASTAL PROTECTION BY MANGROVES

Ecosystem services offered by coastal vegetation, especially mangrove forests, include maintaining biodiversity, regulation of water flows and supplies, carbon sequestration, maintaining the gaseous composition of the atmosphere, controlling floods, recycling nutrients, preserving and regenerating soil, filtering pollutants, and assimilating waste. Mangroves are also home to a large variety of fish, shrimp, crab and mollusc species. These fisheries form a vital source of food for thousands of coastal communities around the world. Mangroves also serve as nurseries for many fish species, including coral reef fish (Muhammed, 2016).

Mangrove wood is resistant to insects and rot, making it very valuable. Many coastal and native communities rely on this wood for fuel or for construction material. These communities also use mangrove leaves as animal fodder and collect medicinal plants from mangrove ecosystems. Recently, mangrove wood has also been commercially harvested for wood chip, pulp and charcoal production (Muhammed, 2016). Ecotourism in mangrove forests has also been a good source of income for local communities. It allows tourists to appreciate the unique ecosystem while at the same time learning about the distinctculture of human settlements that depend on it.

But most importantly, the dense root systems of mangroves trap sediments flowing off the land and down the rivers.

Mangroves along with other indigenous coastal species offer the best defense against coastal damage seen extensively across the coasts of India. They contribute to stabilising coastlines and reducing erosion from waves and storms, as well as providing other co-benefits for local communities.

Under the Mahatma Gandhi NREGS, there is scope for local governments to address the issue of coastal protection while promoting community livelihoods. Coastal protection works can be undertaken in both rural and urban areas. The major heads of works as specified under Schedule I of the MGNREGS directly linked to coastal protection are as below:

- Afforestation and plantation work
- Setting up of nurseries for propagating seedlings
- Belt vegetation: vegetation cover such as mangrove, casuarina and palm plantation has the potential to address coastal erosion.

COASTAL PROTECTION BY MANGROVES

Mangroves are typically diverse and consist of many different species. Each species vary according to different physical parameters such as height, diameter of the roots and stems. The density of the vegetation also varies per species; furthermore, each family of mangroves possesses characteristic attributes such as aerial or stilt roots. Mangrove areas are also characterised by mud flats that are present in front of the side of a forest (Andrzej Tusinski, 2014).

SITE SELECTION

Mangroves cannot be planted at all coastal sites. The site should have characteristics favorable for such a plantation. In order to complete the site selection task, all important factors should be taken into consideration and selection criteria should be developed. The main components of the criteria should be:

1. Accessibility

The site should be accessible for plantations and maintenance.

2. Inaccessibility to the grazers

Mangroves should preferably not be accessible to grazing cattle.

3. Mudflats texture

The texture of the site should be silty/clayey or muddy, rather than loose sand, particularly on the upper surface. Sandy sites tend to be eroded and are unstable for seedling establishment. Loose mud does not provide a very stable substrate for mangroves especially when planted as propagules or seeds.

4. Topography

The site should be slightly sloping, which drains tidal water back to sea rather than flat ground where the water stagnates. The site must not be too low, so that the coverage of tidal water does not persist for too long, nor too high, and so that ground is only covered by the tide in a few days a month. The best sites lie between the mean sea level and mean high water level.

5. Daily tidal coverage

The site should be covered by water during daily high tides to get regular flushing of salts and to offset the water requirements of the plants.

6. Tidal nutrient impact on plant growth

The sea weeds and debris left behind by high tides can damage young seedlings since they are salty in nature and nothing grows in salt. The major source of inorganic nutrients for inter-tidal plant growth is the land-derived nutrients brought in by the rivers and streams. As such, mangroves in estuarine intertidal areas receive the highest amount of nutrients and thus show maximum growth. Since localities away from rivers and streams receive a relatively small amount of plant nutrients, mangroves planted in such areas will take a considerably long time to grow into mature plants. Mangrove plantations in estuaries grow faster than those in other areas.

7. Low salinity and non-shelly soil

The sites compacted with shell contents are not conducive for planting mangrove propagules or seedlings. A site having high salinity due to sea water seepage and evaporation and non-coverage by high tides is not suitable for establishment of mangroves (S. Shahid, 2004).

In order to implement Eco-DRR along coastal areas, local governments have to identify the coastal zone to which they belong. These coastal zones should be mapped, marking those coastal areas with the GPS coordinates, noting important details related to land use, condition of coastal areas, any protection methods adopted, nearby water sources and availability of water, type of soil. Periodic field surveys should be conducted in the study area and data collected on various parameters. Secondary data on terrain features, agriculture, fisheries, land-use changes, population and other parameters is also important in the coastal zone.

SPECIES SELECTION

Leaf shape, presence of breathing roots and their shape as well as the shape and size of propagules (with hypocotyls) are useful characters for identifying mangrove plant species.

BAMBOO POTS

While implementing such a project, the main wastage will be plastic poly bags/pots which are used for developing the saplings. This can be tackled by using bamboo stems and pots instead of plastic poly bags for planting saplings. The roots of the saplings do not get coiled. While replanting them, one needs to give a sharp knock to the bamboo stems to loosen the sapling, just like one would with plastic pots. The benefit of using a bamboo pot is that they can be reused, and if it breaks, it can simply be discarded, and it will decompose.

AFTER CARE METHODS

Intensive care should be given to the young seedlings in a plantation for the first 2 – 3 yrs. The following aspects should be taken care of in order to create a successful mangrove plantation (Wasana de Silva, 2013).

1. Algal growth

All algae (seaweeds) that are entangled with the transplanted seedlings/ propagules should be removed by hand during low tide to minimize seedling mortality. Effect of algae can also be inhibited by using seedlings that are 1-2 years old, so that their leaves would be above water level.

2. Siltation

Silt may get deposited on the leaves of the seedlings (if they get flooded with tide) and later gastropods (molluscs) may damage the leaves. This damage can be prevented by using 1 – 2 year-old seedlings.

3. Predation

Plants predated by cattle or crabs should be substituted. Planting propagules in the hollow of a piece of bamboo or PVC pipe will keep the delicate parts of the seedling from being eaten by crabs.

4. Cattle grazing

The planted area should be surrounded with a bamboo fence/mesh/ barbed wire to keep cattle away. Regular patrolling of the area should be done to check for the presence of cattle.

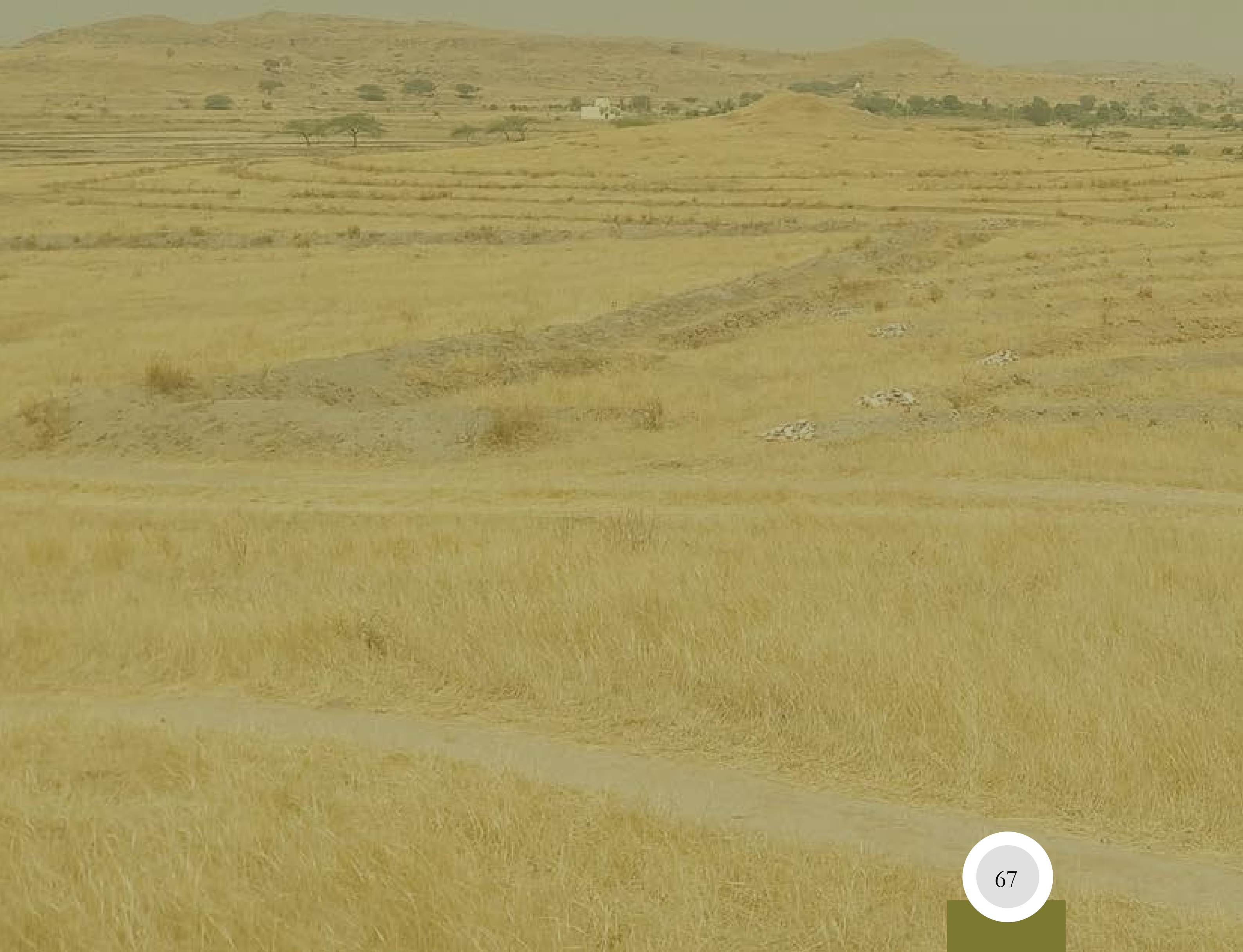
5. Erosion

Mud flats that may erode with tidal water movement can be stabilized first with a suitable species of grass (such as Porteresia sp) that can consolidate the mud before planting the seedlings.

6. Human intervention

The community should be educated about the significance of restoration efforts and should be made part of the team of protectors/monitors.

DROUGHT RESILIENT STRUCTURES FOR ARID LANDSCAPES



8 DROUGHT RESILIENT STRUCTURES FOR ARID LANDSCAPES

ARID AND SEMI-ARID LANDSCAPES

The arid and semi-arid landscape constitute about 35% of the land area of the world. They are typified by scanty rainfall, low and highly variable annual precipitation, where evapotranspiration exceeds precipitation. The arid land receives less than 250 mm of rain per year, whereas the semi-arid regions receive anywhere between 250 to 500 mm of rain per year (Tchakerian, V. P. (2015)). Apart from receiving scanty rainfall the landscape is characterised by higher temperatures and evapotranspiration rates, lower humidity, and a general paucity of vegetation cover. The streams are mostly ephemeral[1] and intermittent[2] dependent on scanty rains and groundwater-dependent streams fed by aquifers. Many watersheds in dry, arid and semi-arid regions have a very seasonal flow in the streams, and thus are quite critical in the protection and maintenance of water resources, human health and the environment. It is because of these dry conditions, that results in a great contrast between the moist riparian areas along the stream channels and adjacent dry upland areas.

[1] Ephemeral: A stream or portion of a stream which flows briefly in direct response to precipitation in the immediate vicinity, and whose channel is at all times above the groundwater levels.

[2] Intermittent: A stream where portions flow continuously only at certain times of the year, for example when it receives water from a spring, ground-water source or from a surface source, such as melting snow (i.e., seasonal). At low flow there may be dry segments alternating with flowing segments.

In India, about 69 % is dry land – arid, semi-arid and dry sub-humid. These regions are heavily populated and show severe degradation with implications for livelihood and food security for millions of people living in these areas.

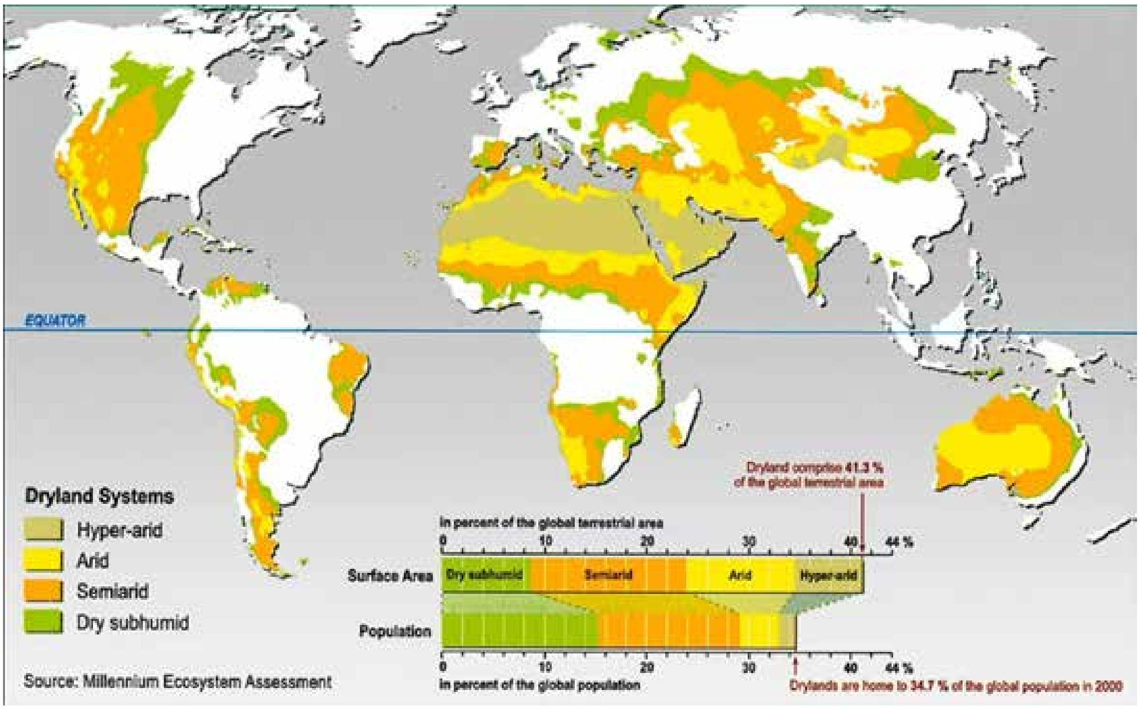


Figure 8.1: Global map showing arid and semiarid areas (Millennium Ecosystem Assessment, 2005).

Dryland systems comprise the most widespread terrestrial biome on Earth and are home to over 20% of the world's people (Glennie, K. W. (2010)). In the last century a combination of natural and anthropogenic factors have exacerbated desertification – which is rather a simplified 'march of the desert' into bordering semiarid regions, and into a more complex phenomenon that includes both natural and anthropogenic causes, the latter primarily the consequence of increased population numbers in the semiarid regions of the world putting undue stress on the subsurface water resources and soil moisture. The distinctive natural environment in arid lands, coupled with the growing human populations in drylands is changing regional rainfall patterns, in association with increasing temperatures because of global warming causing changes in aridity. The increase in aridity, coupled with extensive land use practices is driving severe land degradation. In order to make dryland areas resilient to drought, and reduce impacts of climate variability on dryland systems, traditional water conservation structures combined with low budget and high impact structures are encouraged in line with nature based designs for greater efficiency and long lasting shell life.

DROUGHT

Drought is a natural phenomenon that has a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is a slow-onset disaster characterized by the lack of precipitation, results in a water shortage. It can have a serious impact on health, agriculture, economies, energy and the environment (WHO). Due to natural clim`ate variability for long duration it is expected to make many regions of the world much drier over the coming decades. More intense drought over the arid landscapes can seriously transform and impact base flows with potentially severe consequences on the ecological functions and services. In order to reduce the impacts of prolonged drought, we have to look at aquifers as buffers against reduced precipitation and climate variability.

AQUIFERS

Groundwater can have a critical role in sustaining the functioning of natural ecosystems during droughts, especially in dry and seasonally dry climatic regions. Aquifers act as buffers during severe drought conditions. Aquifers are basically subsurface rock that holds water in permeable strata and act as subsurface buffers during extreme drought conditions. Groundwater extracted in a moderate and managed way from the aquifers has the potential to moderate the impact of droughts and heatwaves by moistening the soil and enabling vegetation to maintain higher evaporation, thereby creating a micro-climate.

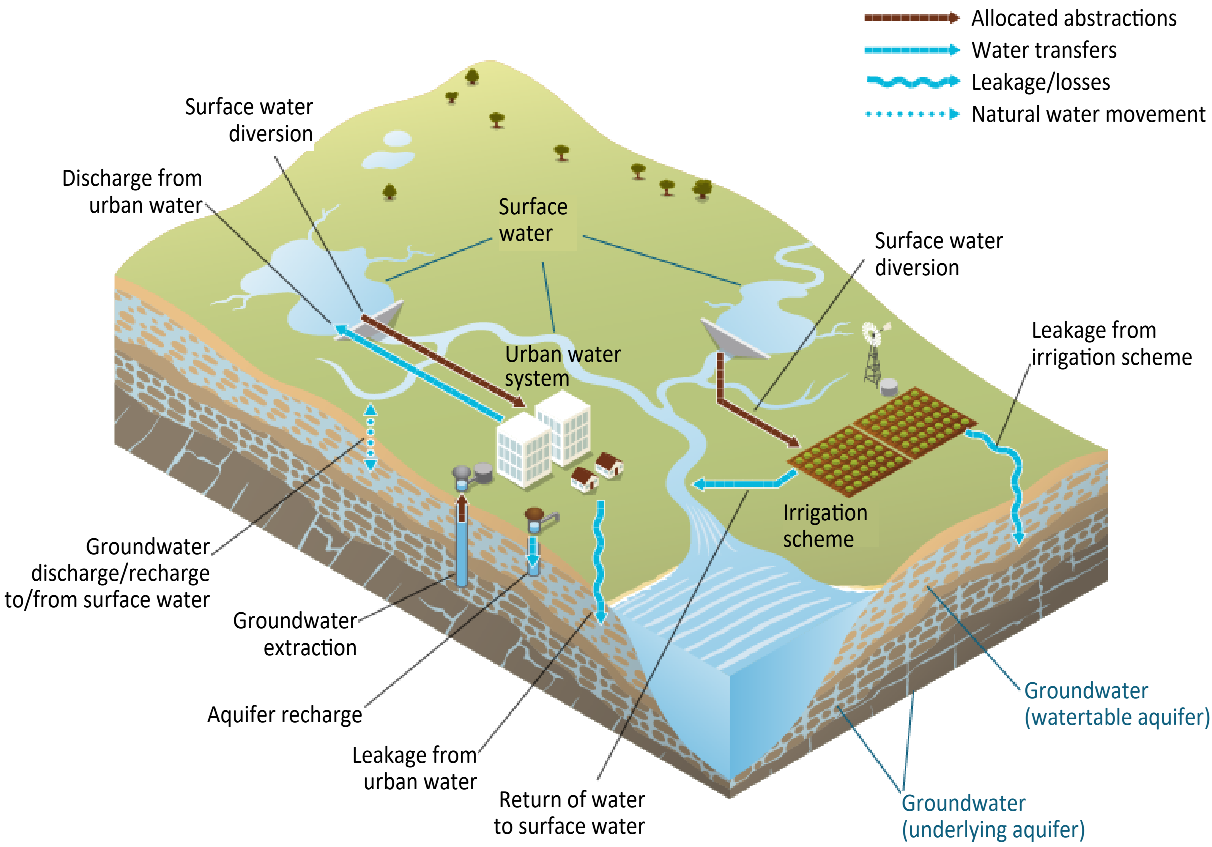


Figure 8.2: A schematic showing flows and stocks above ground and in aquifers (Image courtesy: Bureau of Meteorology, Gov of Australia)

DROUGHT RESILIENT STRUCTURES

People living in arid land regions are particularly vulnerable to extreme drought and drought-like conditions. Having climate resilient storage or recharge structures at appropriate locations can significantly reduce the impacts of drought and increase the resilience of the arid ecosystem from long term shocks of drought. A drought resilient structures along slopes and drainage lines are suggested based on the quantum of rainfall, permeability of the soils and slope of the land. Some of the structures that are ideal for arid landscapes are described below -

SLOPE AREA TREATMENT: CONTOUR TRENCHES

Contour trenches are ditches dug along a mountain or hillside in such a way that they follow a contour line and run perpendicular to the flow of water. The soil excavated from the ditch is used to form a berm on the downhill edge of the ditch. The berm is planted with permanent vegetation (native grasses, legumes) to stabilize the soil and for the roots and foliage in order to trap any sediment that would overflow from the trench in heavy rainfall events. The main purpose of contour trenches are to slow down the velocity of runoff, check soil erosion, improve local soil moisture profile and allow infiltration of water to shallow aquifers. The contour trenches are always dug half a metre deep and half a metre wide and the total length of the contour in an area that is to be spread is determined based on the percentage of quantum runoff divided by the cross-sectional area of the trench multiplied by number of fillings during one rainfall day. The below table provides guidelines for how much space to allow between trenches based on slope percentage. Alternatively, trenches should be one adult human's height apart in elevation.

Table 8.1: Trench spacing interval by hillslope (Sussman, D. (2007).

HILLSLOPE (%)	DISTANCE BETWEEN SUCCESSIVE TRENCHES
0 to 4	10 to 12 m
4 to 8	8 m
8 to 15	6 m
15 to 33	4 m

Figure 8.3: Staggered contour trenches along the lopr to check the velocity of surface runoff & soil erosion

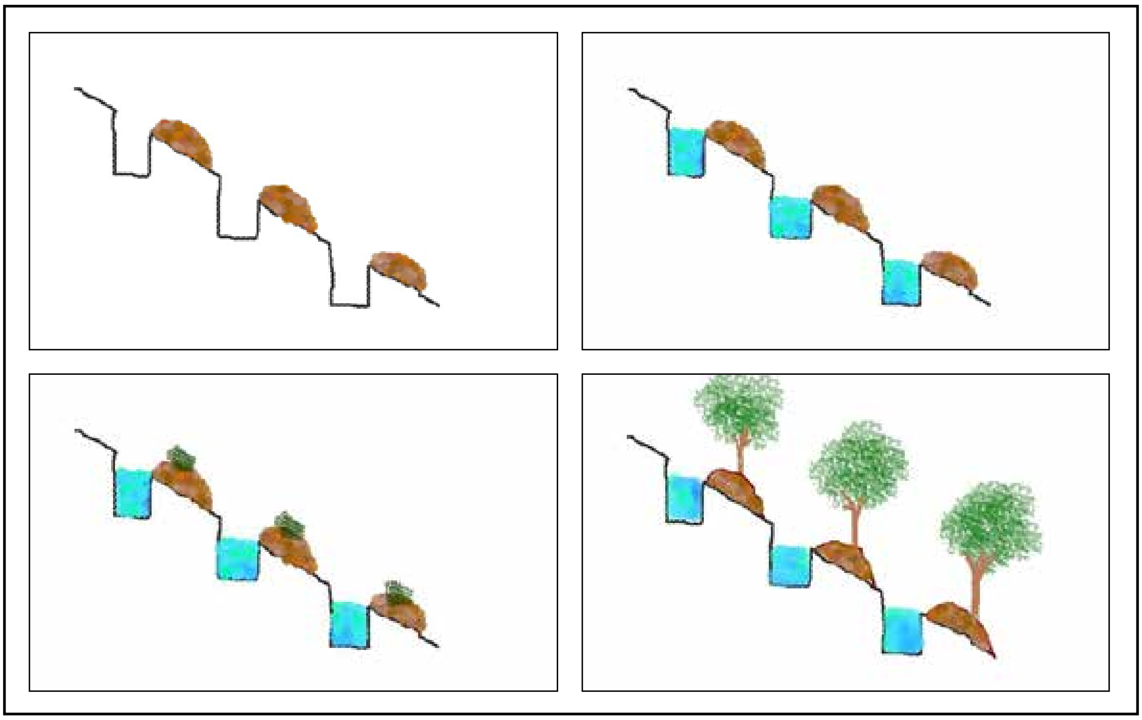


Figure 8.4: A cross-sectional profile of a contour trench and its ecological progression (Diagram © Renie Thomas)

In continuous contour trenches (CCT's) there is a possibility of going off the contour line in which case water will flow along this sloping channel and spill out, creating gullies. A staggered contour trenches (SCT's) minimise the risk of going off the contour and are therefore safer. The choice of staggered or continuous contour trench depends on the slope and amount of rainfall. To reduce creating gullies and over saturation of water in the shallow soil that can create landslides during heavy rainfall events - one CCT at the base of the hillslope and the others upslope can be SCT's.

Some of the precautions to take while constructing contour trenches are -

- Do not make trenches on slopes higher than 25%, instead adopt vegetative measures;
- Do not make trenches on slopes less than 10%, instead construct contour bunds;
- Do not excavate trenches where there is already dense vegetation;
- Do not plant inside the trench;
- Do not excavate if roots of a tree are encountered;
- Do not excavate trenches across large streams or drainage lines;
- Do not start the lay-out of trenches from the shorter section and always begin from the longest section within the largest area of uniform slope.

SLOPE AREA TREATMENT: EARTHEN CONTOUR BUNDS

Construction of earthen bunds is along the contour by excavating a channel and creating a small ridge down slope. Occasionally, the earth used to build the bund is taken from both above and below the structure. They may be reinforced with vegetation or stone for stabilization. Bunds are gradually built up by annual maintenance and adding soil to the bund. The main objective of having an earthen contour bund along the slope is to slow down the velocity of runoff, check soil erosion, recharge groundwater and improve local soil moisture profile. They can be applied on all types of relatively permeable soils (e.g. alluvial, laterite, brown and, shallow and medium black soils) but not on clays or vertisols. It is advised that contour bunds be constructed along slopes that are less than 10%. A typical dimension of the contour bund in permeable and impermeable soil are shown below -

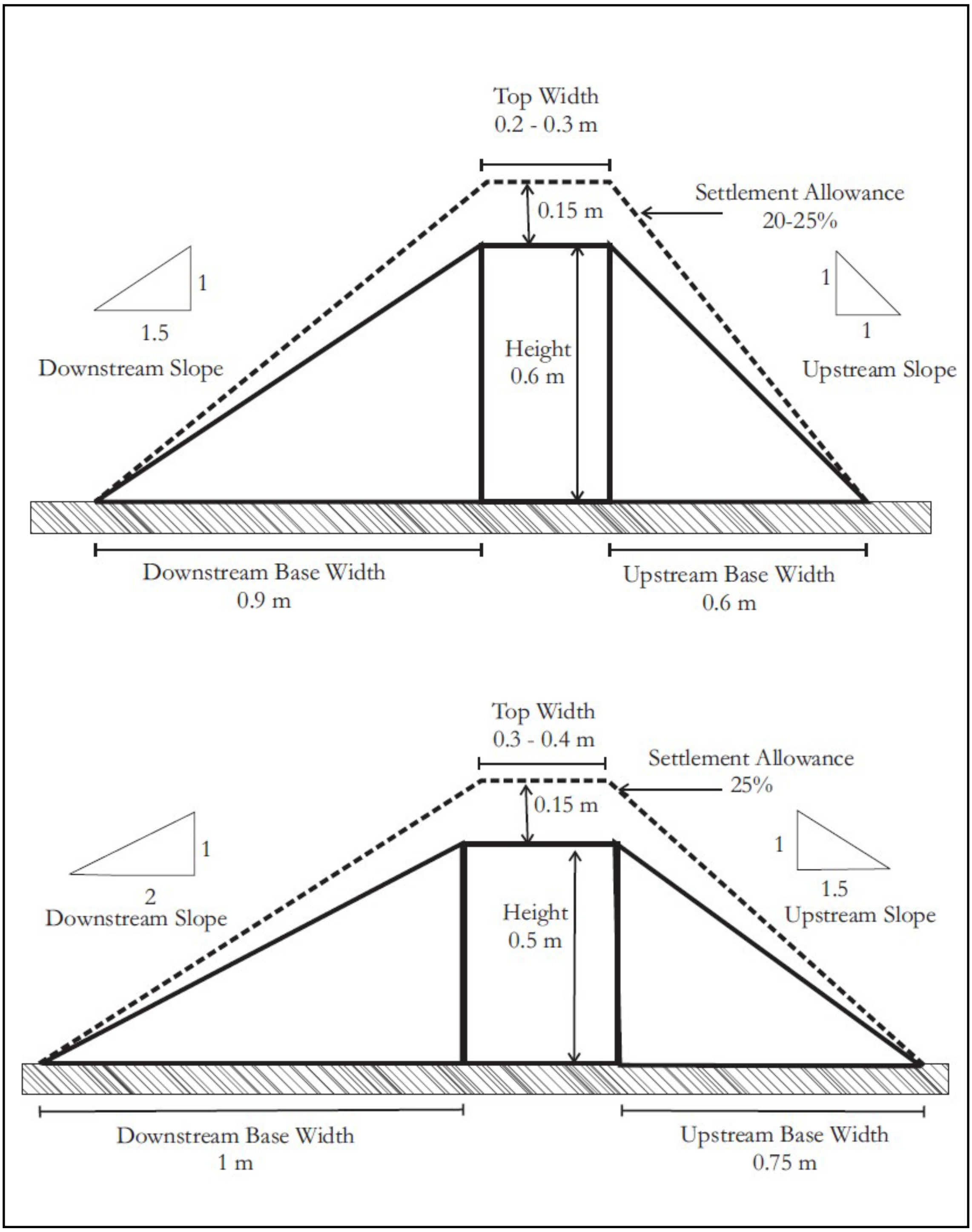


Figure 8.5: Cross-section of contour bund (a) in permeable soils (b) in impermeable soils (Image courtesy: Manual, W. W. (2006))

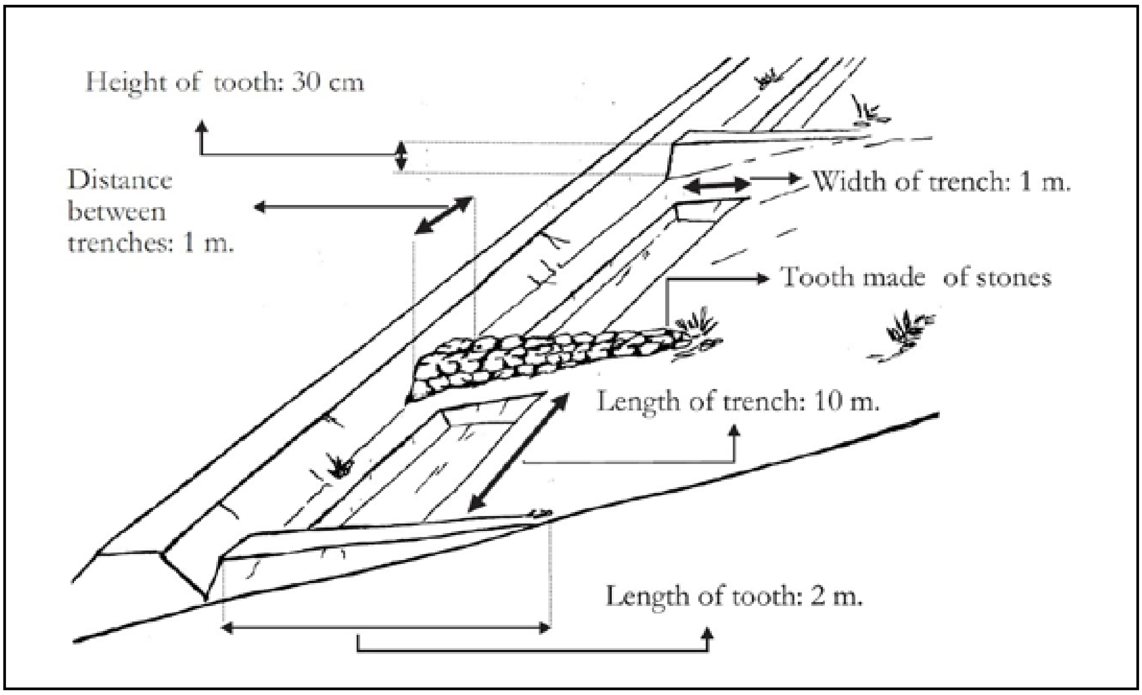


Figure 8.6: A schematic diagram showing the design of contour bunds (Diagrams courtesy: Manual, W. W. (2006))

Figure 8.7: An earthen contour bund on slope that is > 10%

Things to do while constructing a contour bund -

- Always provide a berm of 30 cm;
- Always provide a settlement allowance;
- Exit must be provided in sloping land and in impermeable soils;
- In impermeable soils increase the cross section area of the bunds.

- Do not start the lay-out of bunds from the shorter section, always begin from the longest section within the largest area of uniform slope;
- On high slopes do not make bunds closer than 30 m;
- On low slopes do not make bunds farther than 60 m;
- Do not make bunds on slopes higher than 10%, rather for slopes between 10% and 25% a contour trench are more appropriate, and for slopes above 25%, adopt vegetative measures;
- Do not construct bunds where there is already dense vegetation;
- Do not excavate if roots of a tree are encountered; and
- Do not excavate soil continuously in permeable soils.

SLOPE AREA TREATMENT: DEMI-LUNES/SEMICIRCULAR CONTOUR BUNDS

Demi-lunes (half-moons) are in the shape of a semicircle with the tips of the bunds on the contour. They come in a variety of sizes, which help with water harvesting in semi-arid areas. They help to improve soil fertility when manure or compost is added. The technique of creating Demi-lunes belongs to the overall category of slope area water harvesting interventions and consists of half-moon shaped basins dug in earth. The main goal of water of a Demi-Lune is to collect water, and to make moisture available for vegetation for a longer time. This type of microcatchment water harvesting technique is suitable for slopes up to 15%, however bunds made of earth are seldom used in areas with slopes greater than 5% with a precipitation rate higher than 300 mm/y.

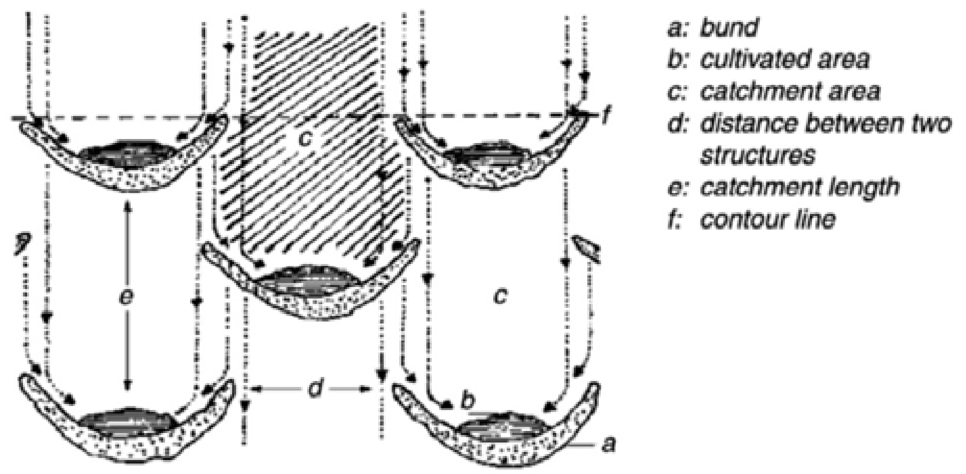


Figure 8.8: A schematic planar view of a Demi-Lunes (Anschuetz et al., 2003)

A demi-lune is created by using earth or stones and has a diameter from 2 to 8 meter (although they can measure up to 12m) depending upon the slope. The bund tips are usually placed on a contour line, facing upslope. Bunds are usually 30-50 cm high. They are arranged in alternating patterns so that the line below can catch the runoff coming from the line above, and so on.

Figure 8.9: Demi-lunes constructed along a slope that is <5% in the semi-arid regions

The bunds are laid out in staggered rows, with their tips on the contour. A gap is left between two neighbouring structures so that runoff water can flow downslope to the next structure. In larger structures stone spillways can be constructed in the bunds to cope with excess runoff from the slopes above. But, when large amounts of runoff can be expected often, the structures have to be protected by digging a diversion ditch. The advantages of these structures are that they are easy to construct, labour efficient because a maximum enclosed area is obtained with a minimum of bund volume, recharges subsurface and retained moisture for vegetation to grow in the basn, and it is suitable for uneven terrain because the structures are free-standing.

DRAINAGE LINE TREATMENT: LOOSE BOULDER STRUCTURES

Boulder checks or gully plugs are loose rock dams made on small drainage lines or seasonal streams which have a catchment area of less than 50 ha. The main aim of constructing loose

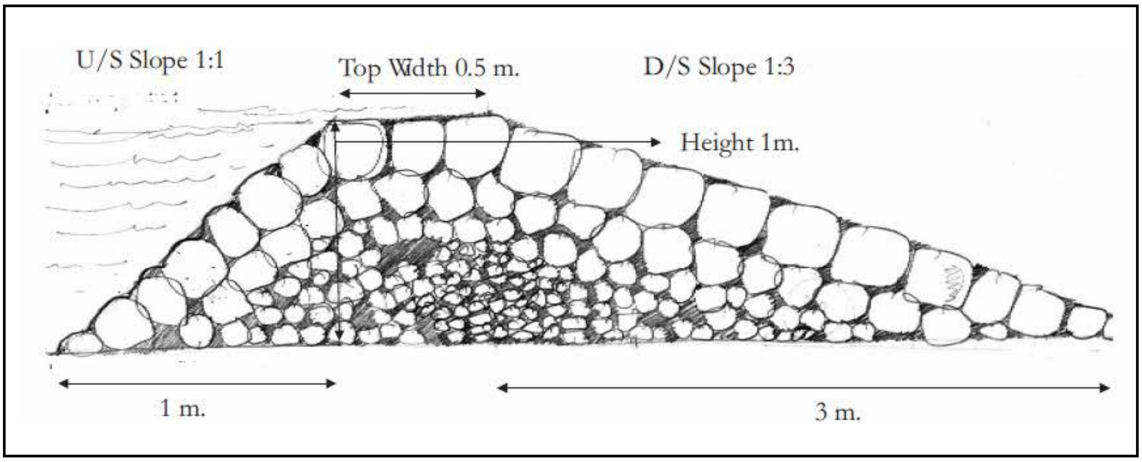


Figure 8.10: Cross-section of a LBS with general dimensions (Diagrams courtesy: Manual, W. W. (2006))

Figure 8.11: A LBS constructed along an ephemeral first order steam

boulder structures (LBS) is to reduce the velocity of water flowing through the drainage line. By reducing the velocity of runoff, boulder checks help in reducing soil erosion; trapping silt which slows the rate of siltation in water harvesting structures in the lower reaches of the watershed; creates a hydraulic head locally which enhances lateral and vertical infiltration of surface runoff into the shallow groundwater system; and increases the duration of flow in the drainage line. Thereby, the capacity of the water harvesting structures created downstream on the drainage line is utilised more effectively as they get many more refills.

Some of the precautions that needs to be taken care of while constructing a LBS -

1. Locate the check only where the height of the stream embankment is greater than or equal to the sum of the peak depth of flow in the drainage line and design height of the structure.
2. The top of the check should be lowest in the middle of the stream and highest at either embankment.
3. The height of the check in the middle of the stream should be 1m above ground level.
4. Upstream slope of the check should be 1:1 while the downstream slope can vary from 1:2 to 1:4.
5. The bed of the stream at the base of the check should be cleared of mud/sand up to 0.25m depth.
6. The top of the check should extend into either embankment by cutting a trench and filling it with boulders.
7. Larger boulders should be placed on the outer portion of the check.
8. The use of angular boulders should be preferred.

9. One needs to avoid construction of a LBS where the bed slope is above 20%
10. No checks should be constructed where boulders are not adequately available within a radius of 50m.
11. Do not use boulders dug up or picked up from the neighbourhood if such use would increase soil erosion in the area from where the boulders are picked up.
12. Do not use boulders of diameter less than 0.15 m at any point which comes into contact with flowing water.

DRAINAGE LINE TREATMENT: GABION STRUCTURE

Gabion structures are rock and wire dams constructed across drainage lines with a catchment area of 50-500 ha. The main aim of constructing gabion structures is to reduce the velocity of water flowing through the drainage line. By reducing the velocity of runoff, gabion structures help in reduction in soil erosion; trapping silt, which reduces the rate of siltation in water harvesting structures in the lower reaches of the watershed; increasing recharge of groundwater; and increasing the duration of flow in the drainage line. Therefore, the capacity of the water harvesting structures created downstream on the drainage line is utilised more effectively as they get many more refills.

Some of the precautions that needs to be taken care of while constructing a Gabion Structure across a stream -

1. Do not build a gabion structure where the embankment is highly erodible or is of insufficient height.
2. Do not build a gabion structure at a point on the stream, below which the stream drops sharply.

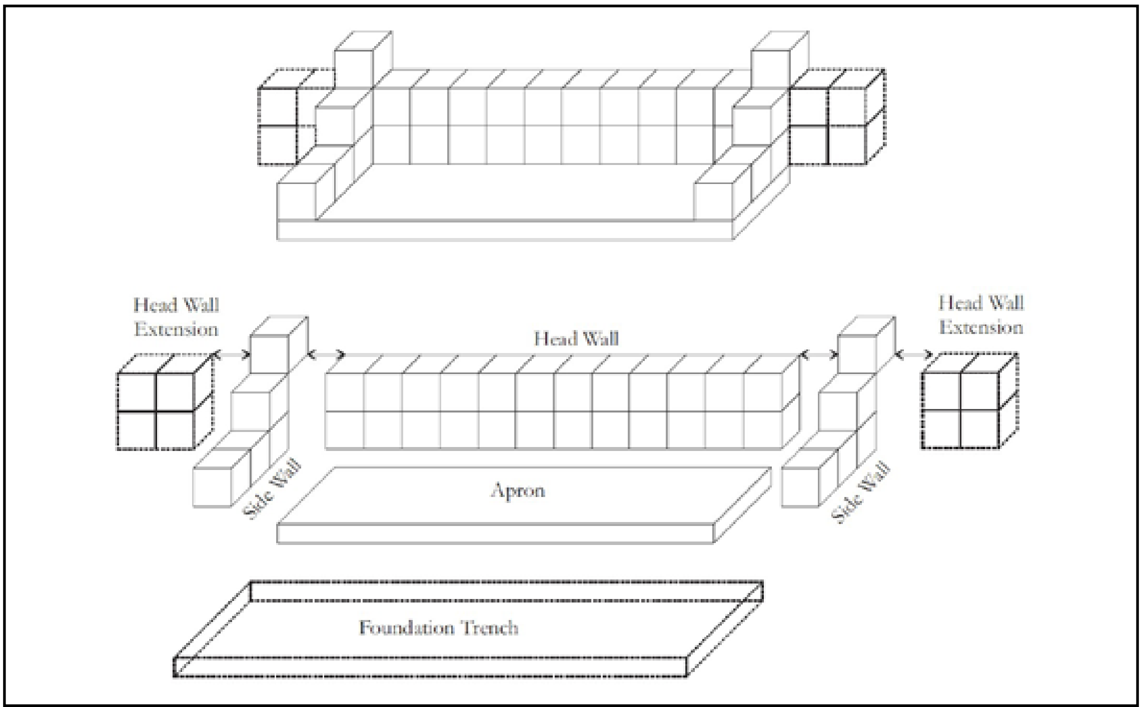


Figure 8.12: A schematic diagram of a gabion structure and their various parts (Diagrams courtesy: Manual, W. W. (2006))

Figure 8.13: A Gabion structure across a stream with weir plates to regulate flow and arrest soil erosion

3. Locate the gabion structure where the naala/channel width is relatively low.
4. Locate the structure where the bed-slope of the naala/channel upstream of the structure is low.
5. Care must be taken that the boulders are placed compactly against each other so that they do not slide or move under the impact of water.
6. Smaller boulders must be placed in the interior part of these boxes while the larger ones must be placed on the outside.
7. Even the smallest boulder should be bigger than the gap in the wire mesh.
8. The wire mesh must be stretched taut so that there is no bulging or sagging.
9. The wire used for tying the wire mesh sections must be of the same strength as the wire used in the wire mesh. It could either be of the same gauge or of a thinner gauge plied and twisted together.
10. For height above 2m, the headwall must be made as a series of steps sloping on the downstream side to impart stability to the structure.

DRAINAGE LINE TREATMENT: CHECK DAMS

A check dam is a linear structure constructed across a stream or river channel, perpendicular to concentrated flows across the waterway to control erosion by reducing the velocity of the flow. The main purpose of the check dam is to reduce the velocity of the water, raise the bed level and reduce the slopes in a gully by silting up and trapping the silt, support the unstable side slopes and promote the water percolation in the soil and conserve water for plant growth and also for the stability of banks.

Some of the precautions that needs to be taken care of while constructing an Earthen/ Cement Dam across a stream -

Figure 8.14: A cement check dam across a ephemerial stream to store water in semi-arid region

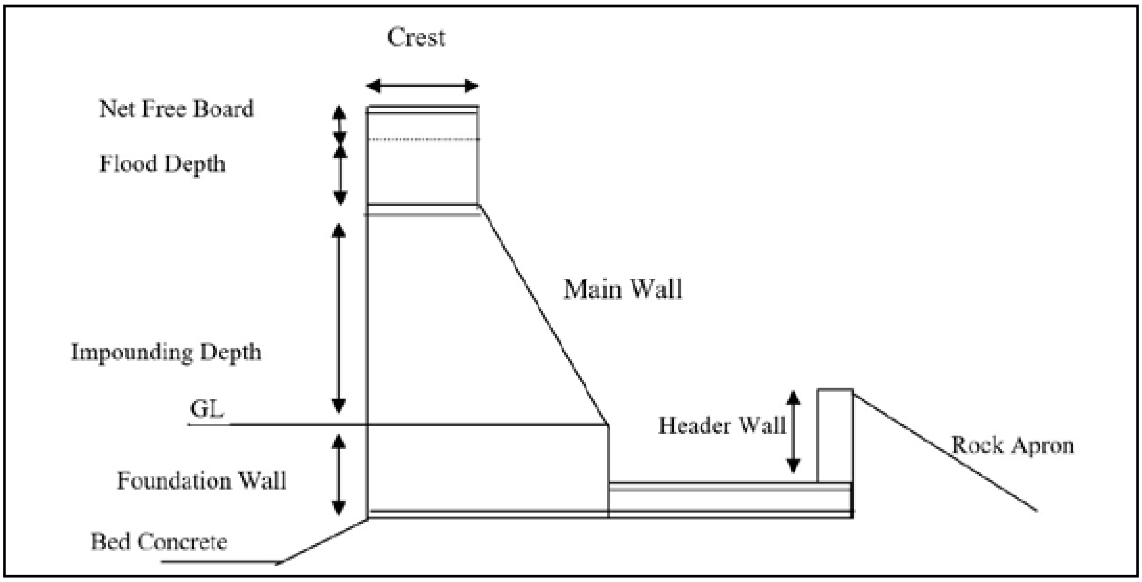


Figure 8.15: A schematic cross section of a cement check dam (Photo: © Renie Thomas)

1. The effective storage capacity of the dam should not be either too large or too small in relation to runoff.
2. At the dam site, the drainage line must have well-defined embankments into which the dam can be anchored.
3. The permission of those whose lands may be getting submerged would also need to be obtained prior to fixing the Full Reservoir Level (FRL). Effort must be made to actively involve them in the planning and design of such structures from beginning to end.
4. The upstream slope of the dam should be lower than the downstream slope;
5. The surplus weir must be properly designed to drain out the peak runoff safely when the water is at FRL.

6. Adequate settlement allowance must be provided for earthen dams.
7. Rock toe must be provided to drag the seepage line downwards.

SLOPE – DRAINAGE TREATMENT: SPRING BOX

Figure 8.16: (a) Spring Box with open bottom (b) Spring Box with open side

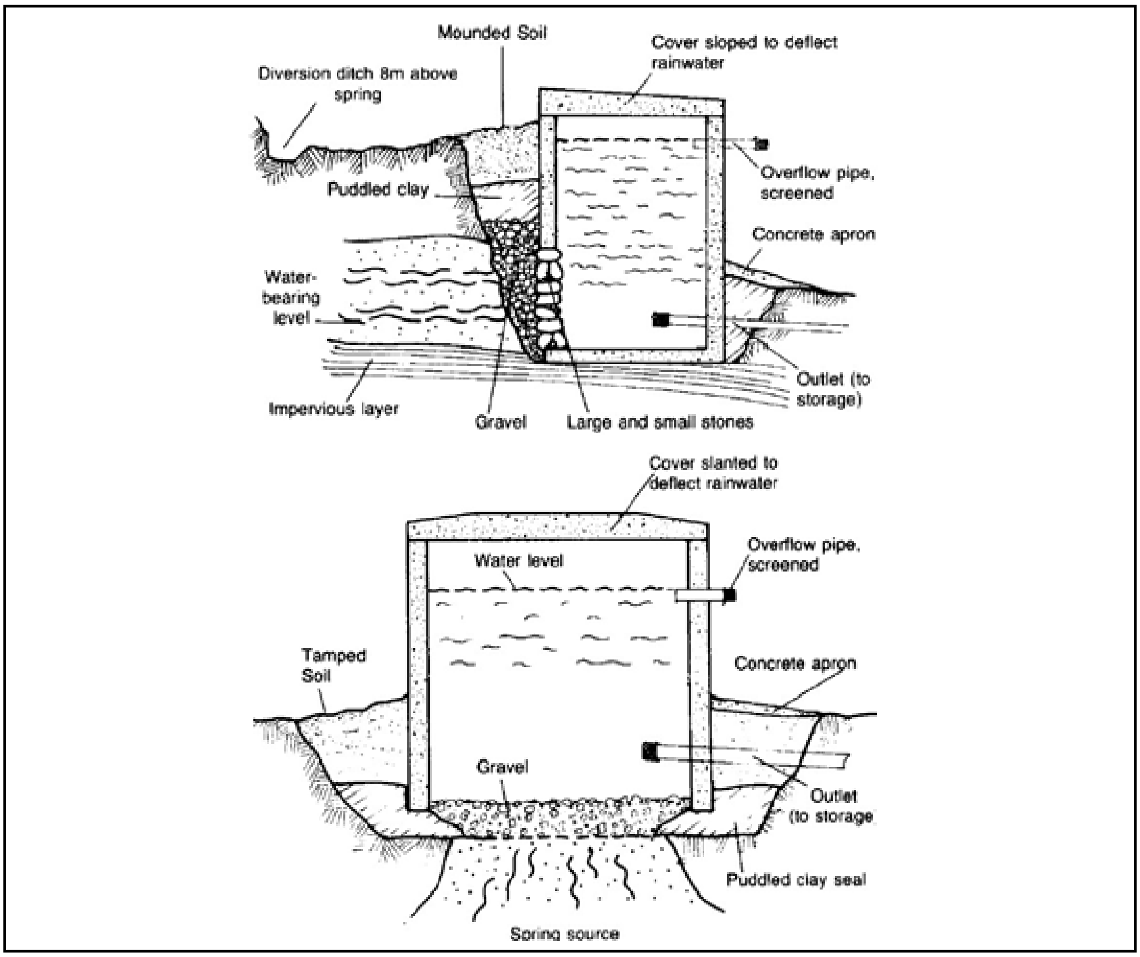


Figure 8.17: A schematic cross section design of (a) Spring Box with open side, (b) Spring Box with open bottom (Image courtesy: Water for the World)

A spring is groundwater that surfaces naturally. Where solid rock or clay layers (an impervious strata/bed) block the underground flow of groundwater, it is forced upward and surfaces on the ground. A spring is a natural outlet of groundwater to the surface. A basic spring water collection system consists of a box made of concrete, fiberglass, galvanized steel, or other material approved to be in contact with potable water that collects spring water. It may be sealed and buried, or it may extend above ground and have access for inspection and disinfection. The spring box functions to protect the spring water from contamination, normally by surface runoff or contact with humans and animals, and provides a point of collection and a place for sedimentation. Arid landscapes consist of spring locations that are found around specific structural rock features along the slope or along the drainage line, and having a water collection system like a spring box ensures that water is collected and is available for drinking during drought spells.

SUBSURFACE - DRAINAGE TREATMENT: SUBSURFACE DYKE/DAMS (REPEAT)

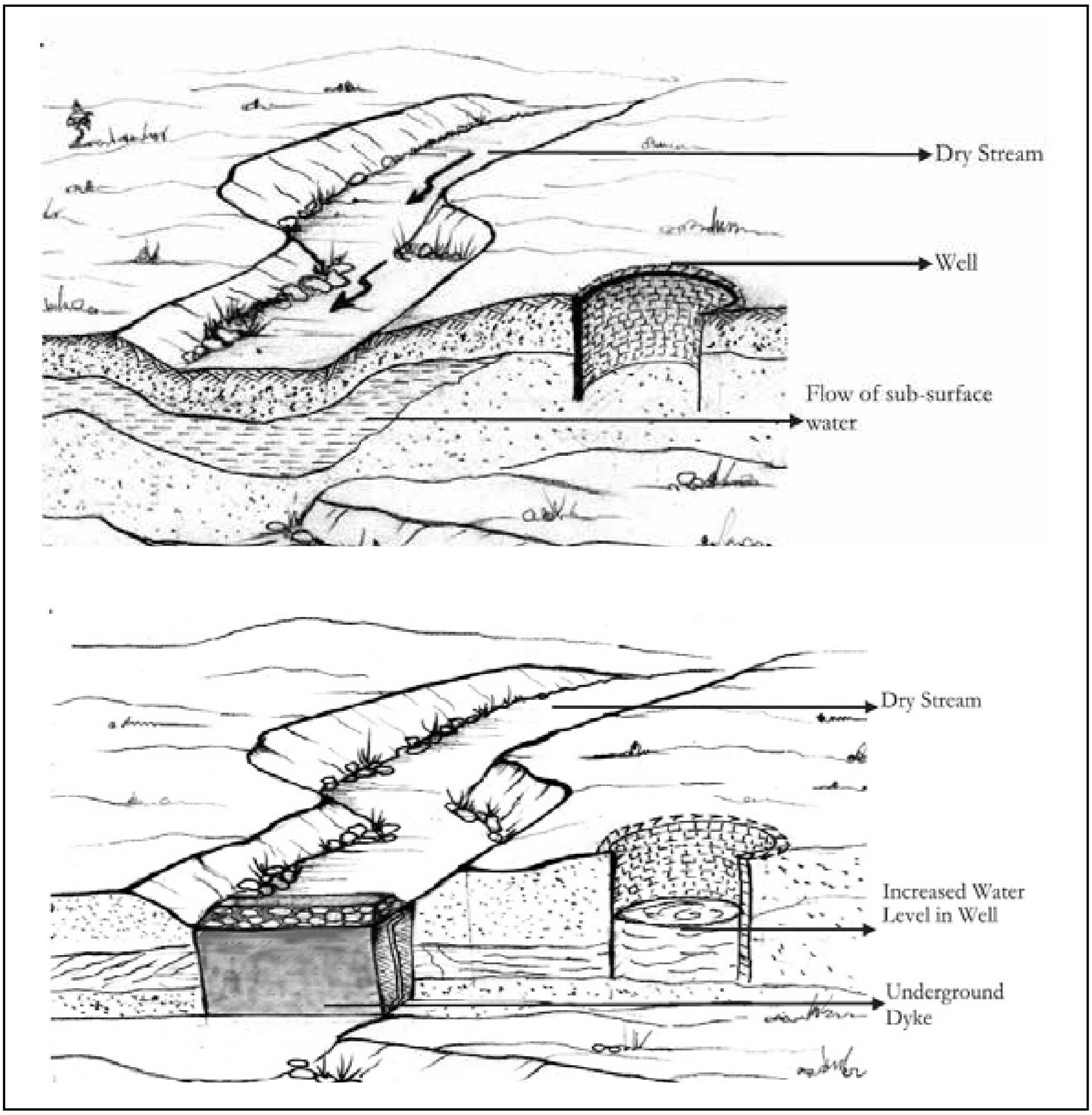


Figure 8.18: (a) Subsurface flows continue several months after stream flow ceases (b) An underground dyke built across the alluvial stream bed, thereby increasing the water table. (Diagrams courtesy: Manual, W. W. (2006))

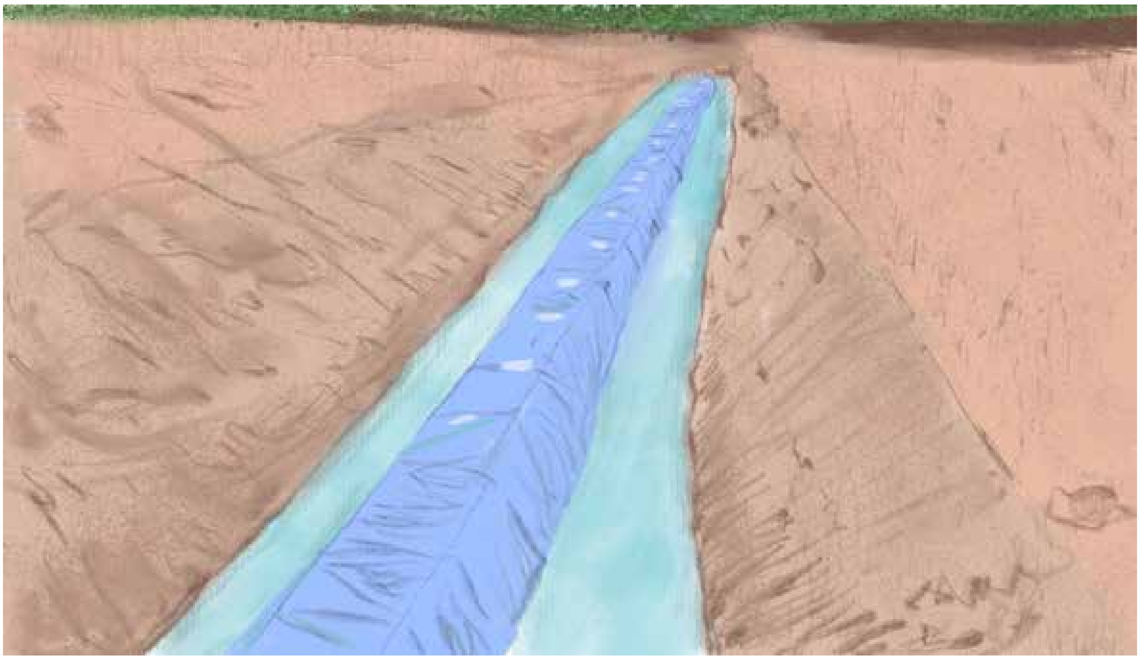


Figure 8.19: A subsurface dyke constructed across a dry alluvial river bed to recharge and hold groundwater upstream

Subsurface dykes or groundwater dams are structures that hinder the natural flow of groundwater to provide storage of water underground. The fundamental principle of a groundwater dam is storage of water underground instead of surface reservoirs and thus preventing evaporation losses. Further, the risk of contamination of the stored water is decreased because microorganisms contaminating surface water cannot breed in the groundwater. The problem of land inundation normally associated with surface dams is absent with subsurface dams, provided that there are no checks built above the dyke.

The main objective of an underground dyke is to impede the flow of subsurface water and make it available in the watershed for a longer period, increase the water level in wells by redirection of this subsurface water to nearby wells and tubewells and to o make surface flows in the drainage line available for a longer period.

Some of the precautions that needs to be taken care of while constructing a subsurface dyke/ dams in a sedimentary (alluvial) channel -

1. Do not construct a dyke where subsurface flows dry up within 3 months after the monsoon, make sure that the subsurface flows occur at least until January;
2. Do not locate a dyke where subsurface flows are available only at a very great depth;
3. Do not locate a dyke where the bed slope of the drainage line is very high;
4. Do not construct a dyke if impermeable strata are only available at a depth greater than 20 ft., because the costs will outweigh the benefits;
5. Locate a dyke near wells/hand pumps;
6. Ensure that the dyke is perpendicular to the overall direction of flow of the drainage line;
7. Continue excavation of the trench until relatively impermeable strata are encountered;

8. Ensure that the clay filling is well watered and puddled; and
9. Ensure that inside the trench the puddled clay balls are compacted properly.

SUBSURFACE - DRAINAGE TREATMENT: SAND DAM

A sand dam is a reinforced rubble cement wall built across a seasonal sandy river. They are a simple, low cost, low maintenance technology that retains rainwater and recharges groundwater. Sand dams are a water solution that is applicable to most dryland environments. They only

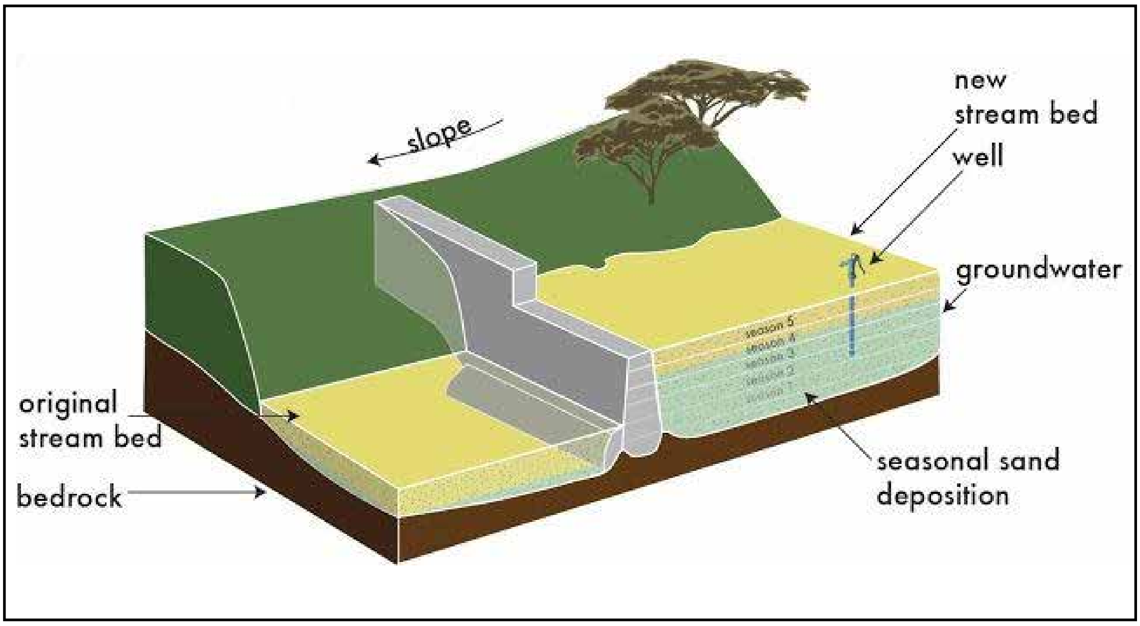


Figure 8.20: A schematic sketch of a sand dam across a dry alluvial stream bed

Figure 8.21: A sand dam constructed across a dry river bed, wherein groundwater is held in the sediments upstream

require a seasonal river with sufficient sandy sediment and bedrock that is accessible in the river-bed. Sand dams are the most cost-effective method of water conservation in dryland environments. By recharging the aquifer, sand dams provide enough water to establish tree and vegetable nurseries. Together, sand dams, farmland terracing and tree planting form a cycle of water and soil conservation that is self-perpetuating. Conserving water and soil on farms increases soil fertility, reduces the time spent collecting water, and increases the time available to farm, learn and innovate.

Sand dams can help combat desertification by recharging groundwater and creating opportunities for sustainable land management, mitigate climate change by creating water security and the time to practice climate-smart agriculture, reduce conflict by increasing access to water for people and livestock in water-scarce dryland environments, support disaster resilience by creating a buffer against drought and enabling vulnerable people to improve food production, and enable the installation of shallow wells producing safe drinking water.

Important rules of a Sand Dam design are -

1. Sand dams must be built on bedrock or a suitable impermeable foundation to a point at least 1.5 metre wider than the annual flood width of the river
2. Sand dams must not change the river's course
3. The spillway height must not prevent the river flowing over the dam or cause dam siltation

SUBSURFACE TREATMENT: MANAGED AQUIFER RECHARGE (MAR)

Managed aquifer recharge (MAR) is a water management approach that can be used to maximize natural storage and increase water supply system resilience during periods of low flows and high seasonal variability. During these periods, such as in the dry season, aquifers are intentionally recharged to recover water. There are different structures that are used to recharge aquifers. The structures made are all geared towards recharging aquifers below. The methods of recharge include either modifying the landscape or building new infrastructure, for example through injection wells or various landscape design infiltration structures. Some include open structures, such as open ponds, soil aquifer treatment facilities (similar to ponds, but using reclaimed water), and trenches. Other types include dams to control water flow that promote aquifer recharge (e.g. subsurface dams and sand dams). Direct injection is also employed, particularly in deep confined aquifers, using water from other wells (for example, for seasonal water supply regulation). The chosen methods should help to reduce the costs of transporting and storing water, as well as losses associated with evaporation during the recharge process.

The water sources for recharge can differ. Commonly used types include surface water, stormwater and treated wastewater. Other water sources, such as water from other aquifers or desalinated water, can also be used. The water must be of adequate quality and should not compromise the quality of existing aquifer resources. Some pre-treatment may therefore be needed before recharge into the subsurface aquifers. For adoption of a MAR system a preliminary aquifer assessment of the region (with the help of a hydrogeologist) is to be mapped to identify and determine the most suitable intervention, it may be a point recharge (e.g. well injection) or an open infiltration structures (e.g. pond).

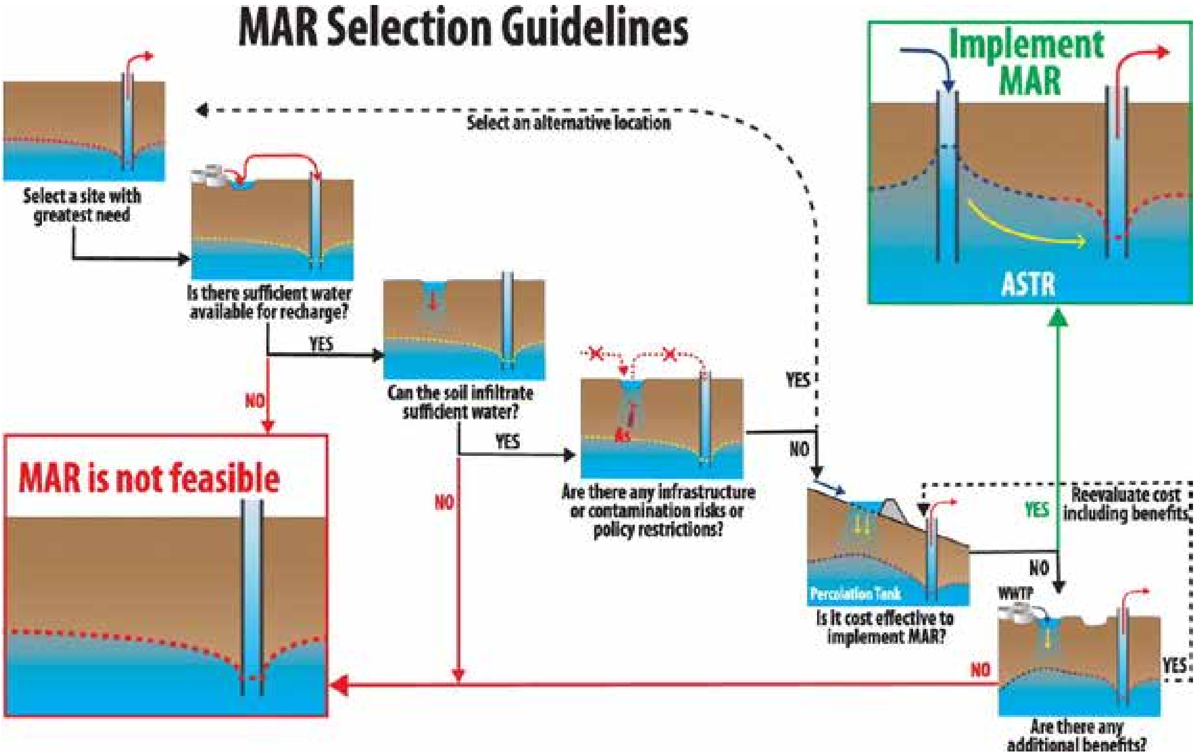


Figure 8.22: Selection criteria for the implementation of MAR (Alam, S. et. al. 2021)

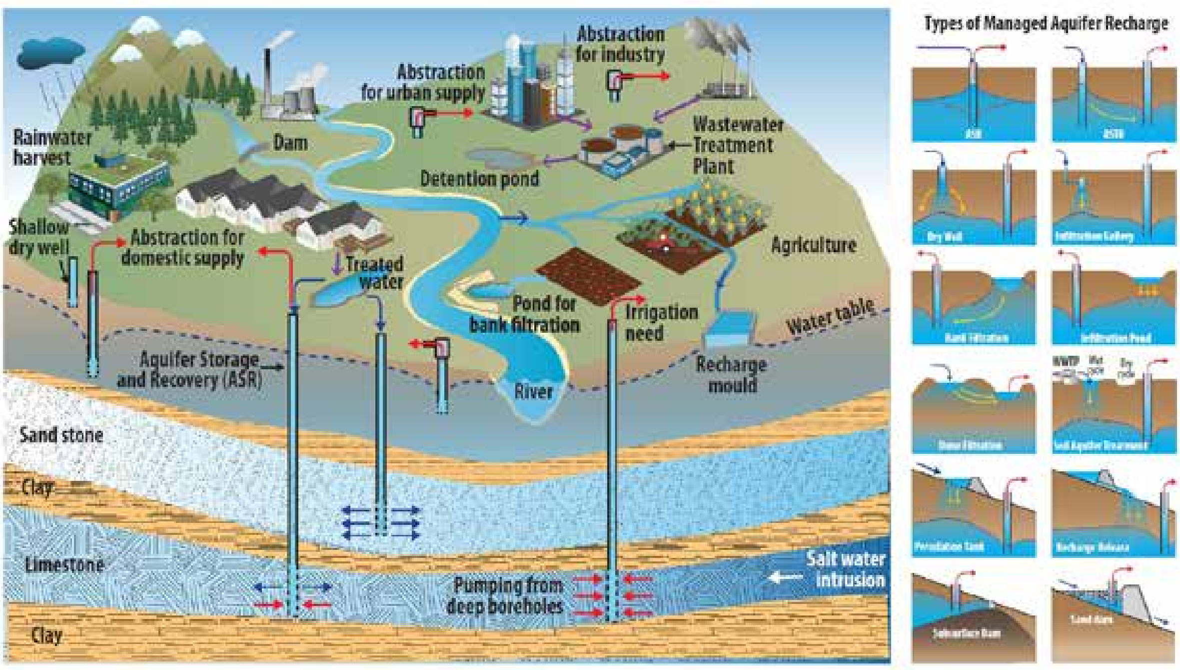


Figure 8.23: A schematic of managed aquifer recharge techniques based on the type of aquifer, topography, land use, and intended uses of the recovered water (Alam, S. et. al. 2021)

MAR selection depends on soil properties, water availability, and water quality. MAR is applied predominantly in sites with sandy clay loam soil with access to rivers. MAR can remove Pb, Zn, E. coli, DOC but is ineffective at removing trace organics. MAR could minimize flood risk, land subsidence, and salt-water intrusion. Source water conveyance and policy restrictions could prevent MAR implementation.

Figure 8.24: Flood water spreading system on a cascading water basin for MAR

Figure 8.25: Borewell recharge using pond

TRADITIONAL STRUCTURES TO AUGMENT DROUGHT RESILIENCE IN ARID LANDSCAPES

The arid landscape is characterized by erratic rainfall, high evaporation, absence of any perennial rivers and scanty vegetation. Because of low rainfall and high evaporation the natural groundwater recharge is negligible. The groundwater table in most places is at considerable depth. Availability of potable groundwater at reasonable depths is found at only a few select locations. For many centuries the local communities have come up with their own indegenious drought resilient structures that have helped them combat severe drought conditions. Some of these traditional structures that has aided rural communities in addition to the already existing structures from the arid regions of Rajasthan to semi-arid regions of Andhra Pradesh other than that have been proposed above are as follows:

1. **Nadi/ Talab**: Village ponds used for storing water from adjoining natural catchment during the rainy season. Sites for nadis are selected by villagers based on natural catchments and their yields.
2. **Tanka**: It is a small underground tank generally circular in shape & lined with fine polish lime, built in the main house or courtyard to collect rainwater. These tank water is used for drinking.
3. **Baoris/Bers**: Community wells collect rainwater for use to meet drinking water needs. Baoris can hold water for a long time because of almost negligible evaporation.
4. **Kuis and Beris**: Seepage collecting structures of 10-12 m deep pits are dug near tanks. Kuis are also used to harvesting rainwater in areas of meagre rainfall. The mouth of a pit is usually made very narrow to prevent evaporation. Pit gets wider as it burrows under the ground to enable it to seep into a large surface area.
5. **Khadin**: A rainwater harvesting system on farmland designed storing surface runoff for agriculture. Its main feature is a long earthen embankment (100-300 m) across lower hill slopes.
6. **Rapat**: Percolation tank with a bund by either masonry wall or earthen, to impound runoff from watershed. It is mainly used for groundwater recharge.
7. **Johads**: Small earthen check dams that capture and conserve rainwater, improve percolation and groundwater recharge.
8. **Bandharas**: Traditional stream/river water harvesting structures consist of check dams or diversion weirs constructed across streams/rivers to raise water level in the streams/rivers for diversion of water to irrigation fields. Most of the Bandharas are defunct today.
9. **Katas/Mundas/Bandhas**: These were ancient structures used for irrigation purposes. A kata is constructed north to south or east to west of a village by a strong earthen embankment curved at either end and is built on a drainage line to guide drainage water from upland to the irrigation field.
10. **Cheruvu**: Traditional water harvesting reservoirs to store runoff.

URBAN FLOOD MITIGATION AND STORMWATER MANAGEMENT

9 URBAN FLOOD MITIGATION AND STORMWATER MANAGEMENT

In natural environments, rain falls on permeable surfaces and soaks into the ground through a process called infiltration. However, in urban areas where large areas are paved and sealed by buildings, natural infiltration is limited and runoff is diverted to nearby watercourses through drainage systems consisting of channels and culverts. Flooding occurs when these drainage systems are overwhelmed due to poor maintenance or design. Lack of proper drainage facilities as well as obstruction in the existing drainage lines also lead to flooding.

Urban flooding is a serious and growing development challenge that is becoming more dangerous and more costly to manage because of the sheer size of the population exposed within urban settlements. The impact of flooding is expected to increase significantly considering the change in climate patterns, and continued urbanization and demographic growth. Urbanization increases flood risk by up to three times due to increased peak flow and high population density. This highlights the need to more effectively manage existing and future flood risks to protect people and their livelihoods from flooding and associated losses.

Urban flooding is aggravated by the complex interaction between the following:

1. Physical factors

Land use change and reduced permeability - Urbanisation alters existing land use patterns, frequently resulting in the loss of natural vegetation and open spaces. These land use changes often cover wetlands; block or divert rivers or streams; and collect and move water through artificial channels like drains, culverts and tunnels that change the natural drainage patterns. An increase in impervious surfaces also dramatically alters the urban hydrological cycle and local climate. This altered urban water cycle can turn normal urban rainfall into localized flooding or flash floods.

Meteorological factors: Heavy rainfall and cyclonic storms cause water to flow quickly through paved urban areas and impound in low lying areas.

Hydrological factors: Overbank flow channel networks and the occurrence of high tides hindering the drainage in coastal areas can also be responsible for urban flooding.

2. Climate and weather-related factors

Urban microclimate and impervious surfaces - The increase in impervious surfaces and dense infrastructure that accompanies urbanization creates a local microclimate that is often warmer than surrounding areas. This is known as the urban heat island (UHI) effect.

Weather and natural climate variability at the local scale - Naturally occurring seasonal weather and multiyear climate patterns are also affected by larger-scale processes such as El Niño and La Niña, which can result in temperatures that are warmer or cooler than normal temperatures and changes in precipitation patterns. These can affect urban flood risk in impacted regions.

Global climate change - Climate change, caused by increasing greenhouse gas emissions worldwide, is leading to increased frequency, intensity and/or duration of extreme weather events such as heavy rainfall, warm spells and heat events, drought, intense storm surges, and associated sea level rise.

3. Governance and management factors

Unplanned urbanization, encroachment, and occupation of drainage systems - In many urban areas, municipal governments have been unable to keep up with rapid growth, often lack detailed land use plans, or are unable to enforce land use regulations. New construction often encroaches on, blocks or fills in natural drainage systems such as dry streams and wetlands. Urban land that has been set aside for drainage, including large concrete drains, storm channels and flood retention areas often becomes settlement sites for the poor.

Inadequate drainage planning, construction and maintenance – Gray infrastructure for stormwater management – such as gutters, drains, culverts, channels and retention areas – needs constant maintenance, including debris removal and updates to increase capacity and keep up with higher volumes of runoff. Due to poor waste management systems, dumping of domestic, commercial and industrial waste and construction debris into drains results in clogging.

Land subsidence - Natural factors (e.g., soil types) and human factors (e.g., over-extraction of groundwater, urbanization) cause land subsidence, or the compacting and sinking of soil. Soil compaction creates low-lying land, thereby increasing the area at risk of flooding and amplifying the impact of sea level rise.

Upstream and coastal land use changes – Reduced infiltration capacity in the upstream areas due to urbanization, deforestation, conversion of land for agriculture, and infilling of wetlands etc. can increase the discharge in surface waterways and lead to an increased flood risk in downstream areas (WWF International, 2016).

Until recently, flood risk management measures in cities were mostly based on conventional engineering techniques such as construction of dams, embankments and channels that are often referred to as gray infrastructure. But now there is a pronounced shift toward asopting soft structures as well.

ECO-DRR IN URBAN FLOOD MITIGATION

When rain falls in the natural landscape, stormwater would slowly drip off tree canopies, and run through the foliage at ground level to natural water storage areas such as puddles, ponds, and swamps. These processes allow nature to manage stormwater through infiltration and evapotranspiration. In contrast, the impermeable surfaces in urban areas cannot slow down water velocity or allow them to infiltrate as in nature, which results in a higher percentage of runoff. The increasing runoff rate is one of the most challenging stormwater management issues in urban areas (FISRWG, 1998).

The underlying principle of sustainable urban stormwater management is to return the urban site to the pre-development flow regime to the extent possible, and to remove urban stormwater pollutants by adopting the following techniques:

- Adopting microscale projects distributed throughout the catchment.
- Controlling stormwater at its source.
- Using simple technologies and employing natural processes to reduce stormwater volume and remove pollutants.
- Creating multi-functional landscapes and infrastructures.

The integration of Eco-DRR to urban stormwater management aims to improve the sustainability and resilience of the urban drainage network. By implementing a range of measures that cover the entire drainage system, flood risks can be reduced more significantly and managed more effectively. This includes going beyond implementing pathway solutions (e.g. drain capacity improvements, diversion canals, centralized detention tanks and ponds, etc.) to work with public and private stakeholders to install source solutions (e.g. decentralized detention tanks and ponds, rain gardens, etc.) and receptor solutions in order to better manage stormwater runoff and protect developments from floods.

Ecosystem-based solutions for stormwater management can be integrated with conventional drainage systems to reduce the surface runoff and attenuate peak flow, rendering the entire drainage system more resilient against unexpected extreme events. Ecosystem-based solutions also embrace sustainable drainage systems such as green roofs, porous pavements and rainwater harvesting facilities.

When implemented on a catchment wide basis, this reduces the risk of flooding at specific sites and also the larger catchment area. In addition, such features provide the additional advantage of pollutant removal, thereby mitigating the deterioration of runoff quality due to urbanization.

PLANNING AND SELECTION OF WORKS

Eco-DRR interventions are most effective when arranged in a series that mimic natural catchment processes in the form of a treatment train. However, these systems must be implemented at strategic places to maximize their value in mitigating flooding. The following data is required for identifying areas that are prone to flood risk:

- Digital Elevation Model (DEM)
- Historic Rainfall data
- Historic Water level and flow measurements including past information on flood levels
- Land-use maps
- Drainage maps
- Groundwater table information
- Soil characteristics (infiltration capacity etc.)
- Maps of local developments (buildings, bridges, parks, sports fields etc.)
- Storm designs

Once the flooding hotspots have been identified, appropriate techniques that best meet the requirements can be selected using particular criteria for each site, especially considering that areas at risk of flooding can be dynamic in nature.

IDENTIFYING CATCHMENT SCALE ECO-DRR OPPORTUNITIES

Below are some points to note to ensure maximum benefits from green infrastructure at a site:

1. Protect Riparian Areas and Floodplains

In some areas, riparian zones have been replaced, destroyed, or negatively impacted by development and redevelopment projects. Green infrastructure practices such as vegetated buffers and living shorelines can be used to protect and restore riparian areas and floodplains (US Environment Protection Agency, 2017).

2. Capture Runoff

Look for areas where runoff can be directed to open grounds and spaces or other green features designed to retain stormwater.

3. Target Hard Surfaces

Impervious surfaces generate the most runoff. Reducing the amount of impervious surfaces at the park can have a big impact on water quality and localized flooding. Another way to reduce the impact of impervious surfaces is to direct the runoff they generate to previous areas rather than the storm drain system or nearby water bodies.

4. Take Advantage of Areas with Infiltration Potential

Areas with high draining capacity like those with sandy soils can infiltrate a large amount of stormwater and are preferred locations for Eco-DRR interventions. Locating Eco-DRR features in well-drained areas saves money because the native soil can be used, and temporary standing water after the storm is minimal.

URBAN FLOOD MITIGATION INTERVENTIONS

GREEN ROOFS

Roofs covered with a system of contained vegetation, waterproofing, and drainage designed to reduce the amount of stormwater entering gutters. In addition to conserving potable water for irrigation and improving air quality, green roofs also cool down buildings and reduce the "heat island" effect by providing a permeable and moist layer to shade the building from sunlight.

PERVIOUS PAVEMENT

Pavements that allows stormwater to soak through it and into the ground rather than flowing across the surface and into the drainage network. These act as a hard surface for walking or driving, while enabling rainwater to infiltrate the soil or underground storage.

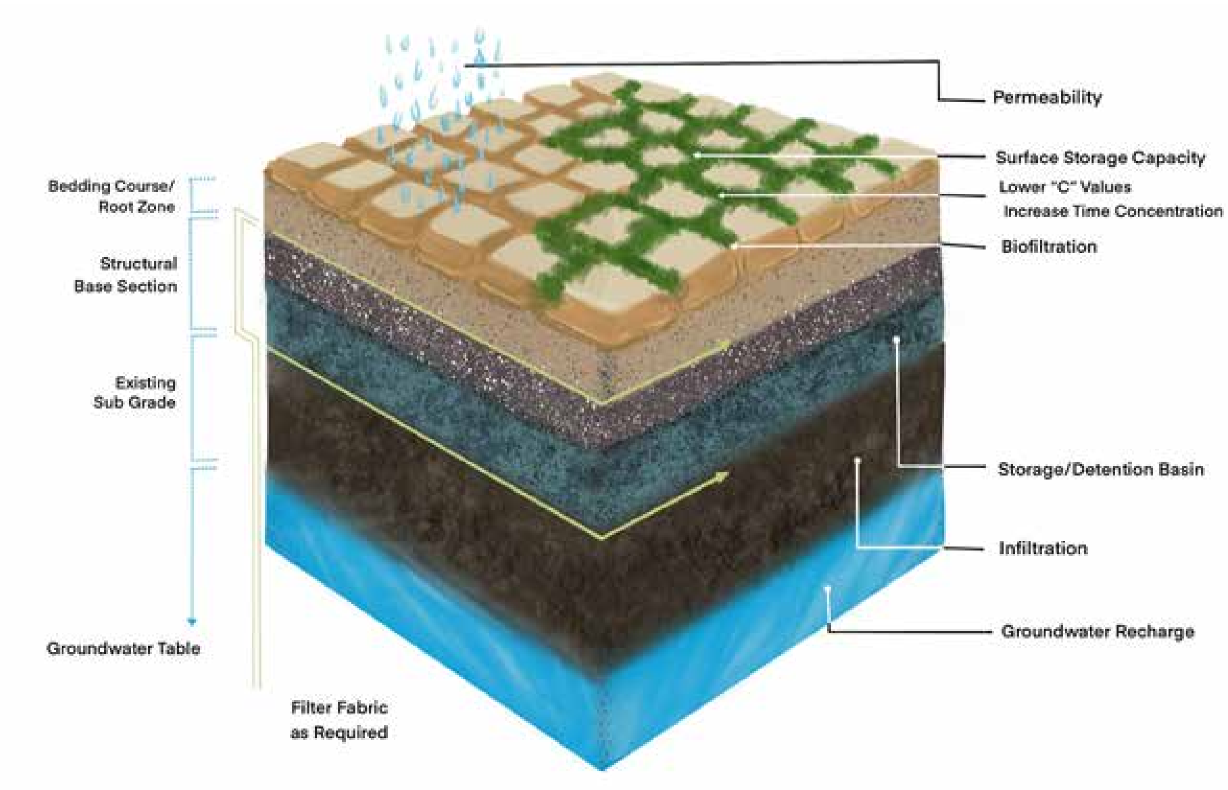


Figure 9.1: Pervious pavement

RAINWATER HARVESTING SYSTEMS

Barrels/cisterns can be used to collect and store rainwater from roofs and other paved surfaces (such as car parks) for reuse. Basins can also be used to capture storm water before it reaches the ground, allowing it to be used later for things like watering lawns or washing cars.

RAIN GARDENS (BIORETENTION BASINS)

Bioretention basins are vegetated land depressions designed to detain and treat stormwater runoff. Their treatment process is the same as bioretention swales; the runoff is filtered through densely planted surface vegetation and then percolated through a prescribed filter media (soil layer). Unlike bioretention swales, they do not convey stormwater runoff.

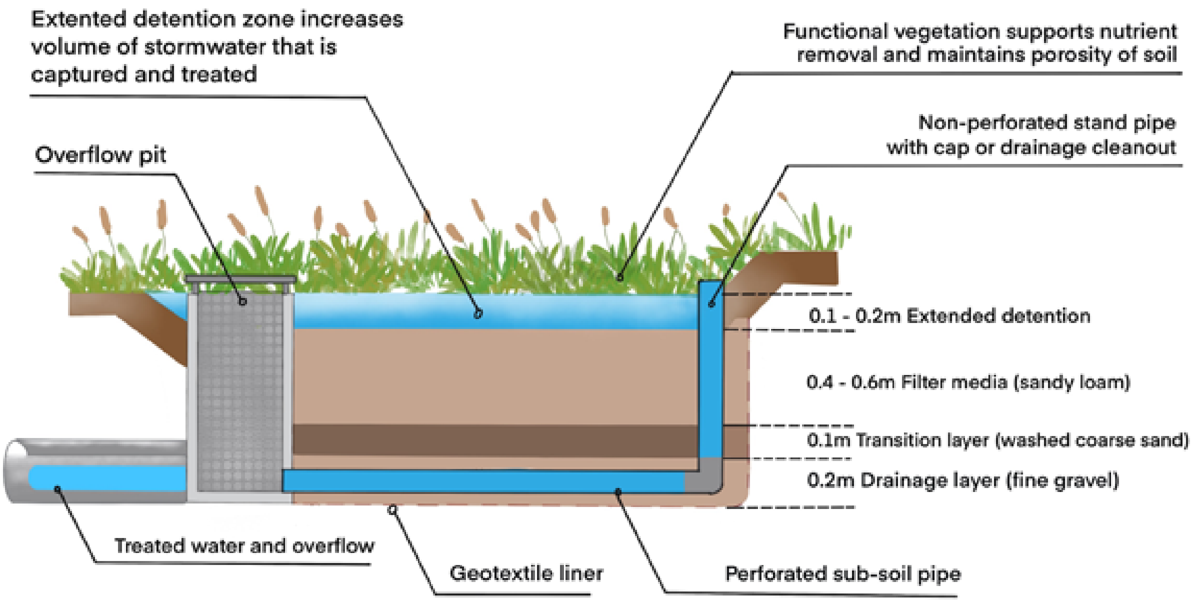


Figure 9.2: Rain Garden

INFILTRATION TRENCHES AND BEDS

Linear ditches or beds that collect runoff, often from roadsides or parking lots, and absorb it into highly porous soil. These can also be installed with subsoil pipes beneath planting beds to ensure that the excess water is recycled.

INFILTRATION BASINS

Basins with capacity to store excess water during storms, which then filters it back into the ground through plants and soils, thereby supporting groundwater replenishment.

VEGETATED SWALES

Natural drainage channels with a mild slope, often planted with trees, shrubs, or grasses that slow runoff and help absorb it into the ground.

BIORETENTION SWALES

Vegetated swales with bioretention systems located within the base. They provide efficient treatment of stormwater runoff and are designed with a gentle gradient and temporary ponding (extended detention) to facilitate infiltration.

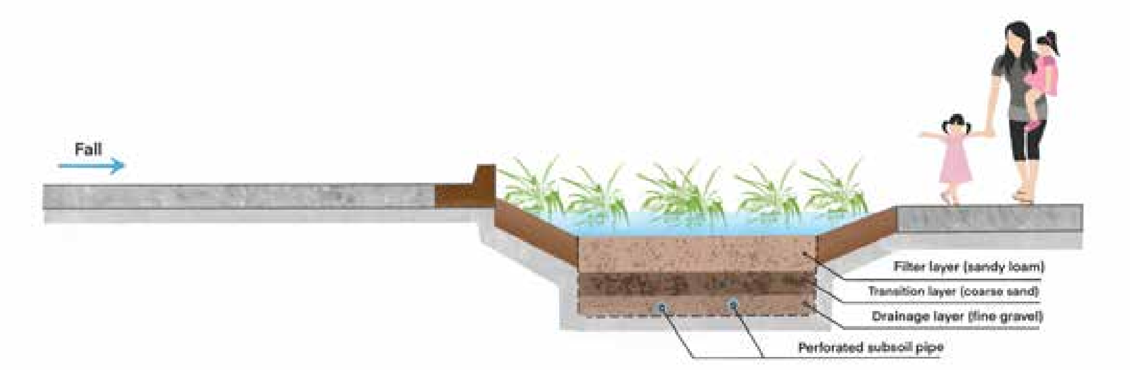


Figure 9.3: Bioretention Swale

CONSTRUCTED WETLANDS

Constructed wetland systems are shallow and extensively vegetated water bodies that generally consist of an inlet zone (designed as a sedimentation basin to remove coarse to medium sized sediment, a macrophyte zone (a shallow heavily vegetated area to remove fine particles and soluble pollutants), and a high flow bypass channel (to protect the macrophyte zone). Constructed wetlands are designed primarily to remove suspended particles and dissolved contaminants. The wetland needs to be configured in such a way as to optimise system hydraulic efficiency, sustain healthy vegetation and ensure a balanced ecosystem.

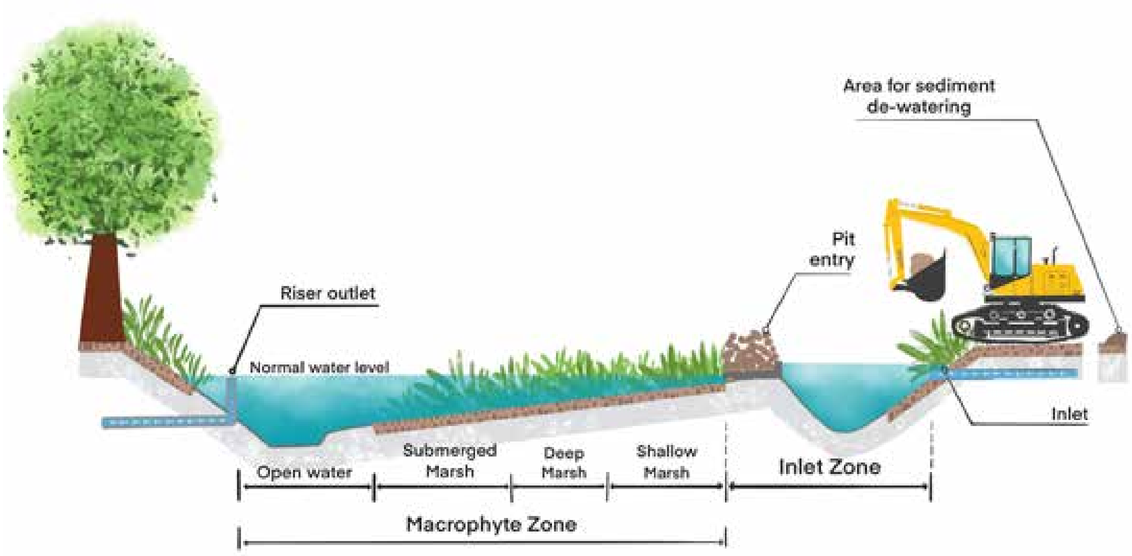


Figure 9.4: Constructed Wetland

COSTING OF THE APPROACH

10 COSTING OF THE APPROACH

Eco-DRR focuses on a whole suite of services provided by the ecosystem/landscape, adding more value to society including economic value, compared to conventional solutions such as built infrastructure. The underlying principle of most Eco-DRR interventions is decentralized ecosystem services management and they require no complex infrastructure. They typically entail use of locally available materials and plant species that are not just cost effective, but also more likely to be resilient and hence more suitable for the region.

The main steps involved in the planning of Eco-DRR which should be considered are:

DATA COLLECTION AND SITE SURVEY

The manpower required at this stage depends on the extent of data that can be sourced from the public domain or relevant agencies. For example, in areas where critical information like drainage drawings and direction of flow etc. are not available, it will be pertinent to conduct detailed site surveys to gather this information. This can be done with the help of schools and educational institutional institutions in the local neighbourhood.

PREPARATION OF DESIGN AND CONCEPTUAL DRAWINGS

Preparation of conceptual drawings along with species selection etc. for the interventions needs to be done by a qualified professional, preferably a landscape engineer. In order to overcome the need to develop conceptual drawings for every individual site, it is better to prepare a set of generic drawings with a selection of suitable plants and trees. This can then be applied within areas which do not vary much in terms of terrain and soil conditions. Fine tuning the design for the specific site may then be done by the site engineer responsible for the implementation.

ESTIMATION AND SOURCING OF RAW MATERIALS

Based on the conceptual drawings, it is possible to estimate the quantity of various materials needed for the construction. Care should be taken to use locally available resources and raw materials as far as possible. This not only helps minimize the cost but also ensures that the Eco-DRR intervention is more suited to the specific area, thereby reducing the maintenance requirements and also making the system more resilient to disasters. The cost of raw materials to be sourced/purchased may be computed based on market rates or government approved rates, whichever is more relevant.

ESTIMATION OF TIME AND LABOR REQUIREMENTS

A quantified surveyor or site engineer may estimate the time and labor requirements keeping in mind the existing site conditions, accessibility etc. Under the Mahatma Gandhi NREGS, SECURE software can be used for this purpose as it allows for the costing of all permissible natural resource management works.

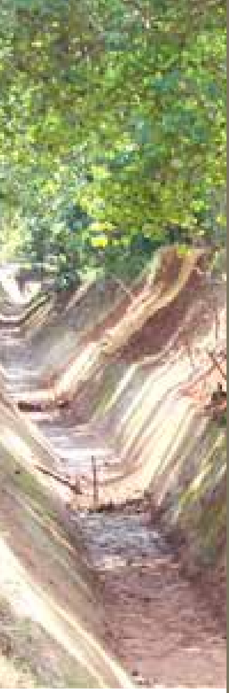
MAINTENANCE COST

While considering the costing, it is necessary to consider both the upfront capital and long-term maintenance costs. For example, conventional DRR, such as the construction of dykes, are relatively inexpensive at the investment level but require high maintenance costs. Certain other ecosystem-based approaches such as wetland restoration have proven to be less expensive in the long-term.

COMMUNITY ENGAGEMENT

The Mahatma Gandhi NREGS and other similar schemes provide money for initial set up and installation of Eco-DRR works, however for long term maintenance and upkeep it would be important to hand over ownership to the local community. Awareness generation is also crucial to the success of such projects, and can be undertaken through local groups and educational institutions.

MONITORING AND EVALUATION



11 MONITORING AND EVALUATION

The existing Monitoring and Evaluation (M&E) systems under the Mahatma Gandhi NREGS show different types of institutional arrangements, some of which engage with the participatory form of governance involving Grama Sabhas, while others utilize the service and expertise of independent expert bodies. The M&E of Eco-DRR interventions is critical for assessing progress and efficiency and effectiveness of interventions. However, the M&E framework has to be realistic, operative and include a protocol for data collection and evaluation, as well as on how to generate information on outcomes and impacts of interventions. This is critical for course correction and for future action and planning.

While mainstreaming Eco-DRR through the Mahatma Gandhi NREGS in rural areas, a strong means of M&E of the works taken up under MGNREGS is important to find out how effective specific works are in meeting the objectives of Eco-DRR. This would also help to rectify mistakes and learn efficient methods of course correction.

Since the Scheme is implemented at different levels of governance, Eco-DRR activities would need a multi-tier M&E framework. There should be on the ground monitoring forspecific interventions. Regular supervision from higher levels is also needed to ensure better results. A clear channel of communication needs to be established through these different levels of governance, as well as through online reporting formats including the Management Information

System portal of the Scheme. Weekly reports can be generated under various heads for monitoring Eco-DRR programmes and monthly field visits conducted for the same.

INSTITUTIONAL FRAMEWORK FOR M&E ACTIVITIES

1. At the local government level, continuous M&E can be conducted through Mahatma Gandhi NREGS working groups. These working groups can be headed by an elected representative as Chairperson; an expert with knowledge in environmental conservation and related areas should be the Vice-chairperson. The Convenor should be the Secretary or a senior official of the local government. Mahatma Gandhi NREGS Engineers, mates, and barefoot technicians can also be members; other members can be experts from community-based organizations, women's self-help groups etc. The working group should ideally have 10 to 15 members. It is to be ensured that the groups have representation from women, SC/STs and other marginalized sections including fishing communities.
2. Community ownership is very crucial for M&E activities; as is community education on the ecological/economic importance of ecosystem services. Local knowledge about the site ecosystem is vital for the success of any such intervention. The involvement of local communities is cost effective and this also creates a sense of ownership in the community to protect the interventions in their areas. Members of the community can take part in seed/seedling collection, setting up nurseries and their maintenance, transportation of seed material, ground preparation, planting and after-care operations. Selection of appropriate persons can be done with the help of village-level local government officials. Members of local community groups, especially those that are concerned about the environment can be assigned the task of restoration, under the supervision of an expert on the subject.
3. Schools and other education institutions can also be brought into the process and be made responsible for ecosystem restoration and monitoring. Basic awareness about the ecosystems should be given to children at schools. They should be educated on the importance of ecosystems and their restoration and motivated to perform restoration work under the supervision of an expert on the subject.

DEVELOPING AN M&E FRAMEWORK AT THE LOCAL LEVEL

1. The local government should set up a broad M&E framework for Eco-DRR activities, and establish its objectives. A simple M&E checklist can be developed.
2. The mode of data collection, dissemination of information, and available technical and financial capacity should be considered at the local level and protocols fixed.
3. A results/outcomes framework should be developed within the M&E framework which details the expected effects of a particular Eco-DRR intervention, including short- and medium-term outcomes and long-term results;
4. Baselines should be determined for assessing the effectiveness of the works.
5. Indicators should be developed to monitor the quantity and quality of change. Indicators should focus on the SMART criteria (Specific, Measurable, Achievable, Relevant, Time-bound) and/or in line with the ADAPT principles (Adaptative,

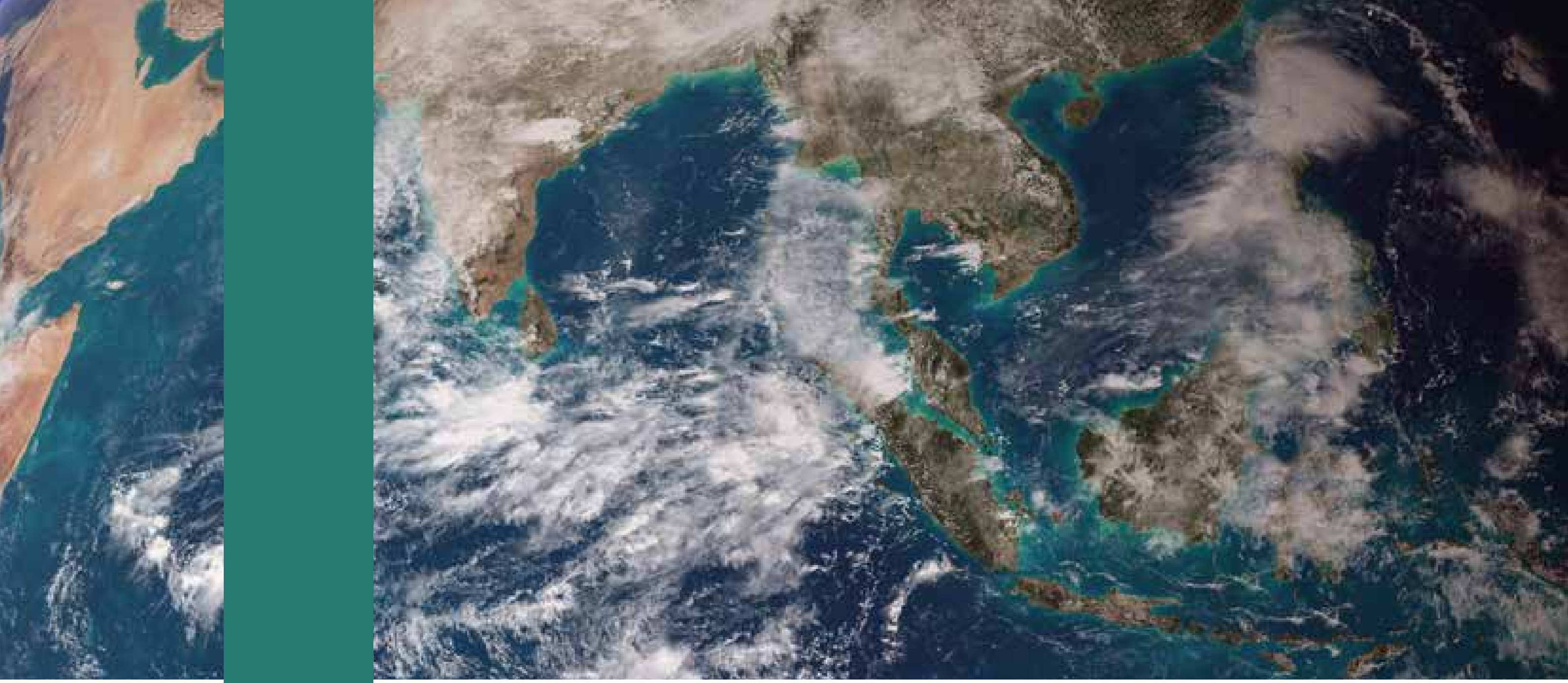
Dynamic, Active, Participatory, Thorough). They should be vulnerabilty and risk oriented and should be in line with the Sustainable Development Goals. Some suggested indicators are included in the below Table.

6. There should be a broad framework fixed for using the data for future decision-making and to correct course of action.
7. There should be methods adopted to document and record lessons learnt.

Table 11.1: Bio-physical indicators for Monitoring and Evaluation

DISASTER RISK	ECO-DRR MEASURE	SOME BIO-PHYSICAL INDICATORS
Drought	Water harvesting structures	Rise in ground water levels Increase in surface water level Improvement in water quality Availability of drinking water Yield from borewells and dug wells in the down-stream side Improvement in vegetative cover Number of wells recharged Area brought under irrigation/increase in agricul-ture productivity Soil moisture content
Flooding	Watershed inter-ventions	Reduction in flood Abundance of native species Increase in surface water level Abundance of Aquatic species Increase in agriculture productivity Rate of siltation in streams Banks stabilized
Landslides	Plantations	Slopes stabilized Rate of soil erosion Soil moisture content Run-off estimation Soil fertility Improvement in vegetative cover
Coastal Ero-sion	Coastal afforesta-tion works using mangroves and other vegetation	Abundance of native aquatic species Improvement in fish stock Resilience to floods Reduction in coastal erosion
Forest Fire	Plantation works in degraded for-ests	Area under tree cover Benefit per tree for its total age i.e. 20-25 years Reduction in forest fire

GIS APPLICATION FOR ECO-DRR



12 GIS APPLICATION FOR ECO-DRR

OVERVIEW

When resources are limited and several objectives exist that cannot be met simultaneously, we speak of a decision problem. In such situations we turn to spatial decision support systems or spatial planning support systems that help us to make judgments about the facts or expected facts we obtain from GIS and models. They assist individuals to analyze tradeoffs, assist groups to understand where compromises can be found and lay out possible pathways to make gradual improvements toward several objectives (Boerboom et al., 2009).

Spatial data refers to any geographically referenced data (do Carmo Dias Bueno 2011). It means that data is connected to a place on the Earth. GIS, which is short for Geographic Information Systems, is an information or computer system to input, retrieve, process, analyze and output multiple layers of spatial data. A GIS is composed of hardware, software, data and brainware (or the user). Within a GIS, different information layers can be overlaid due to its spatial reference. One of the most important uses of GIS and its capabilities for spatial analysis is to support decision making on land use planning. It can be a great tool for decisions about risk reduction and adaptation. Input data can range from cartographic maps, to field data and satellite images. The most common outputs from GIS software are maps, statistics and tables, charts or databases.

As human pressure on ecosystems continues to increase, research involving the effective incorporation of social values information into the context of comprehensive ecosystem services assessments is becoming more important (Sherrouse et al.,2011). Including quantified, spatially explicit social value metrics in such assessments will improve the analysis of relative tradeoffs among ecosystem services.

GIS APPLICATIONS

GIS technology is a dynamic tool to understand spatial dimensions of the world. It can be applied in both problem solving and decision-making processes, as well as for visualization of data in a spatial environment. Geospatial data can be analyzed to determine (1) the location of features and relationships to other features, (2) where the most and/or least of some features exist, (3) the density of features in a given space, (4) what is happening inside an area of interest (AOI), (5) what is happening nearby some feature or phenomenon, and (6) how a specific area has changed over time and in what way. It can answer questions such as:

1. **Mapping where things are:** We can map the spatial location of real-world features and visualize spatial relationships among them
2. **Mapping quantities:** People map quantities, such as where the most and least are, to find places that meet their criteria or to see the relationships between places.
3. **Mapping densities:** Sometimes it is more important to map concentrations, or a quantity normalized by area or total number.
4. **Finding what is inside:** We can use GIS to determine what is happening or what features are located inside a specific area/region. We can determine the characteristics of "inside" by creating specific criteria to define an area of interest (AOI). For example, a map can show a flood event and the land parcels and buildings in the floodway. We can use tools like CLIP to determine which parcels fall inside the flood event. Further, we can use attributes of the parcels to determine potential costs of property damage.
5. **Finding what is nearby:** We can find out what is happening within a set distance of a feature or event by mapping what is nearby using geoprocessing tools like BUFFER.
6. **Mapping change:** We can map the change in a specific geographic area to anticipate future conditions, decide on a course of action, or to evaluate the results of an action or policy (UWL, 2022).

Geospatial data is created, shared, and stored in many different formats. The two primary data types are **raster** and **vector**. Vector data is represented as either points, lines, or polygons. Discrete (or thematic) data is best represented as vector. Data that has an exact location, or hard boundaries are typically shown as vector data. Examples are country boundaries, the location of roads and railroads using lines, or point data indicating the location of fire hydrants.

By contrast, raster data is best suited for continuous data, or information that does not have hard boundaries or locations. As rasters, the data is viewed as a series of grid cells where each cell has a value representing the feature being observed. Think of raster data as appropriate for modeling surfaces like elevation, temperature, precipitation, or soil Ph. These phenomena are measured at intervals (think weather stations), and values in between are interpolated to create a continuous surface. Raster data also includes remote sensing imagery, like aerial photography and satellite imagery (UWL, 2022).

The mapping efforts integrate multiple disciplines, combining advanced technology and sophisticated models and methods. Mapping the ecosystem services would allow urban/rural designers and planning practitioners to help and inform policymakers during the decision process and management of various landscapes (Pulighe et al., 2016).

GIS DATA USED IN ECOLOGICAL APPLICATIONS

Ecological problems ranging from biodiversity loss to land-use change have benefited greatly from advances in geospatial technologies such as GIS and remote sensing, both in the provision of data and access to spatial data analysis tools. The integration of GIS and remote sensing for ecological mapping and monitoring, while addressed in earlier research (Stoms, 1993; Franklin, 1995; Goodchild, 1994), has become even more important as these data and technologies continue to evolve, and as ecological issues become more critical. The key motivations for integrating GIS and remote sensing for ecological research and management are:

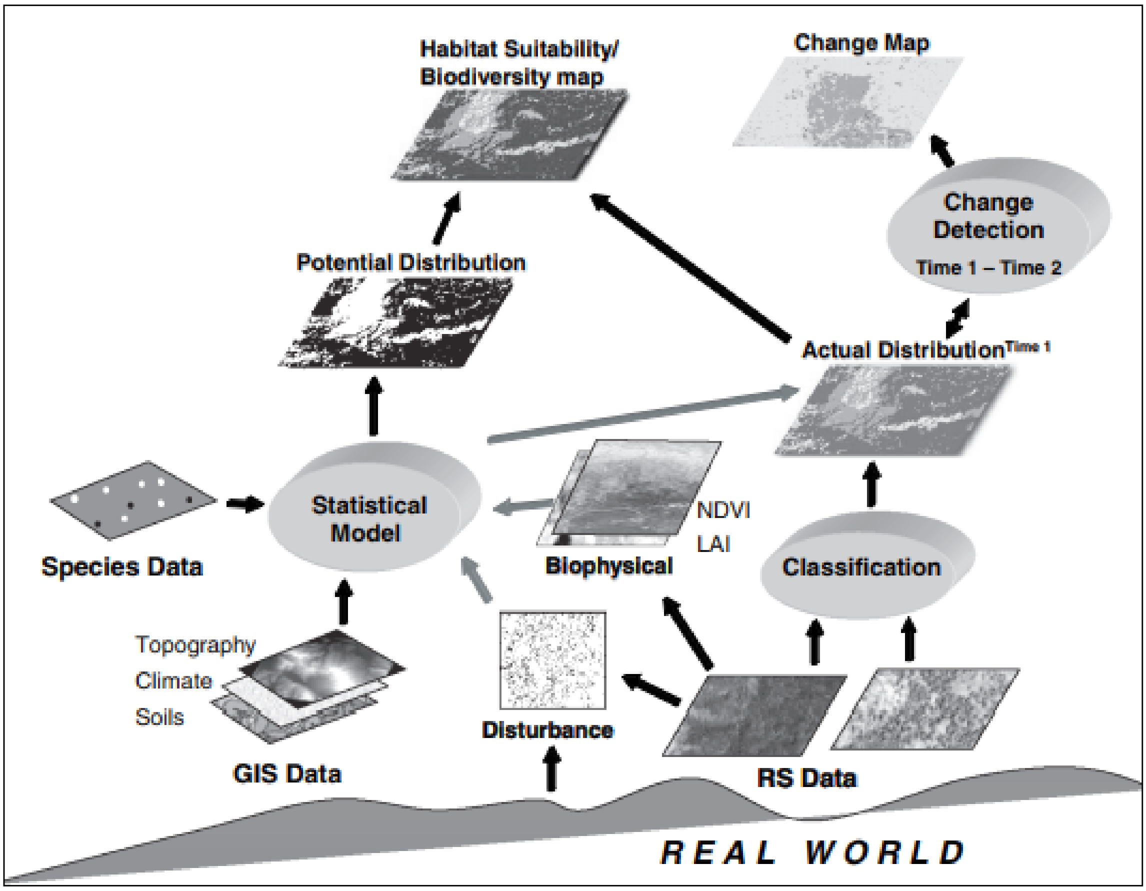


Figure 12.1: Illustrates the typical flow of information and data types used when GIS and remotely sensed data are integrated for ecological mapping and monitoring.
Source: Zimmermann., et al., 2000)

1. The acceptance of the landscape context and scale for sustainable ecosystem management (Liu and Taylor, 2002).
2. The importance of retrospective and prospective monitoring for conservation (Urban, 2002; Turner et al., 2003).
3. Increased familiarity with GIS and remote sensing data and methods within resource management agencies (Jennings, 2000).
4. Improved geospatial data quality and availability (at reduced cost) (Rogan and Chen, 2004).

'GIS data' is used here to describe non-spectral digital environmental data, as they are stored, manipulated and typically derived in a GIS. These data are derived either by interpolating field or station observations to a continuous surface (e.g. temperature) or by calculating new surfaces from existing spatially continuous data (e.g. slope, elevation). There are a number of environmental variables including climatic and topographical variables that are most widely used predicators in disaster risk reduction as they describe broad-scale physiological tolerances related to water and temperature and site energy and moisture availability associated with micro-climates. For example, the gradient analysis explores how plant species' composition and distribution change along environmental gradients (Whittaker, 1973; Kessell, 1979; Franklin, 1995). Spectral data have been used most often to derive some variation of a map of land-cover type (vegetation, biotype) or quality (biomass, NPP), from which habitat distribution (Osborne et al., 2001) can be identified.

OPPORTUNITY MAPPING TOOL OF UNEP FOR ECOSYSTEM-BASED DISASTER RISK REDUCTION

Geospatial information is widely used for prioritizing areas for ecosystem restoration and/ or conservation. It is also used for risk assessments, for instance in establishing flood risk zones to limit construction in such areas (Le Cozannet, et al 2020; Lorenzo-Alonso et al. 2019). However, it is rare to combine the two (Renaud et al. 2013; Sudmeier-Rieux et al. 2021). Ecosystems have rarely featured in risk assessments even though they are an important component for risk and vulnerability reduction (PEDRR, 2011). UNEP's Opportunity Mapping (PEDRR, 2021) tool is the first to offer a cross-mapping of ecosystem distributions and human exposure to hazards at a global scale.

The "Opportunity mapping tool" was developed by the United Nations Environment Programme (UNEP) Global Resource Information Database (GRID) to provide global data sets on main ecosystem coverage (forests, mangroves, coral reefs, seagrass cover), hazard occurrence (flooding, tsunamis, tropical cyclones and landslide) and exposure (population data in comparison to hazards) in 10X10 km grids globally. The most important feature is the algorithm that analyzes where ecosystem coverage can provide protection against hazards for decision-making on site selection for investment in ecosystem restoration (Sudmeier-Rieux et al., 2019).

By overlaying global datasets on ecosystem distribution and hazard exposure, the Opportunity Mapping tool highlights areas where ecosystem restoration and / or protection measures/ interventions can be used to protect the greatest number of people globally. Specifically, the tool highlights geographic locations where ecosystem restoration or protection are particularly appropriate for reducing the impact of certain hazards. Areas where there is an overlap between population exposure to hazards and low ecosystem coverage because they have been depleted, degraded or damaged, are highlighted as areas with opportunities for restoration to reduce disaster risk. In areas where ecosystem coverage and population exposure to certain hazards is high, ecosystem protection (e.g. through the establishment of protected areas), can further reduce disaster risk, by ensuring that ecosystems stay healthy and protect people and assets (Sudmeier-Rieux et al, 2019).

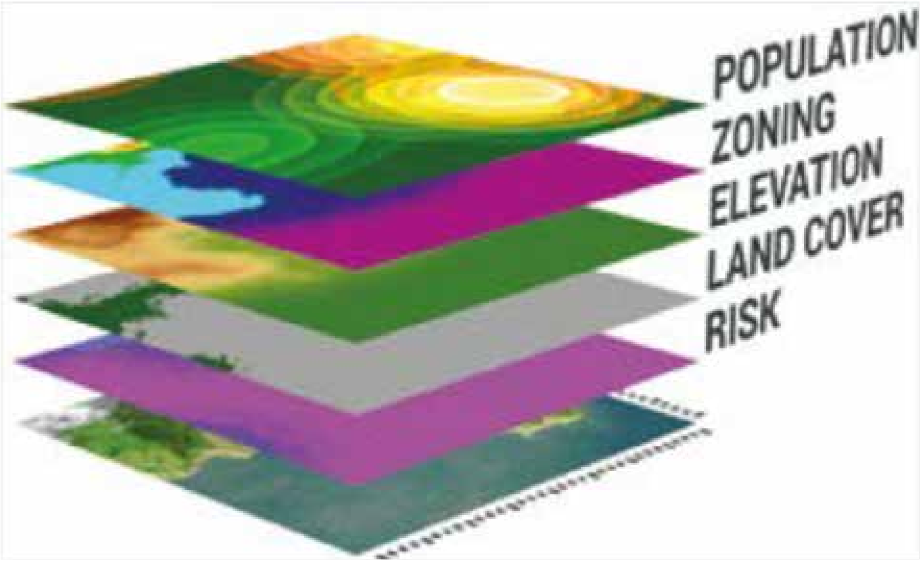


Figure 12.2. Opportunity mapping for ecosystem-based disaster risk reduction main data layers. Source: Sudmeier-Rieux et al, 2019

APPLICATION OF GIS IN NATURAL RESOURCE MANAGEMENT

In natural resource management, remote sensing and GIS can be used mainly in the mapping process. These technologies can be used to develop a variety of maps. Examples include:

1. Land cover maps
2. Vegetation maps
3. Soil maps
4. Geology maps etc.

However, before these maps are developed, there is a variety of data that needs to be collected and analysed. Most of this data is collected with the help of remote sensing technology. Data can be collected using either ground photographs, aerial photographs or satellite photographs of the area of study.

The choice of the photograph usually depends on the topography of the area of study and the aim of the study. For instance, aerial photographs (vertical or oblique) are always useful when spatial data needs to be collected in the same area of study within intervals (hours, days, seasons, years etc). This form of data collection shows the variations of the area of study within different periods of time (Elias, n.d.).

Satellite photographs can also be used to collect relevant data for the study. These types of photographs are however superior to aerial photographs in the sense that they have higher spectral, spatial, radiometric and temporal resolutions. Thus, satellite images are more detailed hence a lot of data can be generated from them. However, for remote sensing data to be effective, it needs to be incorporated together with topographical maps that show the variation of climate, soils, and other factors.

The visual and digital data that has been collected is usually analyzed to generate a pre-field map. Various components and elements of the data is analyzed. According to Elias (n.d.), elements such as tone, texture, pattern, association, size and shape are essential in the analysis process. These elements bring about a detailed view of the area of study. The pre-field map that has been generated together with the results from the analysis of the various elements is used to determine the characteristics of different elements and themes found on the ground (GIS Lounge, 2012).

Ground verification of the collected data is a critical process. To ensure that it is carried out in the most effective and efficient manner, the study area is usually divided into quadrants or transects. This is done to ensure that the interpreted elements of the satellite data conform to the ground characteristics. The data that is collected on the ground is geo-referenced with the help of a GPS to ensure that its corresponding location can be accurately identified in the images that were collected earlier (GIS Lounge, 2012). Additionally, field points identified in the images are visited to verify information regarding the state of the vegetation, geomorphology, topography, soils, and so on. With the use of the pre-field map that was generated, information from ground verification procedure and any other secondary source that might have been used, the final map is usually prepared. The scale of the map is also variable depending on the nature and extent of the study and the goals that it aims to achieve.

APPLICATION OF GIS DATA IN FOREST MANAGEMENT

Being a renewable resource, forest cover can be regenerated through sustainable management. Hence, with the help of remote sensing and GIS data, a forest manager can generate information with regard to forest cover, types of forest present within the area of the study, human encroachment into forest land/protected areas, encroachment of desert like conditions and so on. This information is critical in the development of forest management plans and in the process of decision making to ensure that effective policies have been put in place to control and govern the manner in which forest resources are utilized. For example, the biomass data of an area could be identified using this mapping. Also the activities for forest restoration, forest ponds construction, man-animal conflict resolution etc could be done using this mapping. Forest fires are a major hazard in climate change scenario due to the increase in temperatures. Forest fire hazards can also be mapped using GIS tehnologies.

APPLICATION OF GIS DATA IN WATERSHED MANAGEMENT

Water as a resource has been diminishing over the years. In Africa and other developing nations, the availability of clean water has been always scarce. Water management has therefore been a challenge in developing nations. However, with the use of satellite data, water bodies such as rivers, lakes, dams and reservoirs can be mapped in 3D with the help of GIS technology. The data can be used in the sustainable management of water bodies since respective authorities can decide which regions need effective protection and management. At the same time, decisions regarding the most effective means of utilization of these regions can always be arrived at. Similarly, activities like finding ideal places for watershed activities, river/canal rejuvenation, well recharging, underground water availability etc., could be mapped for efficient water management.

APPLICATION OF GIS DATA IN COMBATTING DESERTIFICATION

Geospatial data can be used to determine the soil types present in a given area and nutrient availability. Negative change can always be identified once this data is collected over a long period of time. GIS data can also be used to determine the land use practices within a given area and vegetation constitution and the impact that they have on the environment. Consequently, slope information of a region can also be determined with the use of GIS data. With all this information, an individual can easily determine whether desert-like conditions are occurring in an area. If desert-like conditions have been identified, its impacts and intensity can be analyzed in order to decide whether artificial or natural methods can be used to combat the situation.

APPLICATION OF GIS DATA IN BIODIVERSITY MANAGEMENT

Geospatial data can also be used in the management of flora and fauna within protected areas. Ground and aerial photographs, for instance, are essential in this practice. Aerial and satellite photographs can be used to determine the presence and distribution of vegetation within a protected area. These photos can also be used to determine the presence and distribution of invasive species within an ecosystem. This information is essential as it determines the amount of cover and food that is present, particularly for herbivores during various seasons of the year. Geospatial data can also be used to show human encroachment into protected areas as well as animal activities outside protected areas. This data is critical especially in the process of resolving human/wildlife conflicts. Finally, the use of GPS technology can be applied to monitor the movement of endangered species as well as newly introduced species to determine their progress as well as protecting them from poachers. Geospatial data can also be used to carry out environmental impact assessment (EIA) of various projects carried out within protected areas. Projects such as building of roads, buildings, pipeways, dams, and so on might have various effects on the flora and fauna of the ecosystem. Thus, geospatial data has become essential in biodiversity management.

APPLICATION OF GIS DATA IN ECOSYSTEM RESTORATION FOR DISASTER RISK REDUCTION

GIS based mapping can be used to examine changes in the ecological and climatological scenarios. It also helps to assess impacts of the direct and indirect aspects of environment change and to explore suitable strategies for eco-development with focus on disaster risk reduction. The remote sensing and GIS can be used to reveal the presence of dark patches. A careful examination of a particular feature in term of its location, shape, size, association, its nature towards the upstream/downstream could help in assessing ecological degradation. Similarly, remote sensing imagery could also be used to strengthen conservation and restoration practices to reduce erosion.

APPLICATION OF GIS BASED OPPORTUNITY MAPPING TOOL TO PRIORITIZE ECOSYSTEM RESTORATION FOR DISASTER RISK REDUCTION IN THE KELANI RIVER BASIN IN SRI LANKA

GIS based Opportunity Mapping Tool was applied by the International Union for Conservation of Nature (IUCN) to identify spatial locations in the upstream catchment of the Kelani River Basin to strengthen conservation and restoration practices to reduce erosion to achieve multiple benefits. It was understood that an increased canopy structure could minimize erosion, as also support the gray infrastructure to be effective and encourage infiltration of water into soils/ groundwater, thereby minimizing the immediate overland flow of water to streams (flood peaks) and potential landslides. The process of opportunity mapping involved finding the areas where the forest degradation had occurred and where the forest cover was maintained. Results of the opportunity mapping recommended the conservation of healthy forest cover while strengthening the restoration efforts in areas that the forest cover had reduced.

To identify the forest loss (1991 – 2020), an application was developed by the International Union for Conservation of Nature (IUCN), Sri Lanka, using two land use and land cover (LULC) datasets, namely a) the Forest cover 1991 and 2012 developed by the World Bank (WB) and European Space Agency (ESA) (Fayas et al., 2019) and b) the Global Forest Change 2000–2020 by the Department of Geography of University of Maryland (Hansen/UMD/Google/ USGS/ NASA) (Hewawasam, 2010). After processing the data, the output indicated the areas where forest loss was continuous (1991 to 2020) and the recent losses (losses initiated after 2012). The areas of forest losses (degradation) were combined with erosion and landslide hazards to identify the opportunities

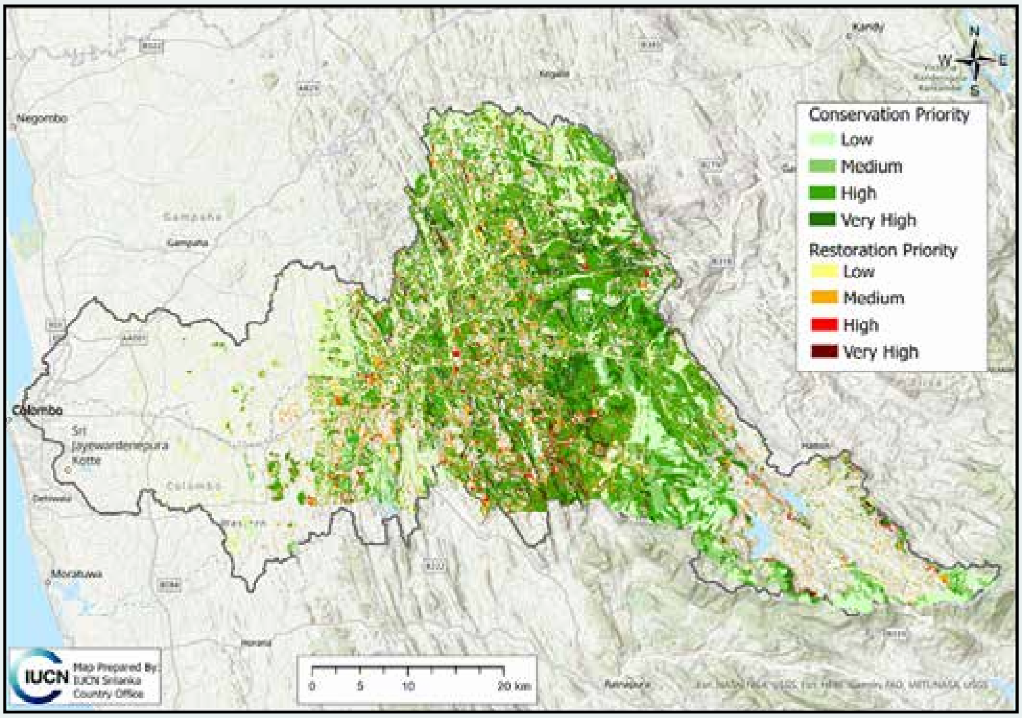


Figure 12.3: Opportunities for landslide management

Table 12.1: Opportunities for erosion, flood and landslide mitigation via conservation and restoration

Opportunity	Soil Erosion and Flooding		Landslide Mitigation	
	Conservation (ha)	Restoration (ha)	Conservation (ha)	Restoration (ha)
Low	39,693	6,537	19,282	4,804
Medium	2,393	12,267	7,617	9,403
High	41,023	1,246	48,725	4,734
V High	1,898	443	9,286	1,649
Total (ha)	85,007	20,493	84,910	20,590

for conservation and restoration with priorities assigned.

Spatial maps on erosion hazard were combined with the forest loss categories to arrive at the conservation and restoration opportunities. Later, the landslide susceptibility map was combined with the forest loss map to generate the opportunity map for landslide risk mitigation using green cover. For erosion control, opportunities are higher in both for conservation and restoration. The priorities for conservation or restoration could be guided by the conservation and restoration classes as identified and using the spatial map (Figures 10) to obtain the spatial locations. The areas identified as high and very high conservation priorities could be utilized for landslide mitigation. Similarly, priority areas for restoration could also be identified.

This study highlights the importance of conservation of existing less disturbed areas mixed with limited restoration to achieve intended results. On the other hand, the same fact highlights the importance of factoring the conservation of highland forest patches in development planning for maximizing the potential contribution of Nature based Solutions (NbS) and Eco-DRR applications.

APPLICATION OF MAPPING TO DECISION SUPPORT

Ecosystem services play an important role as measures for disaster risk reduction. At the same time, it is important to find out where and how ecosystem-based disaster risk reduction can really make a difference. The geographical information obtained from spatial-temporal simulation modelling and spatial multi-criteria evaluation, can be used for analyzing and monitoring what could be the effect of alternative development scenarios on exposure to natural hazards, or for understanding different combinations of engineered, ecosystem-based and other non-structural risk reduction measures (Krol, Bart, et al.,2016). Depending on their biophysical properties, ecosystems have the potential to supply services. Healthy and well-managed ecosystems help communities to cope with the impacts of more frequent and extreme hazard events and thereby adapt to climate change (Estrella et al., 2013). Increase in agricultural production systems, for example often comes at the cost of biodiversity and/or other regulating services. This causes an imbalance in available ecosystem services that will only increase human exposure to extreme events (Renaud et al. 2013). A model-based approach of mapping ecosystem services will result in a better exploration of risk reducing scenarios and policy alternatives. Different value maps of ecosystem services could be produced and combined using weighted overlaying techniques depending on the priorities of planners and stakeholders involved.

USE OF FLOOD BY-PASS DEVELOPMENT NEAR DUTCH TOWN KAMPEN:

A good example is the national Room for the River programme in the Netherlands. This integrated flood risk management programme represents a governmental response to coping with higher water levels in the Dutch rivers without merely raising and strengthening river dikes. An approach of 'working with nature' (Van Koningsveld, et al., 2012) instead of fighting against it has resulted in 34 different flood risk reduction projects spread over the Netherlands. One of these projects is the Flood By-pass development near Dutch Town Kampen.

Figure 12: Overview of the spatial development plan for Ijssel delta near Kampen (Ijssel river, new flood channel and other water bodies in blue colours; wetlands and other vegetation in green colours) (Image courtesy – A. Otten, Province of Overijssel).

A combination of increased water discharge (rainfall-induced) by the IJssel River and expected sea level rise make the Dutch towns of Kampen and Zwolle and their hinterland increasingly more vulnerable to the effects of flooding. To increase the resilience to climate change and at the same time improve the spatial quality of the area, a new flood channel, the Reeve Deep by-pass, will be constructed in the IJssel river delta. Apart from flood protection measures, there are several other spatial issues to be considered in the development of an integrated flood protection plan, including attention to nature management (the development of a new wetland area, in particular), interests of the agricultural sector, options for recreation, the development of new housing areas, and the presence of a railway

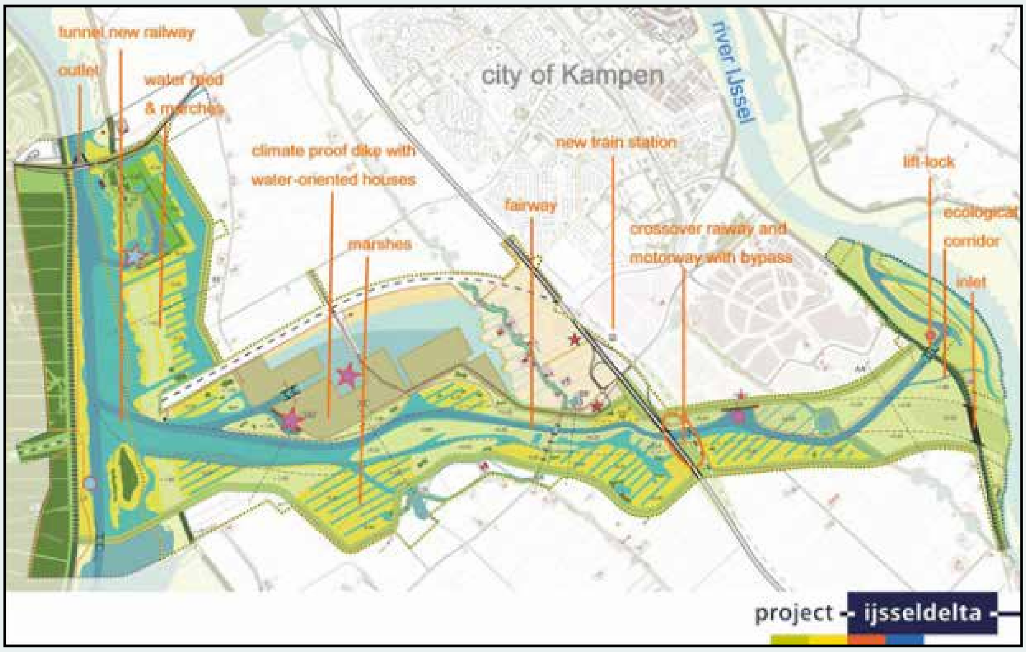


Figure 12.4: Overview of the spatial development plan for Ijssel delta near Kampen (Ijssel river, new flood channel and other water bodies in blue colours; wetlands and other vegetation in green colours) (Image courtesy – A. Otten, Province of Overijssel)

and several highways. For the spatial design of the flood by-pass a Digital Elevation Model (DEM) was used. Both the average and expected extreme water levels are projected on this model. This helps to obtain a better geographical understanding of the delta landscape and the potential wetland areas. Taking into account the hydraulic requirements set by the national Room for the River programme, an integrated spatial plan for the IJssel delta was developed.

CONCLUSION

An understanding of the environmental factors that determine species distributions (type, abundance, level of diversity) has always been of great interest in ecological based activities, but its importance has increased along with the interest in studying the consequences of changing environmental conditions. The ability to map, model and monitor these distributions is dependent upon the ability to collect, manage and analyse data that adequately describe them. GIS and remote sensing have become indispensable tools in this regard, providing increasingly more ecologically relevant data at higher spatial and temporal resolution, as well as the methods to derive more information from the data and to analyse them statistically. A more extensive integration of GIS and remote sensing for ecological mapping and monitoring is yet to be fully realized.

With the increasing pressure on natural resources due to the rising human population, remote sensing and GIS can be used to manage these limited resources in an effective and efficient manner. Geospatial data is effective in the analysis and determination of factors that affect the utilization of these resources.

CONCLUSION

13 CONCLUSION

Eco-DRR is a strategic step going forward, across the globe and especially in ecologically fragile and biodiversity rich nations like India. The critical opportunities which Eco-DRR offer for cost effective, long-term, ecologically safe solutions are many and ours for the taking. Particularly in India, there is already awareness of the benefits of natural infrastructure such as mangrove forests in offering a natural defense since the fatal tsunami of 2004 in the Indian Ocean (Finn Danielsen, 2005). Interestingly, the legal provisions granting protection for mangrove patches in the country have been in existence even before that in the form of the Coastal Regulation Zone Notification, 1991. However, it is true that the benefits of mangroves or other such natural infrastructure has not been captured comprehensively, except in pockets. Also, the approach for conserving such natural infrastructure still remains largely confined to the domain of biodiversity conservation rather than for the other ecosystem services they offer, including disaster risk reduction and climate change adaptation.

It is amidst this policy conundrum that the Mahatma Gandhi NREGS has, over the last 15 odd years helped identify ways for resisting drought through water-harvesting structures (The Hindu, 2021). Much progress has been made as a result of this. However, this has mostly remained limited to drought resistance in arid regions of the country and the scope for other measures for disaster risk reduction has largely not caught the imagination of government and practitioners. This Handbook has been an attempt to try and bridge those gaps and to draw attention to the myriad opportunities at the local level under the Scheme, especially in convergence with other schemes and with the utilisation of technology aids. Steps for opportunity mapping with hazard layers can open up much scope for planning works in an effective way.

The work that has gone into this Handbook also presents the scope for further research around land use and resource management, especially in India. Such research can help address some of the other challenges faced in policy shaping in this area, including the concern that Eco-DRR approaches are complex and difficult to replicate at scale (DasGupta, 2018). Further, this could also help solve the issue of predictability of Eco-DRR works (Mann, 2012). Solving such questions could also support the case for adopting this approach in other settings across the globe as well through similar development schemes like the Mahatma Gandhi NREGS.

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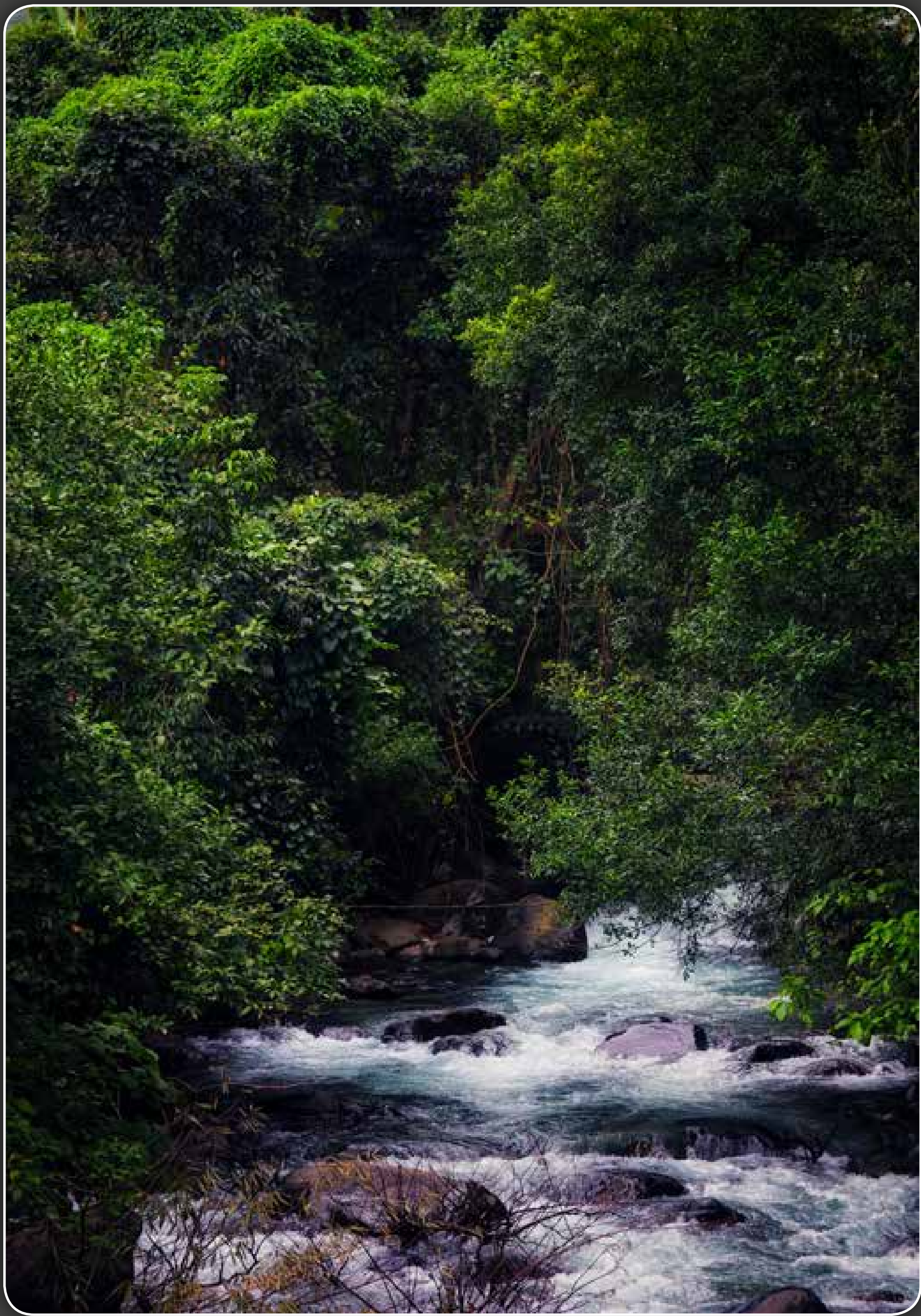

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