International Journal of
Land

https://journals.stmjournals.com/ijl

Volume 1, Issue 1, 2024
January–June
DOI (Journal): 10.37591/IJL

Research IJL

Effective Strategies for Sustainable Soil and Water Management: Enhancing Agricultural Productivity and Environmental Conservation

G.H. Shah[1, *]

Abstract

Soil and water are essential natural resources, and their degradation due to erosion, overgrazing and other factors is ongoing. Water erosion is influenced by climate, topography, vegetation and soil, while wind erosion is affected by wind characteristics, surface features, topography and soil properties. Unsustainable land and water management practices lead to reduced soil fertility, soil loss, lower crop yields, water depletion, deforestation, and diminished biomass. Of the 1386 million cubic kilometres of water on Earth, only 2.5% is freshwater, with most of it locked up, making just a small fraction available for use. Freshwater demand is rising, with agriculture using the most (70%), followed by industry (20%) and domestic use (10%). One kilogram of rice and wheat production requires 2975 liters and 1300 liters of freshwater, respectively. Groundwater is being depleted faster than it can be recharged in some areas, highlighting the need to focus on capturing and storing rainfall and improving soil moisture retention. The integrated watershed management approach is effective for managing soil and water resources, involving all stakeholders in planning and implementation. This includes mapping natural resources, demarcating watershed boundaries, identifying local needs, and developing sustainable action plans. These plans should improve soil and water conservation, enhance productivity, and maintain ecological integrity. Key activities include surface water harvesting, groundwater recharge, soil conservation measures, and promoting diversified farming systems. Monitoring, evaluation, and community involvement are crucial for success. Adopting a scientific approach in integrated watershed management can achieve desired conservation outcomes globally.

Keywords: Natural resources, erosion, integrated watershed management, ground water recharge

INTRODUCTION

Soil and water are the prime natural resources upon which human beings depend for their existence, livelihood, human welfare and economic development. The significance of land and water intensifies due to a multitude of compelling factors. Firstly, severe droughts in parts of the world contribute to major food crises. Secondly, the increase in population is more rapid than in agriculture production. Land and water being two vital resources must be considered together for meeting the increasing demand of growing population, a better protection of environment and addressing the issues of draughts and floods. The scope of international development goals has significantly broadened over the years. Initially, the primary focus was on increasing food production to ensure food security for growing populations. However, these objectives have now expanded to encompass a wider array of critical issues. In addition to

***Author for Correspondence**
G.H. Shah
E-mail: drshahgh7@yahoo.co.in

[1]Post Harvest Technologist Department of Horticulture, Arba Minch University, Ethiopia

Received Date: July 29, 2024
Accepted Date: August 29, 2024
Published Date: August 30, 2024

Citation: G.H. Shah. Effective Strategies for Sustainable Soil and Water Management: Enhancing Agricultural Productivity and Environmental Conservation. International Journal of Land, 2024; 1(1): 18–36p.

boosting agricultural output, there is a strong emphasis on reducing poverty and safeguarding the environment and natural resources.

Protecting natural resources presents a formidable challenge on a global scale. The sustainable management of these resources is essential to prevent their depletion and degradation, which can have far-reaching consequences for ecosystems and human well-being. This task demands a heightened level of attention and concerted efforts to curb the overexploitation of natural resources. Greater emphasis and innovative strategies are required to ensure that development progresses in a manner that is both equitable and environmentally sustainable.

Soil erosion and land degradation, along with the decreasing per capita availability of land and water, pose significant threats to the environment. While soil erosion is a natural process, it is greatly accelerated by human activities that misuse land and water resources. Practices such as overgrazing, improper land management techniques, and deforestation, combined with population pressure and the exploitation of natural resources, exacerbate this issue. These activities contribute to the degradation of vital resources, threatening their sustainability and availability worldwide.

Soil

Land is a natural resource and a pre-requisite for primary production system as well as for meeting social priorities such as shelter, communication, industrialization etc. Shrinkage of arable land due to soil erosion, desertification and other degradation processes is a great threat. Efforts to meet the challenges of sustainable land development are very much in vogue, yet there is a need to adopt most effective technique to conserve this natural resource.

Until recently, land was often viewed narrowly as a mere physical entity, defined by its topography and spatial characteristics. However, a more comprehensive and holistic perspective has emerged. This broader view considers both vertical aspects, encompassing everything from atmospheric climate to groundwater resources, and horizontal aspects, identifying the repetitive sequences of soil, terrain, hydrological features, vegetation, and land use elements.

Soil and land are vital natural reserves for human sustenance. They provide essential nutrients, directly or indirectly, to all forms of life. Plants draw their nourishment directly from the soil, while other life forms depend on food chains and ecosystems fundamentally controlled by soil health and quality.

The function of land in supporting human and other terrestrial ecosystem is enormous. Besides, directly supporting life, it helps to store and protect evidence from historical or pre historical records; act as buffer; filter or modifier for chemical pollutants and maintaining global hydrological cycle.

Land degradation, particularly through erosion, is widely acknowledged as a significant threat to human well-being. While geological or natural erosion does not always pose a danger, accelerated erosion can quickly cause extensive damage to the land. Poor land management practices often lead to soil erosion, which is one of the most visible and severe consequences. Wind and water are two main agents of erosion. Winds blowing at a high velocity lift up soil particles from land surface and blow them off in dust storms. When the velocity of dust borne wind gets reduced, the coarser soil particles get deposited in dunes and fertile lands are covered and rendered unfit for cultivation. In some places fertile soil is drifted and blown by wind and the subsoil layer is exposed. Reduced productive capacity is a significant concern. One of the main contributors to this issue is wind, which causes three distinct types of soil movement: saltation, suspension, and surface creep [1] as discussed hereunder.

Saltation involves the movement of soil particles in a series of short bounces. This process primarily affects fine particles that range from 0.1 to 0.5 millimetres in diameter. These particles are lifted off the ground and carried short distances before falling back to the surface, creating a bouncing effect.

Suspension occurs when very fine soil particles, those less than 0.1 millimetres in diameter, are lifted into the air by the action of particles in saltation. These tiny particles remain airborne for longer periods and can be transported over greater distances by the wind.

Surface creep, on the other hand, involves larger soil particles. These particles range in size from about 0.5 to 1.0 millimetre in diameter. They are too heavy to be lifted into the air and moved by saltation. Instead, they are pushed or rolled along the ground by the impact of the bouncing particles in saltation.

Together, these processes illustrate how wind can transport soil particles of various sizes, leading to soil erosion and a subsequent reduction in productive capacity.

In water erosion the beating force of rain drop detaches, puddles and splashes the soil, and the runoff water caries such detached soil away. The surface layer of productive soil is thus lost. Water erodes soil mainly in two ways; (1) by violent splash created by the falling rain drops on bare soil and (2) by scouring action of soil laden water rushing down the slopes.

The productive land loses the top fertile soil and moisture due to indiscriminate deforestation, overgrazing and faulty cultivation practices. Signs of erosion are visible to everyone, but the magnitude of erosion is not apparent to many. The havoc of erosion is worked out through the loss of top fertile soil, plant nutrients, surface and subsurface water, silting of water sources, tanks and reservoirs leading to reduction of command area, floods and destruction of communication and reduction of productivity of land.

Water

Water is a vital natural resource falling from the sky, bubbling up into springs and lakes, flowing in streams and rivers and is so fundamental to human activity that it has to be managed in such a way that everyone has an access. Leaving aside questions of unequal power over resources, the very nature of water militates against this. Water in lakes and reservoirs is constantly evaporating. Water in the landscape never stands still. It is always on the move. It sleeps into the soil for use by plants and creatures, or percolates into aquifers where it renews underground supplies. It travels downhill on even the slightest of gradients. Navigating around whatever impediments it finds in its way, surface water enters into a complex system of streams and tributaries connecting river basin, joining an ever large flow destined for the sea. Many of these linked river networks are occupied by different peoples, states and jurisdictions. At any and every stage along its journey, water is used and sometimes reused several times, to support life and economic activity.

Water has always been revered as a divine gift. The water or hydrologic cycle plays a crucial role in driving the processes on our planet, as water is in constant motion. This perpetual movement directly influences the atmosphere, the gaseous envelope that sustains life on Earth. The interaction between the oceans and the atmosphere shapes our weather patterns. Water endows the Earth with the capacity to support life. Amphibians, for instance, instinctively lay their eggs in water, ensuring the survival of their species.

Water is an extraordinary solvent, capable of dissolving most elements and compounds due to its powerful molecular structure. Gases such as oxygen and carbon dioxide also dissolve in water, making them available for both photosynthetic and non-photosynthetic organisms. Water's viscosity enables smaller fish to thrive near the shore while allowing larger fish to swim efficiently in strong currents. Viscosity also generates eddies, creating turbulence that mixes air in the water and ensures a uniform distribution of microscopic organisms.

However, the world faces a severe shortage of usable water needed to grow sufficient food for future generations. Rapidly, forests, wetlands, and other critical habitats are being converted into agricultural land to meet growing demands, with major rivers being diverted for food production. The challenge lies in producing more and better food while maintaining or improving essential ecosystem services, all without compromising our environment.

Global Water Scenario

The Earth holds about 1,386 million cubic kilometres of water. The vast majority of this water, almost all of it, is saltwater. This saltwater is found in the oceans, seas, saltwater lakes, and in underground aquifers located beneath the oceans. Only a small fraction, specifically 2.5 per cent, of the Earth's total water is fresh water. Furthermore, of this limited amount of freshwater, more than two-thirds is not easily accessible because it is trapped in glaciers, snow, ice, and permafrost. Of the fresh water that is technically 'available" for people to use; only a tiny portion (0.01%) is on the surface of earth. The rest is to be found underground in aquifers. The Global Water Scenario [2] is reflected as under;

Total Water on the Planet =1386 million cubic Kilometres
Salt Water = 1351 million cubic Kilometres (i.e. 97.5%)
Total Fresh Water =35 million cubic Kilometres (2.5` %)

(a) Unavailable (Under glaciers, = 24.5 million cubic Kilometres(69.5 % of fresh) Snow, ice and permafrost)
(b) Available
    (i) Ground Water =10.6 million cubic kilometres (30.1% of fresh)
    (ii) Lakes, soil moisture, air humidity, =135000 cubic Kilometres (0.4% of Marshes and wetlands, rivers, fresh and 0.01% of Total Water)

Plants and Animals)

Though some Scientists report slightly different percentages of different forms of water, but there is no denial to the fact that the salt water is more than 97 percent and fresh water is less than 3 percent. According to earlier reports [3], approximately 97.2% of the world's water is saline, primarily found in oceans. This leaves only 2.8% of the global water supply as fresh water. Of this 2.8% of fresh water, roughly 2.2% is accessible as surface water, while the remaining 0.6% is found as groundwater. Within the 2.2% of surface water, about 2.15% is locked away in glaciers and ice caps, with only around 0.01% present in lakes and streams. The remaining 0.04% exists in various other forms within the hydrological cycle.

Regarding groundwater, out of the 0.6% of the world's total water stored underground, approximately 0.25% can be economically extracted with current drilling technology. The rest remains inaccessible due to its greater depth.

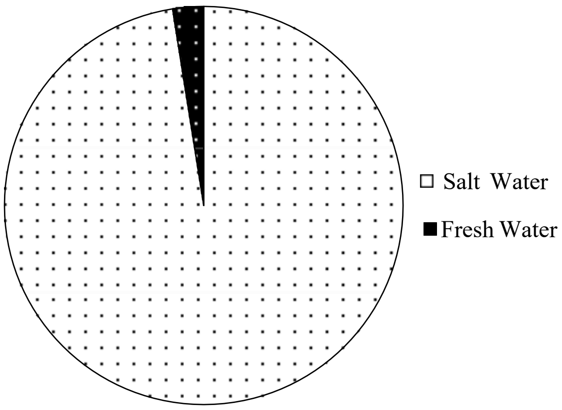

Figure 1. Global Scenario of Water.

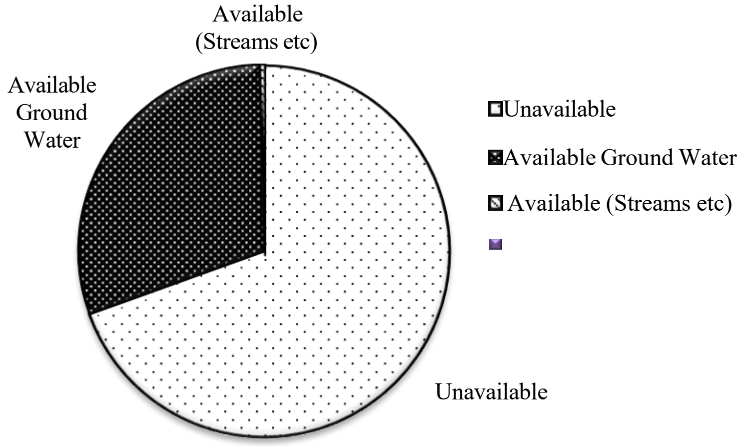

Figure 2. Fresh Water Scenario.

When considering the circulating water, which is the 0.04% of total water, about 82.1% of this originates from ocean evaporation. The remaining 17.9% comes from evaporation from soils, lakes, streams, and other sources. Of the 82.1% from ocean evaporation, only about 7.1% is directly contributed by the oceans. Therefore, only 25% (which is the sum of 17.9% and 7.1%) of the circulating water ends up falling on land surfaces.

Understanding and Managing Water Demand

Every year, approximately 4,000 cubic kilometres of fresh water are withdrawn, which equates to about 1,700 liters per person per day. While this volume far exceeds the amount needed for personal use—such as drinking, filling swimming pools, or watering gardens around the clock—much of our water consumption occurs indirectly. This indirect usage is embedded in the production of food and industrial goods. For instance, meat-rich diets and high-consumption lifestyles that include purchasing cars, televisions, and other products contribute to significant water consumption through their manufacturing processes. As a result, the total water footprint associated with these activities continues to grow. The water use can be grouped in three categories agriculture, industrial and domestic/municipal (Figure 3). Water for agriculture is by far the largest extractive category. Average amount of water needed to produce one kilogram of food [4] is depicted in Figure 4 that sufficiently explains the demand of agriculture sector for water. Requirement of water for industrial use is the second largest (20%) after agriculture sector. Domestic requirement of water is just 10 percent of the total demand.

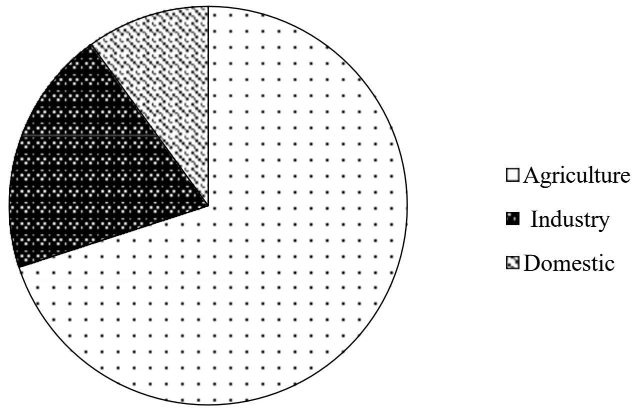

Figure 3. World Water Use.

Every year, the demand for water continues to rise. In many areas, cities rely significantly on groundwater rather than surface water for drinking purposes. This preference for groundwater is due to its lower likelihood of contamination compared to surface water.

Even for agriculture sector which is a voracious consumer of water, pumping of ground water has been increasing. Exhaustive withdrawals can lead to serious environmental problems.

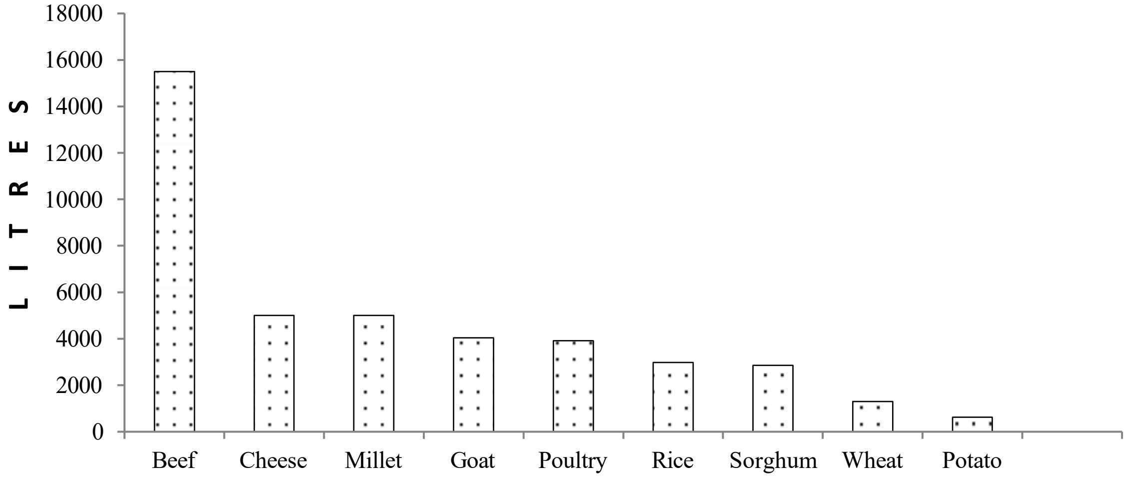

Figure 4. Average amount of water (litres) required to produce 1 Kilogram of Food

Groundwater can no longer be considered an infinite or limitless resource that can be used indefinitely to supplement surface water sources. Its management must now focus on sustainability, ensuring that it is used responsibly and maintained for future generations. Aquifer recharge is now an important focus of initiatives in the developing world. In some water scarce regions particularly in rural areas, there has been a profusion of small scale efforts at ground water recharge by use of rain water harvesting, recharge pits and other conservation methods.

Integrated Approach for Soil & Water Conservation

Land, water and vegetation are the basic natural resources for the sustenance of life. Soil and water act together under the congenial conditions of air, temperature and light as a system for the survival of life. Economic stability and wise use of these resources are inseparable. The future of any country and the ever growing population depend to a great extent on the conservation, maintenance and proper use of these resources.

Land degradation is a significant global issue characterized by a decline in land quality due to human activities. This problem is of great concern because it directly impacts world food security and the overall quality of the environment. While high population density might seem like a contributing factor to land degradation, it is actually the way in which a population manages and utilizes the land that determines the level of degradation.

People can play a crucial role in reversing land degradation if they are in good health and are motivated by political and economic incentives to care for the land. However, factors such as subsistence agriculture, poverty, and illiteracy can exacerbate land and environmental degradation.

Since land resources are essentially non-renewable, it is important to adopt sustainable management practices to preserve these finite resources. One effective strategy for conserving natural resources is the watershed approach. A watershed is a natural unit of land from which all the runoff water drains to a specific point in the drainage system. Using a watershed-based approach allows for more effective and sustainable planning and management of land resources.

Though concentrating on soil and water conservation has to be main focus of watershed, but in order to make it sustainable an integrated approach which will take care of social, financial and institutional aspects in the area is essential. Association of inhabitants/residents of the watershed area is highly essential for successful conservation of natural resources. Effectively managing watershed projects can be greatly enhanced by assigning users specific roles and responsibilities for overseeing different areas. By empowering individuals with designated tasks, the overall efficiency and effectiveness of the management process are significantly improved, as users are more invested in and accountable for the areas they are tasked with. Users at basic level (village or watershed level) are to be associated. Organizing of community into an institutional setup at basic level of watershed (Village), blending of indigenous technical knowledge and techniques with exogenous technical knowledge & techniques, focus on technical options rather than limited number of standardized technologies, equity for resource poor families, enhancement of stake of people in the programme through contributory approach, implementation of works by people themselves rather than by contractors, decentralization in decision making process, monitoring and supervision of works by community, social audit are some of the important approaches to be adopted during treating a watershed. Such a approach will not only conserve soil, water and vegetation but will also help a sustainable development, assured food production and livelihood generation in the area.

Fostering a sense of stewardship among local communities is a crucial element in effective watershed management. While implementing appropriate technology is a valuable component, it represents only a part of the overall solution. The more significant factor is the behavior of farmers and local residents, who are influenced by the economic and social pressures within their community or country.

Participatory watershed management is a concept that underscores the need for an interdisciplinary, intersectoral, and multi-institutional approach. This approach is defined as a process designed to build a self-sustaining system, which is fundamental for ensuring long-term sustainability. In such a system, stakeholders are given the opportunity to collaboratively negotiate their interests, establish priorities, assess opportunities, and oversee the implementation and monitoring of outcomes.

When addressing watershed issues, the following guiding principles should be considered:

1. *Equity:* Watershed development projects should be viewed as opportunities for promoting inclusiveness and ensuring that all stakeholders have a fair and equitable stake in the process. All segments of the population which include different communities, genders etc. must be taken into consideration.
2. *Capacity building and technology inputs:* Adequate stress must be given to capacity building. Emphasis must be given to knowledge and skill development.
3. Monitoring, Evaluation and learning process must be in place.
4. Technology inputs must be strengthened. Use of GIS facilities, remote sensing, information technology and other such advanced technologies will help for better planning, implementation and monitoring of the programme.

To effectively manage a watershed, creating a "Detailed Project Report" (DPR) is crucial. This report should comprehensively document various aspects of the watershed area. Specifically, it should include:

- *Production Information:-* Details about current land use, agricultural practices, and any other productive activities in the area.
- *Problems:-* Identification of challenges or issues affecting the watershed, such as erosion, pollution, or water scarcity.
- *Technologies:-* Information on existing technologies used in the watershed and any new technologies that could be beneficial.
- *Facilities/Infrastructure:-* A record of the facilities and infrastructure currently available, as well as what additional resources or structures might be needed.

To gather the necessary information, both primary data (collected directly through observations or surveys) and secondary data (gathered from existing reports or studies) should be used. Effective planning, as outlined in the Detailed Project Report (DPR), is one of the most crucial steps to ensure successful watershed management and achieve the desired outcomes.

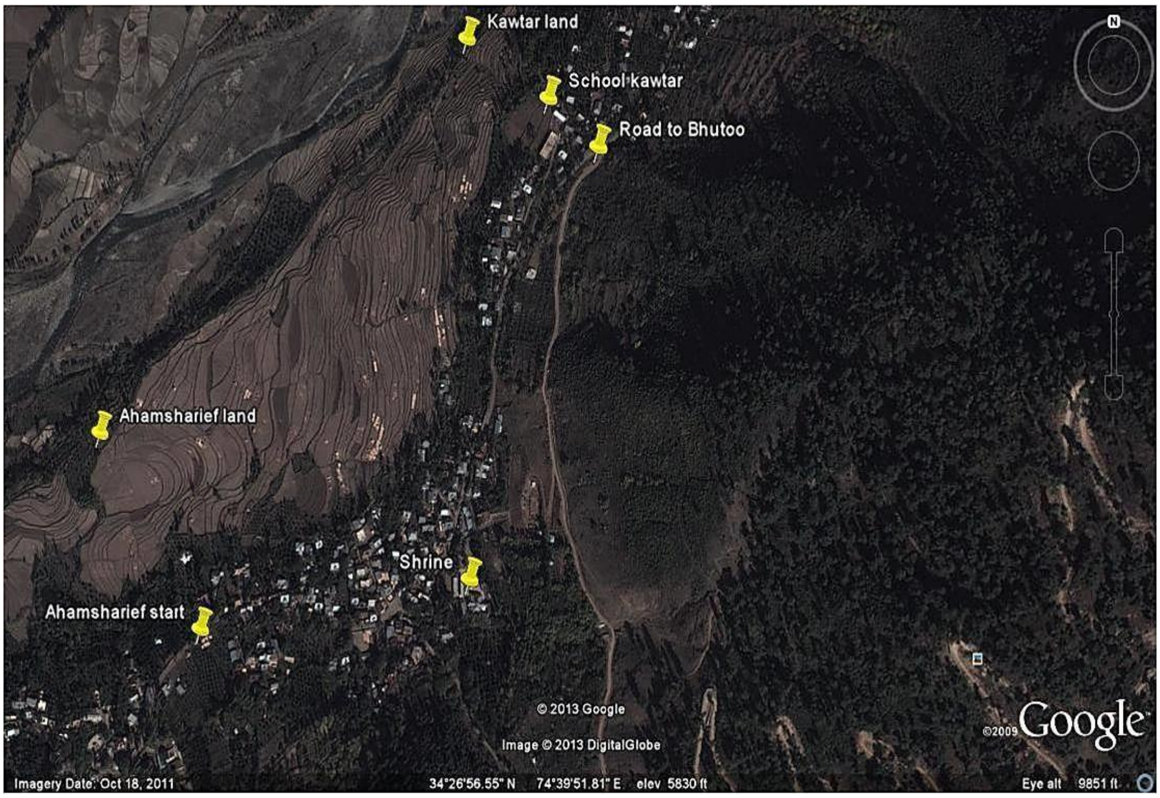

Figure-5. Identification of patches on Google Maps.

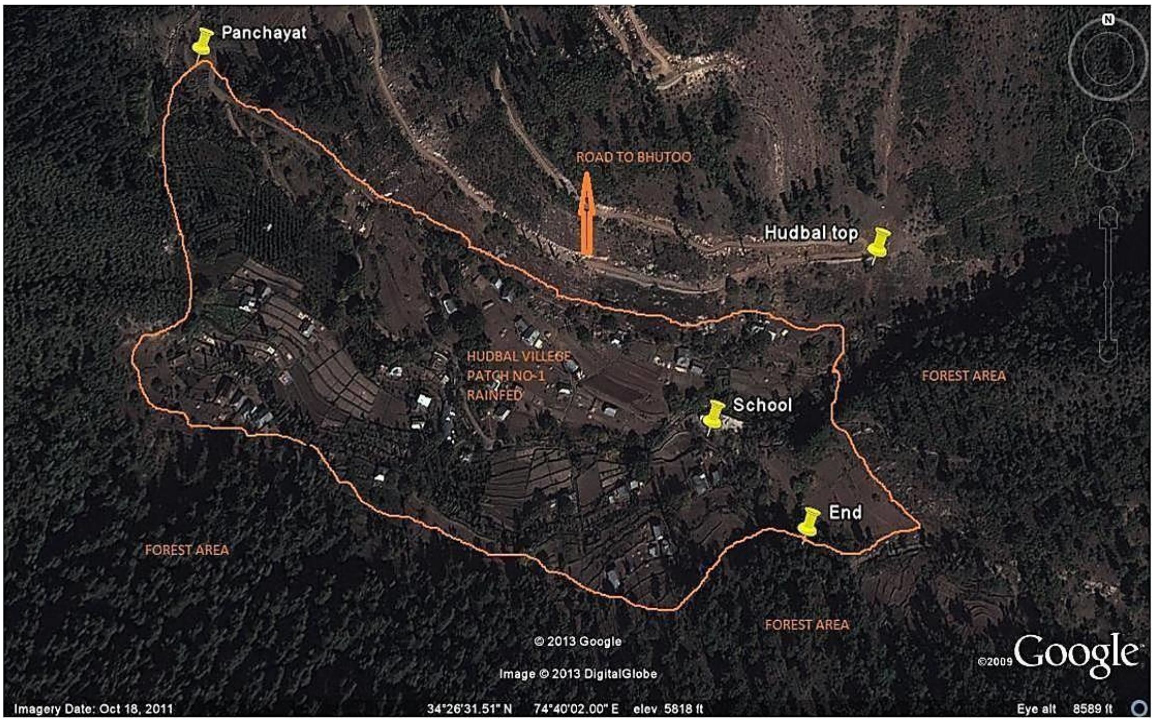

Figure-6. Identification of selected Micro Watersheds.

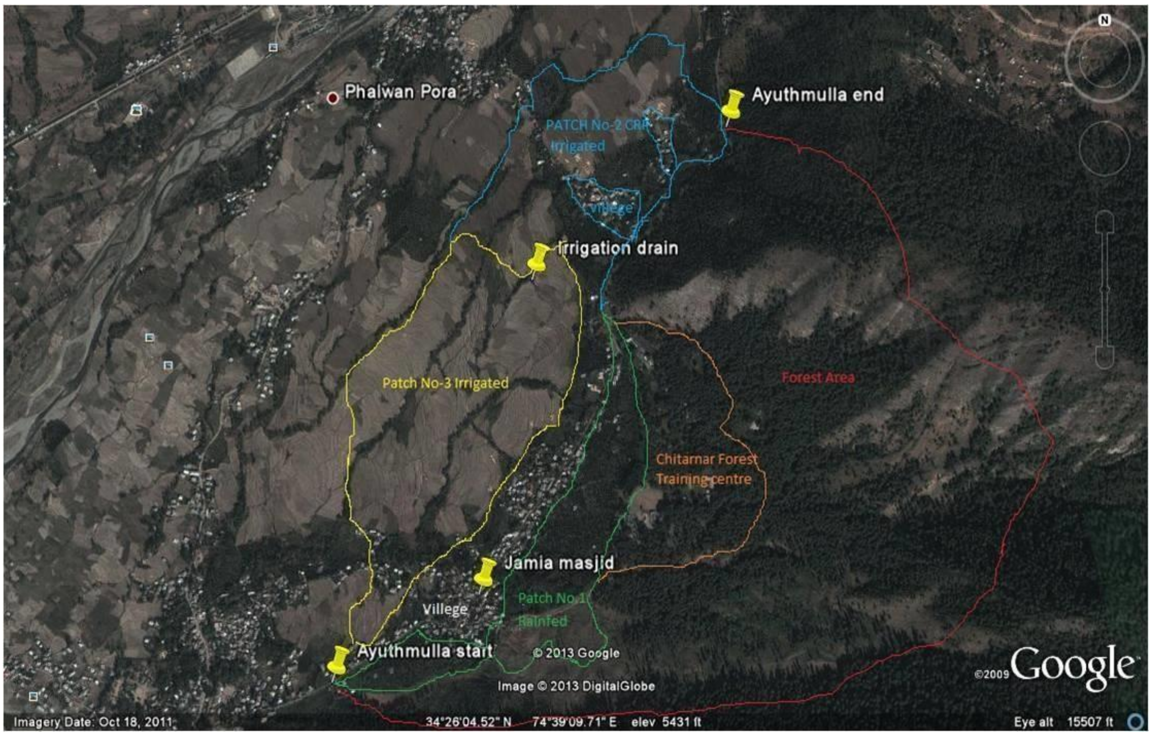

Figure-7. Patch Integration for full Micro Watershed.

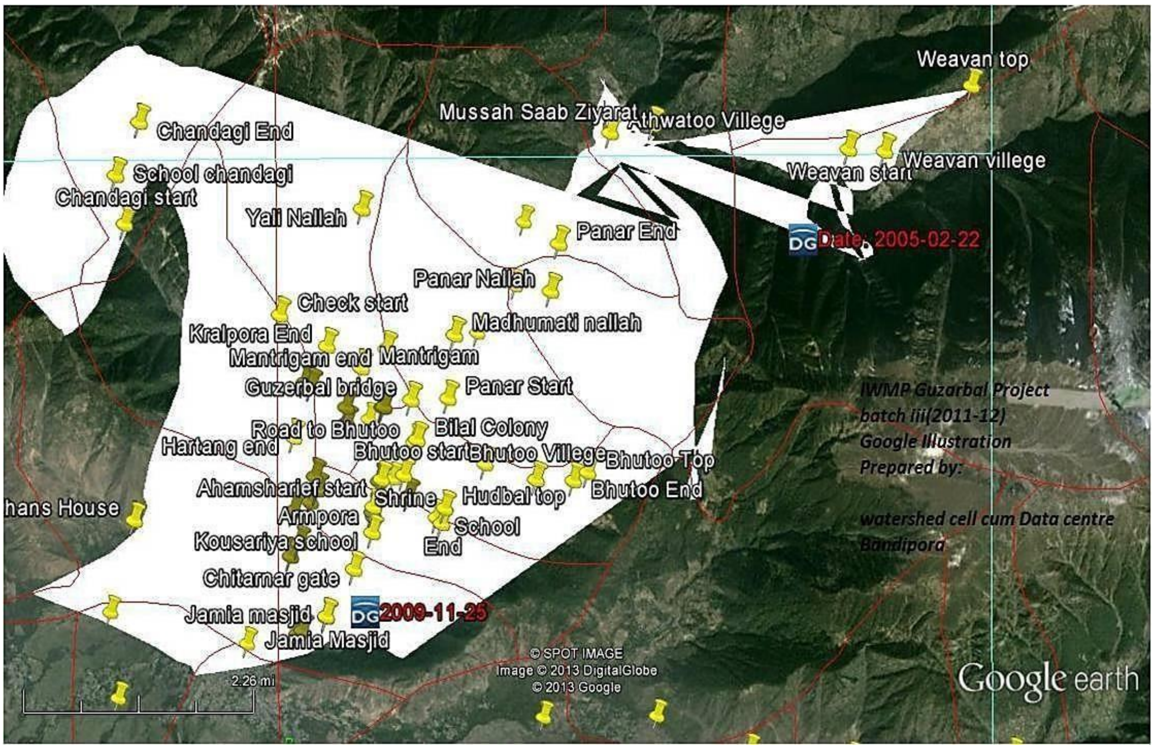

Figure 8. Micro Watershed Integration into full Watershed Project.

Modern sophisticated tools like satellite communication (SATCOM), Geographical Information system (GIS) and Management Information System are now being used effectively for management of soil and water. SATCOM has become an integral part of the project for capacity building of rural masses. GIS is the core technology adopted for resource mapping, data base generation, analysis and information extraction for watershed planning, implementation and monitoring.

Geographical Information System (GIS) is a new technology, which is adopted as a tool for analysing and integrating the spatial and non – spatial data in the project to help technical experts and communities to prioritize works and together develop comprehensive action plans for each micro- watershed. It is also used as an information database and analytical tool and as a decision supporting system. Thematic information generated from satellite and other ancillary information is integrated under GIS domain to generate local specific action plan on micro watershed basis for watershed development. This tool is also used for monitoring.

While drafting the DPR and planning the soil and water conservation, certain Bench Marks (outcomes) are to be listed and reflected for deciding the targeted goals. Such Bench Marks must include target of minimizing soil erosion, increase in ground water table, boost in forest/Agriculture/Horticulture, Animal Husbandry/Dairy/ Fisheries and Economic & financial development of the area.

Preparing of strategy plan for treating a watershed is essential. Three important components need to be addresses while preparation of a strategic plan.

i. Development of Natural Resources
ii. Improved management of farm production system.
iii. Improved management of non-farm based livelihood.

Development of natural resources would focus on land and water. The watershed plan must generate such activities which should save as much of the precipitation as possible either through infiltration in soil profile or through run off collection & storage and promoting optimum use of land and water and also promoting different vegetative cover according to land capability classification. The watershed plan must have two major aspects. First related to promotion of long gestation activities for optimizing the use of land and water and restoration of ecological balance and the second is to promote short gestation income generating programmes for the people to meet their immediate needs and to improve their income. The components of long gestation activities are fixing and alignment or various soil and water conservation structures, minute topographical variations, afforestation, minor irrigation and land development works. The component of short duration activities comprises development of agriculture, animal husbandry, pasture land and non-farming activities.

Soil & Water Conservation

Land degradation and water scarcity are widely recognized as major factors limiting food production and economic development for impoverished communities, with predictions indicating that these issues will worsen over time. However, there are opportunities to mitigate or even reverse land and water degradation. Sustainable intensification of agricultural practices, which balances the needs of nature and society—including food production, clean water, biodiversity, and carbon sequestration—has been successfully implemented in various regions. Uncontrolled exploitation of natural resources threatens sustainability, making it crucial for everyone to conserve our diminishing resources and safeguard them for future generations. Land should be utilized according to its capacity to avoid potential problems, and water remains the most critical input for agriculture.

Two important factors effecting soil and water and water conservation are (1) dispersive power of falling raindrops and amount & velocity of runoff, (ii) the dispersion of soil particles and its resistance. While adopting any technique for soil and water conservation, few basic principles as listed here must be kept in mind;

1. Reduce the velocity of rain before it touches the ground.
2. Reduce the velocity of runoff.
3. Improve binding of soil particles.
4. Use land according to land capabilities.
5. Create ponds/infrastructures/reservoirs for storage of runoff water and ground water recharge.

Though there are number of techniques to conserve soil and water, but the most commonly practised techniques could be classified as under;.

1. Biological Control Measures
2. Mechanical or Engineering Methods.

1. *Biological Control Measures:* A permanent vegetative cover is the best way to conserve the soil. The common methods of Biological control measures are Agronomic Practices, Agrostological methods and Dry Land farming**.**

Agronomic Practices

Such agricultural practices which contribute to the conservation of soil and water are also referred to conservation framings or advanced agronomical methods. These are listed as below. :-

i. Contour Farming.
ii. Tillage & keeping the land fallow.
iii. Crop Rotation, Sowing of leguminous crops & mixed cropping.
iv. Mulching.
v. Strip Cropping.

i. *Contour Farming*: This technique is particularly beneficial for regions with hilly terrain or slopes. In contour farming, the land is ploughed and seeded along the contours of the slope, creating circular furrows that follow the natural contour lines of the land. This method is designed to capture and hold the downward-flowing water, allowing it to be absorbed by the soil rather than running off. The resulting ridges formed by the furrows help slow down the flow of water, thereby reducing soil erosion. By planting crops in circular rows across the slope, contour farming not only mitigates soil erosion but also conserves water and enhances crop yields.
ii. *Tillage Operation & Keeping the Land Fallow:* Research indicates that in arid regions, shallow ploughing can lead to better crop yields compared to deeper ploughing. Additionally, allowing goats and cattle to graze on and tread the soil can contribute to its fertility. When the land is kept fallow—meaning it is left unplanted for a period of time—this practice helps improve soil health and prepares it for future cultivation.
iii. *Crop Rotation, Sowing of Legumes & Mixed Cropping*: Crop rotation involves alternating different types of crops in a specific sequence over several growing seasons. This practice helps prevent the depletion of particular nutrients in the soil, as different crops have varying nutrient requirements. An effective rotation plan typically includes a combination of new crops, small grasses, and legumes, or a mixture of legumes and grasses. When planning crop rotation, factors such as climate, economic conditions, soil types, and slopes should be considered. Mixed cropping, where multiple crops are planted together in the same field, further enhances soil productivity, reduces the risk of crop failure, and helps control soil erosion.
iv. *Mulching*: This method involves covering the soil surface with materials such as straw, leaves, or grass. The primary purpose of mulching is to protect the soil from erosion and to retain moisture. By creating a protective layer over the soil, mulching helps reduce water runoff and soil erosion, thus maintaining soil fertility and enhancing plant growth.
v. *Strip Cropping*: Strip cropping is a comprehensive approach that integrates various advanced cultivation practices, including contour farming, proper tillage, crop rotation, mulching, and cover cropping. This method involves planting crops in alternating strips or bands across the field. Different types of strip cropping include counter strip farming, field strip farming, wind strip cropping, and permanent or temporary buffer strip cropping. Each variation focuses on optimizing the benefits of these practices to enhance soil conservation, reduce erosion, and improve overall crop productivity.

Agrostological Methods

These techniques include:-

i. Cultivation of grasses (Ley Farming)
ii. Retiring the land
iii. Afforestation & reforestation
iv. Checking of Overgrazing

i. *Cultivation of Grasses (Ley Farming):* This method consists of growing grasses in rotation with agricultural crops. This practice improves the soil fertility, binds soil, and thus prevents erosion.
ii. *Retiring the land:* Areas subjected to heavy soil erosion, if put under thick cover of grasses will help to reduce soil erosion.
iii. *Afforestation & Reforestation*: Afforestation means growing forests at places where no forests exists. Reforestation means replanting of forests / trees at places where forests have been destroyed. Plantation of trees in short blocks is called wind break and extensive plantation of trees is called shelter belts. Wind breaks also help in reducing wind erosion.
The challenge of afforestation primarily involves selecting the appropriate tree species for a specific area. To address this issue effectively, the entire region should be segmented into various catchment zones based on factors such as climate, soil type, and existing vegetation. For each defined catchment zone, it is crucial to choose tree species that are well-adapted to the local conditions, preferably from among those species that are already thriving in the area. This approach ensures that the afforestation efforts align with the ecological characteristics of each zone, leading to more successful and sustainable outcomes. Knowledge of succession trends of vegetation will be of great help in afforestation practices. Afforestation/vegetation is most effective agent to prevent accelerated erosion and leakage/runoff of water.
iv. *Monitoring Overgrazing:* Since it is often impractical to completely halt grazing in areas prone to soil erosion, implementing a system of restricted and rotational grazing can help mitigate erosion to some extent. In this approach, grazing areas are managed in such a way that specific regions are grazed only during designated periods. After a period of grazing, these areas are closed off to grazing for the subsequent years. This allows time for the natural regeneration of forests and helps maintain robust ground vegetation. The goal is to restore the soil's structure and prevent degradation while still allowing for controlled grazing activities.

Dry Land Farming

Dry land farming is a comprehensive and strategic approach to cultivating crops in areas with limited rainfall. This method focuses on growing drought-resistant crops that can thrive with minimal water. Key practices in dry land farming include contour farming and compartmental farming. Contour farming involves ploughing along the contour lines of the land to reduce water runoff and soil erosion, while compartmental farming involves dividing the land into smaller sections to manage water more effectively. These techniques aim to maximize the retention of rainwater in the soil, ensuring that crops have access to water throughout their growth period. The objective is to optimize water use and improve crop yields in arid and semi-arid regions.

MECHANICAL METHODS

The Engineering Techniques must also focus on basic principles of soil and water conservation with due consideration to the local topography. Most commonly used mechanical or engineering techniques for soil and water conservation are under:-

i. *Contour Trenches:-* This technique involves digging a series of deep trenches or pits along the natural contours of a slope, spaced at suitable intervals. The soil removed from these trenches is used to build a bund (a raised barrier) along the lower edge of each trench. On the ridges between the trenches, tree seeds are planted. This method helps in controlling erosion and improving water retention on sloped terrain.]
ii. *Contour Furrows:-* Furrows are drawn across the slope, to facilitate more absorption of water, reduce runoff and minimize soil erosion.

iii. *Earthen Bunds:-* Contour Trenches are a method for managing erosion and improving water retention on slopes. This technique involves digging a series of deep trenches along the natural shape of the slope. The soil dug out of these trenches is used to create a barrier, called a bund, along the lower edge of each trench. Tree seeds are then planted on the ridges between the trenches. This setup helps to prevent soil erosion and keeps water on the land better. Contour bund is generally recommended for low rainfall (600 mm) and for permeable solids up to slope for about 6% in agricultural land. Bunds can be either open ended or hooked up at the ends. If the ends are hooked up the intercepted water is made impound on the upper edge till the water is absorbed into the soil. With the open ends till the build-up head of water causes the excess to drain off slowly after giving opportunity to infiltrate into the soil. As regards spacing between the bunds, it will not exceed 1.5 m vertical drop or 67.5m horizontal spacing, whichever is less.
iv. *Zingg Terracing:-* Zingg terracing is adopted in such areas that have a rolling topography and the soil of relatively heavy nature ranging from sandy loam to clay loam with moderate depths. The major objective of zing terrace is to cut down the length and slope for minimizing the velocity of runoff flow, to harvest the runoff from the upper area for the benefit of the crops grown in lower side of the field in the level portion on conserved moisture condition; to provide adequate storage of runoff during the period of low intensity storms by storing water in the levelled portion; and to ensure adequate drainage during the periods of heavy down pour as the level portion during having grade acts like a shallow water channel. Such terracing is generally recommended for lands with 3 to 10% slope, on steep slopes fencing is recommended.
v. *Bench Terracing:-* Bench terracing is a method used to manage sloping land and reduce soil erosion while making it suitable for farming. Here’s how it works:
    1. *Creating Terraces:* The land is shaped into wide, step-like platforms called bench terraces. These terraces are constructed along the natural contours of the land to ensure a gradual drop from one level to the next, which typically ranges from 1 to 2 meters in vertical height.
    2. *Preventing Erosion*: To stop rainwater from washing away the soil, bunds (small embankments) about one foot high are built along the edges of each terrace. These bunds help to keep the rainwater on the terrace and reduce the risk of soil erosion.
    3. *Transforming Slopes:* On steep or uneven land, bench terracing involves a process called "half cutting and half filling." This means cutting into the hillside to create flat areas and filling in the lower parts to level out the land. This transformation changes a sloping area into flat, level fields.
    4. *Usage:* Bench terracing is particularly effective on slopes ranging from 16% to 33%, but it can also be used on gentler slopes. It helps in the uniform application of irrigation water and is especially useful for growing crops like paddy, which require consistent water levels.

Overall, bench terracing helps convert difficult, sloped land into manageable, level fields that are less prone to erosion and better suited for farming.

i. *Countour Stone Wall:-* These are adapted mainly in areas where stone is available in plenty. The walls are constructed to reduce runoff and soil loss.
ii. *Earthen Bunds:-* Bunds constructed along the contour in slopes less than 10% these bunds are reinforced with grass etc. Such structures enhance ground water recharge and also minimize soil erosion.
iii. *Stone Checks:-* Loose boulder check dams. These check dams are made with relatively small rocks /bunds available in the area and are placed across the gully. It facilitates seepage of water into subsoil and also raises ground water table. Loose stone check dams are employed to stabilize key and minor gullies.
iv. *Masonry Check Dams:* Masonry check dams are built in areas with steep slopes where earthen methods are insufficient to control the flow of water. These dams are constructed using cement mortar and are typically made with rubble that has been blasted. Their primary purpose is to capture both fine and coarse materials carried by flowing water in a gully, which helps to reduce the flow's velocity and manage erosion.

v. G*abion Check Dams:* Gabion check dams are effective in controlling channel erosion. They are built using gabion boxes made from 10-gauge galvanized wire and filled with stones. As silt accumulates in these gabion structures, they become a permanent fixture in the drainage area, enhancing the stability and durability of the structure. Additionally, gabion check dams can be used in conjunction with gabion retaining walls to stabilize riverbanks and prevent erosion, especially in areas prone to landslides.

vi. *Brushwood Check Dams*: Brushwood check dams are commonly used in primary drains to manage water flow and reduce erosion. They work by trapping materials carried by the flowing water within the channel. To create a brushwood check dam, brushwood is arranged across the flow of water and secured with galvanized wire or fiber material, and filled with twigs, logs, and grass. This setup helps to slow down the water, reducing its erosive force and protecting the channel from erosion.

vii. *Grassed Waterways:-* Grassed waterway is a channel layered by indigenous varieties of grasses which prevent scouring of the channel and reducing velocity of flow.

viii. *Stone Pitched Countour Bunds:-* Stone pitched contour bunds are embankments made across slope with the aim to reduce the length of the slope. Terrace the land and prevent runoff from attaining erosive velocity. Stone and rocks arranged across the slope are strengthened and reinforced with fodder grass and other suitable species. Structures constructed along the counter specified vertical intervals help in erosion control, infiltration and ground exchange.

ix. *Drip Irrigation:-* This method delivers water directly to the root zone of plants through a network of pipes and emitters. By allowing water to drip slowly and precisely where it's needed, drip irrigation conserves both water and fertilizer, minimizing waste and maximizing efficiency.

x. *Sprinkler Irrigation*: This technique mimics natural rainfall by spraying water over plants from above. To ensure that water is distributed evenly, the system must be carefully designed, including the pump, sprinklers, and operating conditions, to achieve uniform coverage.

xi. *Centripital Terrace*:- Circular basins/trenches made at the base of perennial trees to conserve moisture and trap rainwater. Husk overlay within the basin helps to prolong the moist period and prevent moistures from being washed away.

xii. *Graded Bunds:-* Graded bunds consists of earthen bunds and channels constructed at gentle grade across general land slope. These are constructed in places with heavy rainfall. They reduce soil erosion and to divert access water through lined channels. The earthen barriers reduce the length of overland flow along the slope resulting the consequent reduction in runoff and soil loss.

xiii. *Inwardly Sloping Strip Terraces*:- Suited for slopes up to 33% on contour. Water collected in inwardly sloping terraces infiltrate down and thus help ground water recharge.

xiv. *Live Fencing:-* Plants, hedges, constructed across the slope help in soil and moisture conservation. These are low cast soil conservation measures that help retain fertile top soil and supplement organic matter.

xv. *Moisture Conservation Pits:-* Pits across the slope to excess surface runoff and silt. This facilitates erosion control and ground water recharge. However it is not suitable for landslide prone areas. It is a low cast technique.

In addition to the water and soil conservation techniques mentioned earlier, there are several methods for harvesting and storing water. One of the most time-honored techniques is rainwater harvesting, which has been utilized since ancient times.

Generally, rain water harvesting depends on three basic criteria, namely source of water available, required storage duration and use of harvested water. On the basis of criteria, the water harvesting techniques are classified in the following groups:

- Surface water harvesting
- Roof water harvesting

- Run-off water harvesting
- In situ water harvesting, and
- Flood water harvesting

Surface Water Harvesting

Surface water harvesting is generally classified as short term and long term water harvesting. Short term water harvesting is designed to collect the 24-hour rainfall excess for a ten year recurrence interval. Field bunds, contour bunds, V-ditches, contour trenches etc. are the measure commonly known as short term water harvesting techniques. Long term water harvesting is generally done for building a water stock for the purpose of agriculture, irrigation, drinking, fish farming and ground water recharge. This is accomplished by constructing a reservoir in the area. These measures are mainly designed on the basis of peak runoff rate, expected run-off yield of the catchment, suitable collection site and minimum losses from seepage and evaporation. The most common type of long term surface runoff harvesting measures are farm ponds, percolation ponds, sunken ponds, etc. which are widely adopted.

Roof Water Harvesting

Roof water harvesting is mainly applied for domestic purposes, depending upon the availability of roof water. This water can be used for drinking by humans as well as livestock because it is free from soil pollutants. This technique is highly suitable for low rainfall areas where the number of run-off producing rainfall events is limited and there is scarcity of drinking water.

Managing and Storing Harvested Water

Storage is a crucial component of any water harvesting system. In runoff farming, the storage reservoir is typically within the soil itself. However, when water is intended for domestic use or supplemental irrigation, a dedicated storage facility is necessary. It's important to carefully balance storage capacity with catchment size to minimize overall costs.

There are three primary methods for storing harvested water:

1. *Excavated Pits or Ponds*: These are commonly used due to their ease of construction, especially in relatively flat areas with deep soil. Their compact design makes them a popular choice.
2. *Tanks*: Constructed from materials such as steel or wood, tanks provide a durable storage solution.
3. *Plastic or Rubber Bags*: These flexible storage options can be an efficient and cost-effective alternative.

Properly designed and implemented storage solutions are essential for maximizing the efficiency and cost-effectiveness of water harvesting systems.

A water barrier such as natural clay soil, bentonite, bituminous material, soil cement mixture, stone lining, cement concrete, asphalt & synthetic material can be used to control seepage losses of stored water. Tank generally offers certain advantages that cannot be obtained with excavated pits. The only disadvantage of vertical tanks is their initial high cost. Flat tanks may also be used to store the harvested water. Storage bags made of plastic or rubber may be easily installed in an excavated pit or basin with side slopes not exceeding the angle of repose of the soil. This system is completely closed and both seepage and evaporation losses are controlled. Their main demerit is susceptibility to damage by rodents and livestock and vermin attack.

*Farm Ponds:-*Farm ponds are small reservoirs built to store water, primarily from surface runoff. They serve several essential purposes:

1. *Irrigation*:- Farm ponds provide supplemental irrigation to crops, ensuring they receive adequate water, especially during dry periods.

2. *Domestic Use*:- The stored water can be used for household needs, such as drinking, cooking, and cleaning.
3. *Pisciculture:-* Farm ponds can support fish farming, providing an additional source of income and food for farmers.

When numerous farm ponds are constructed within a catchment area, they can positively impact downstream water flow by regulating and slowing down the movement of water. This can reduce erosion and improve water availability. In regions that rely on rain-fed agriculture, farm ponds are particularly valuable. They capture and store rainwater, which can then be used for critical or life- saving irrigation during dry spells. Large farm ponds have the added benefit of aiding in groundwater recharge. By allowing water to percolate through the soil, they help replenish underground aquifers, which is crucial for maintaining water levels and ensuring a sustainable water supply.

Overall, farm ponds play a crucial role in enhancing water management in agricultural areas, particularly those dependent on rainfall, by providing irrigation, supporting domestic needs, facilitating fish farming, and contributing to groundwater recharge.

Types of Farm Pond

Depending on the source of water and its location with respect to the land surface, farm ponds are divided into four types

i. Dugout ponds
ii. Embankment type ponds
iii. Spring fed ponds and
iv. Off-stream storage ponds

i. *Dugout Ponds*:- These ponds are typically used when only a small supply of water is needed. Stored water is pumped from the pond to the cropped area for irrigation. The side slopes of dugout ponds should not be steeper than the natural angle of repose of the excavated material and generally should be flatter than a 1:1 ratio.
ii. *Embankment Ponds*:- Also known as surface ponds, these are the most common type of farm ponds. They are partially excavated, with an embankment constructed on the downslope to retain the water. A site with a natural depression is usually chosen for pond construction. The pond is fed by surface runoff from its catchment area. Key components of these ponds include the earthen embankment, mechanical spillway, and emergency spillway. It is preferable to use a gravity outlet to draw water from the pond for irrigating lower fields, making site selection crucial.
iii. *Spring Fed Ponds:-* These ponds are supplied by a spring or creek, common in hilly areas with natural springs or creeks. Runoff water from these natural sources is collected in appropriately sized ponds located at suitable sites. The stored water is used for supplemental irrigation.
iv. *Off-Stream Storage Ponds*:-In certain situations, constructing a storage reservoir directly on a stream may be impractical or unfeasible. This could be due to various reasons such as environmental concerns, geographical limitations, or regulatory restrictions. In such cases, a more suitable option is to use off-stream storage.

Off-stream storage involves creating a reservoir that is not situated directly on the stream itself. Instead, water is diverted into this reservoir from the stream or other sources. This can be achieved through methods such as constructing channels to guide the water flow or using pumps to transport the water. This approach allows for the effective storage of water while avoiding the complications associated with building directly on the stream. These ponds are constructed by the sides of ephemeral streams which flow seasonally. In this type of pond, seasonal water is stored by way of a suitable arrangement for safe conveyance of the stream flow into the pond.

Design of Farm Ponds

The design of farm ponds consists of selection of site, capacity of the pond, design of the embankment, design of mechanical and emergency spillway, disposal of excavated material and provision of seepage control and planning.

Selection of site:-Some of the important physical features that must be considered in locating dugout sites are as follows.

- Watershed characteristics
- Silting possibilities
- Topography and
- Soil type

To ensure a dugout pond is adequately supplied, the watershed should provide enough annual runoff to keep it filled. Supplemental drainage can be added using diversion ditches. A natural depression's low point is often an ideal location for a dugout pond due to favourable discharge conditions.

Before construction, thoroughly investigate the soil type at the site. Assess the soil's permeability to determine if it will effectively retain water and to avoid encountering excessively hard material. If the farm pond experiences excessive seepage, appropriate lining methods such as paddling, compacting to the optimal bulk density, or applying a bitumen spray may be necessary.

Avoid sites with soils underlain by limestone with crevices, sinks, or channels, as these can lead to water loss. In areas where the water table rises within a few meters of the surface, dugouts can be constructed to intercept this groundwater, with their depth adjusted to account for expected fluctuations. Such locations can provide a reliable water supply year-round.

Considerations for the Selection of Reservoir Site

While constructing the reservoir the following point must be kept in mind.

- Maximum storage volume with minimum earth work.
- Adequate drainage area.
- Watershed under soil conservation treatment.
- Pollution free site.
- Proper spill way site.
- Availability of good fill material.
- Impervious foundation i.e. to avoid seepage loses i.e. sandy soil should be avoided.
- Location close to the point use.
- Safety consideration.
- Absence of buried cables, pipeline, low hanging power lines etc.
- Easy accessibility for recreational purposes.

Construction of the dam / Reservoir /Tank

The area to be used as base of the dam is cleared of all trees, tree roots, stems and boulders. Trees and bushes are cut, flush with the ground and removed from the pond area. The surface soil from the proposed dam site is scraped off and stock piled out of the way. The entire base of the dam should be disked and ploughed immediately before starting to place the fill material.

The soil used for filling is placed in thin layers that are 15 to 20 centimeters thick. Each layer is thoroughly compacted either by using a sheep foot roller or a weighted rubber tired tractor. The soil must be reasonably moist, moist enough to form a cast when squeezed in the hand but not sticky. It is a good practice to steepen the slopes around the shore line so that there will be a minimum of shallow water less than 1m deep. A permanent fence is built around the pond to prevent damage to the earth dam and the spillway from livestock.

Lat.32.89011 N Long.74.95608 E

Figure-9. Rain water Harvesting Tank in Watershed Area.

Some Do's and Don'ts in Water Harvesting

- Encourage traditional system of water harvesting
- Do not go for big structures in case of check dams and the like
- Small is beautiful cheaper and manageable
- Small structures benefits more of the poorer people as they are to be constructed in the upper reaches where these people cultivate
- Do not go for high water demanding crops like rice, sugarcane and wheat

Design Steps for Water Harvesting Tank

While designing, care should be taken that supply must be equal to demand so that the desired result can be obtained. The design of water harvesting tank mainly consists of five steps and they are:

- *Step 01:* Objectives should be clear i.e. why water harvesting
- *Step 02:* How much water to be captured through roof top or runoff from catchment, how much is evaporation, loss in conveyance system etc.
- *Step 03:* Determine collection area: either from roof top or runoff. In general efficiency varies between 70 to 90% depending upon catchment and surface producing runoff.
- *Step 04:* Calculate volume of runoff from rainfall and it varies with respect to season
- *Step 05:* Calculate ultimately demand both indoor for human beings and animals as well as outdoor for crops which also varies with season as mentioned in table 1 & 2 for Rabi and Kharif season
- *Step 06: Channel Side slope:* Channel side slopes are determined by the soil texture and stability.
- *Step 07:* Maintain proper water balance.

CONCLUSION

Water and soil are the basic natural resources for the sustenance of life, protection of environment and for meeting social priorities. Water and soil are fundamental natural resources that play a crucial role in sustaining life, protecting the environment, and addressing various social priorities. These resources are essential for agricultural production, maintaining ecosystems, and supporting human and animal life. However, a range of factors are contributing to the degradation and depletion of these vital resources. One significant issue is soil erosion, which is the process by which the top layer of soil is worn away by natural forces such as wind and water. This erosion reduces the soil's fertility and its ability to support plant life. Additionally, inefficient use of rainfall exacerbates the problem, as water that could nourish the soil instead runs off, leading to further erosion and loss of soil quality.High population pressure is another contributing factor. Increase in population increases demand for land and water resources, leading to overexploitation and unsustainable use. This, in turn, causes further degradation of these resources. Moreover, there is an acute shortage of fodder for livestock, which often results in overgrazing. Overgrazing can strip the land of vegetation, leading to soil compaction and increased susceptibility to erosion. Mismanagement of natural resources also plays a significant role. Poor agricultural practices, deforestation, and inadequate land use planning all contribute to the deterioration of soil and water resources. These practices disrupt the natural balance and reduce the resilience of the land to environmental stresses. All these factors combined result in the depletion of these precious resources, threatening their availability for future generations and jeopardizing the sustainability of life on Earth.Integrated Watershed Management approach is most efficient method for conservation of natural resources. Appropriate techniques for conserving soil and water will only be productive if people are a part of the conservation process. Effective soil and water conservation requires the active involvement of the local community. Their intimate knowledge of the land, combined with their commitment to sustainable practices, can significantly enhance efforts to preserve soil and water resources. A proper plan has to be devised to adopt technologies that ensure soil and water conservation on watershed basis. Use of remote sensing, GIS and other latest technologies are very helpful to plan and execute activities in the watershed area. But these techniques must also address the social, economic and financial problems of the residents.

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