Review Article

Revitalizing Rainfed Agriculture: The Transformative Potential of Watershed Development

ABSTRACT

Out of the 1.5 billion ha (11% of the world's land surface of 13.4 billion ha) of cropland worldwide, 1.20 (80%) billion ha is rainfed and 60 per cent of the world's food comes from rainfed areas. In India, rainfed agriculture occupies about 51 percent of country's net sown area and accounts for nearly 40 percent of the total food production. In HP, over 10% area of the state is under cultivation, of which about 81% is rainfed, facing frequent water scarcity. Watershed development constitutes a holistic strategy aimed at enhancing the resilience and productivity of rainfed farming systems. This approach integrates various interventions targeting soil and water conservation, afforestation, agricultural practices, and socio-economic empowerment of local communities. The essence of watershed development lies in its comprehensive and participatory nature, which addresses the complex interactions among hydrological, ecological, and socio-economic factors influencing rainfed agriculture. Through the implementation of watershed management techniques, such as contour bunding, check dams, and afforestation, soil erosion is minimized, water resources are conserved, and micro-climatic conditions are ameliorated. Concurrently, sustainable agricultural practices including agroforestry, conservation agriculture, and water harvesting techniques are promoted to enhance farm productivity and diversify livelihood options for farmers. Moreover, watershed development programs prioritize community involvement and capacity building, fostering local ownership and empowerment. This abstract elucidates the multifaceted benefits of watershed development in revamping rainfed farming systems, emphasizing its potential to mitigate environmental degradation, enhance agricultural resilience, and improve rural livelihoods.

Keywords: Watershed development, Rainfed farming, Soil and water conservation, Sustainable agriculture, Community participation

INTRODUCTION

Rainfed agriculture plays a vital role in global food production, supporting the livelihoods of millions of smallholder farmers in diverse agro-climatic regions. However, rainfed farming systems are inherently vulnerable to climate variability, soil degradation, and water scarcity, posing significant challenges to agricultural productivity, food security, and rural livelihoods. In response to these challenges, watershed development has emerged as a holistic approach aimed at rejuvenating rainfed farming landscapes through integrated land and water management strategies. Watershed development encompasses a suite of interventions designed to enhance soil moisture conservation, water availability, and ecosystem resilience within a defined geographical area. These interventions range from soil and water conservation measures to afforestation, water harvesting structures, and community-based management initiatives. The primary goal is to optimize the use of available natural resources, minimize environmental degradation, and improve the socio-economic well-being of local communities dependent on rainfed agriculture.

The imperative for watershed development is underscored by the global significance of rainfed agriculture. Approximately 80% of the world's arable land is rainfed, accounting for over 60% of global food production (FAO, 2021). In regions such as sub-Saharan Africa, South Asia, and parts of Latin America, rainfed farming sustains the livelihoods of the majority of the rural population, serving as a crucial source of food, income, and employment. However, the productivity of rainfed agriculture is often constrained by erratic rainfall patterns, soil erosion, and limited access to irrigation water, exacerbating rural poverty and food insecurity. The challenges facing rainfed farming systems are exacerbated by climate change, which is projected to intensify the frequency and severity of extreme weather events such as droughts, floods, and heatwaves (IPCC, 2021). These climatic stressors not only jeopardize crop yields and livelihoods but also undermine the long-term sustainability of agricultural production systems. In this context, watershed development offers a proactive and adaptive approach to building resilience and mitigating the adverse impacts of climate variability on rainfed agriculture.

The rationale for watershed-based interventions is rooted in the hydrological principle that water resources and land use are intrinsically linked within a watershed. A watershed, also known as a catchment or drainage basin, is defined as the area of land where all surface water flows to a common outlet, such as a river, lake, or reservoir. By managing land and water resources at the watershed scale, it is possible to optimize the distribution, utilization, and conservation of water resources, thereby enhancing agricultural productivity and ecosystem sustainability. Evidence from numerous case studies and research initiatives underscores the efficacy of watershed development in revitalizing rainfed farming systems. For instance, in the semi-arid regions of India, watershed management practices such as contour trenching, check dams, and afforestation have led to significant improvements in soil moisture retention, groundwater recharge, and crop yields (IWMI, 2018). Similarly, in the degraded highlands of Ethiopia, integrated watershed management approaches have resulted in enhanced soil fertility, reduced soil erosion, and increased resilience to droughts, benefiting thousands of smallholder farmers (UNEP, 2019).

The success of watershed development initiatives hinges on several key principles, including community participation, stakeholder engagement, and adaptive management. Unlike conventional top-down approaches, watershed management emphasizes the active involvement of local communities, farmers' associations, and civil society organizations in decision-making processes, planning, and implementation. This participatory ethos not only enhances the social acceptability and ownership of interventions but also fosters innovation, knowledge exchange, and collective action at the grassroots level. Furthermore, watershed development promotes synergies between agriculture, water, and environmental management objectives, aligning with the principles of sustainable development and integrated resource management. By adopting a multi-disciplinary and multi-sectoral approach, watershed interventions can address interconnected challenges such as soil erosion, water scarcity, biodiversity loss, and rural poverty in a holistic manner. Moreover, investments in watershed development yield multiple co-benefits beyond agriculture, including improved water quality, ecosystem services, and climate change adaptation.

In summary, watershed development represents a promising approach to revitalize rainfed farming systems by harnessing the potential of integrated land and water management strategies. By optimizing the use of available natural resources, enhancing ecosystem resilience, and empowering local communities, watershed interventions offer a pathway towards sustainable intensification of rainfed agriculture. However, realizing the full potential of watershed development requires concerted efforts, policy support, and investments to address the complex socio-economic, institutional, and environmental dynamics of rainfed farming landscapes.

Dryland agriculture

Dryland agriculture refers to crop production in regions where water availability is limited, relying predominantly on rainfall rather than irrigation. This form of agriculture is practiced in arid and semi-arid areas worldwide, often characterized by low and erratic precipitation patterns. Farmers in dryland regions employ various techniques such as drought-resistant crop varieties, soil conservation measures, and water harvesting systems to mitigate the challenges of water scarcity and maximize agricultural productivity. Dryland agriculture encompasses three distinct categories based on annual rainfall levels:

1. **Dry Farming**: This method involves cultivating crops in regions characterized by annual rainfall below 750 mm. Farmers practicing dry farming rely solely on rainfall for crop irrigation and employ various water conservation techniques to optimize crop yields in arid conditions.
2. **Dryland Farming**: Areas experiencing rainfall levels between 750 mm and 1,150 mm fall under dryland farming. In these regions, farmers utilize both rainfall and supplementary irrigation methods to cultivate crops, adapting their agricultural practices to suit the semi-arid environment.
3. **Rainfed Farming**: Rainfed farming occurs in regions where annual rainfall exceeds 1,150 mm. Farmers in these areas benefit from ample rainfall, allowing them to cultivate crops without the need for additional irrigation. Rainfed farming often occurs in humid climates, where precipitation levels support robust crop growth throughout the year.

Extent of rainfed agriculture

Globally, approximately 80% of cultivated land, out of a total of 1.5 billion hectares, relies on rainfall for crop growth, contributing to 60% of the world's food supply (FAO, 2021). In India, rainfed agriculture occupies 51% of the total cultivated area, providing nearly 40% of the country's food output, with 61% of farmers dependent on rainfed practices (MoA and FW, 2022). In Himachal Pradesh, over 10% of the state's land is cultivated, with 75% of it relying on rainfall, often facing water scarcity issues (https://icar.org.in/node/17266).

Role of rainfed agriculture

Rainfed agriculture encompasses approximately 51% of global agricultural land, making it the predominant form of farming. Despite occupying a significant portion of agricultural land, rainfed systems contribute around 40% of total food production. These systems support roughly 40% of the world's human population, highlighting their crucial role in sustaining livelihoods. Moreover, rainfed agriculture also supports approximately 60% of the global livestock population, indicating its importance in the livestock sector. Rainfed agriculture significantly contributes to the production of various crops and commodities. Approximately 40% of rice, 89% of millets, 88% of pulses, 85% of oilseeds, 69% of cotton, and 64% of cattle are produced under rainfed conditions. This demonstrates the crucial role of rainfed farming systems in meeting the food, fiber, and livestock needs of populations across different regions. Despite challenges such as water scarcity and climate variability, rainfed agriculture remains a cornerstone of agricultural production, supporting millions of smallholder farmers worldwide.

Rainfed agriculture for food security

Agriculture remains indispensable for nourishing and sustaining the expanding global populace. Projections indicate that by 2025 and 2050, India's population may surge to 1.46 billion and 1.81 billion, respectively, constituting 17.5% and 19.0% of the world's populace. Out of the estimated 8 billion global inhabitants, approximately 2.4 billion individuals encounter moderate to severe food insecurity, with an additional 900 million confronting acute food scarcity (UN, 2022).

Problems or constraints for crop production in rainfed areas

Crop production in rainfed areas faces a multitude of challenges stemming from climatic, soil, and resource-related constraints. These constraints significantly impact agricultural productivity and livelihoods, posing obstacles to food security and rural development.

A. Climatic Constraints:

1. Rainfall Characteristics:

i. Variable Rainfall: Rainfed areas often experience erratic and unpredictable rainfall patterns, leading to fluctuations in water availability for crop growth.

ii. Variable Intensity and Distribution: The intensity and distribution of rainfall are inconsistent, resulting in uneven moisture distribution across fields, affecting crop development.

iii. Aberrations in Monsoon: Variations in the onset, duration, and withdrawal of monsoon rains, including delayed onset, early withdrawal, or prolonged dry spells, disrupt planting schedules and crop growth cycles.

2. High Atmospheric Temperature: Elevated temperatures exacerbate water stress on crops, accelerating evaporation rates and reducing soil moisture retention.
3. Low Relative Humidity: Low humidity levels exacerbate moisture stress on crops, particularly during periods of high temperatures and inadequate rainfall.
4. High Atmospheric Water Demand: Intense evapotranspiration due to high temperatures and wind exacerbates water demand, further straining soil moisture availability.

B. Soil Constraints:

1. Inadequate Soil Moisture Availability: Shallow soil depth and low organic matter content limit water-holding capacity, resulting in frequent moisture stress for crops.
2. Poor Soil Fertility: Soil erosion, coupled with inadequate organic matter, leads to nutrient depletion and reduced fertility, compromising crop productivity.
3. Salinity and Alkalinity Problems: Soil salinization and alkalization exacerbate water stress and hinder nutrient uptake by crops, limiting their growth and yield potential.
4. Soil Deterioration due to Erosion: Wind and water erosion degrade soil structure, diminish soil fertility, and reduce crop productivity, particularly on sloping terrain.
5. Soil Crust Problem: Surface crusting impedes seedling emergence, restricts root penetration, and exacerbates surface runoff, further depleting soil moisture.

C. Resource Constraints:

1. Subsistence Level of Farming: Limited access to resources and financial capital constrains farmers' ability to invest in agricultural inputs, modern technologies, and improved practices.
2. Reluctance to Adopt New Technologies: Cultural and socioeconomic factors contribute to farmers' resistance to adopting innovative technologies and practices, impeding productivity enhancements and resilience building.
3. Non-availability of Suitable Varieties and Quality Seeds: Limited availability of drought-tolerant crop varieties and high-quality seeds tailored to rainfed conditions hampers farmers' ability to optimize crop yields and resilience.
4. Lack of Adequate Linkages between Crop and Animal Components: Insufficient integration between crop and livestock production systems limits resource recycling, nutrient cycling, and income diversification, undermining the sustainability and productivity of rainfed farming systems.

Addressing these constraints requires integrated and context-specific approaches encompassing improved water management, soil conservation, technology adoption, capacity building, and policy support. Collaborative efforts involving farmers, researchers, policymakers, and development agencies are essential to enhance the resilience and sustainability of rainfed agriculture, ensuring food security and livelihoods for millions of rural inhabitants.

What is watershed?

A watershed refers to an area of land where rainfall runoff is collected and flows towards a single outlet point, forming a natural drainage system. Essentially, it is an expanse of land delineated by a boundary, directing water flow towards a central location (as illustrated in Fig.1). This geographical unit encompasses all the land that channels water to a common endpoint, often termed a drainage basin or catchment area. The watershed, synonymous with a ridgeline in the U.K., serves as a manageable hydrological entity and constitutes the fundamental unit for development planning.

A catchment area, often referred to as the recharge zone, represents the uppermost section of a watershed where water infiltrates the ground to replenish aquifers and streams. This region serves as the primary source of water input to the entire watershed. Moving downstream, we encounter the command area, also known as the transition zone, where water flow begins to gather and gain momentum. Here, the land facilitates the transfer of water from the catchment area towards larger water bodies. Finally, we arrive at the delta area, or discharge zone, where water exits the watershed, either flowing into larger bodies of water such as rivers or lakes, or being absorbed into the ground. The ridge delineates the highest points of the watershed, forming a boundary along which water either flows into the catchment area or outwards towards the discharge zone. Understanding the dynamics of these zones within a watershed is crucial for effective management and sustainable development of its soil, water, and biomass resources.

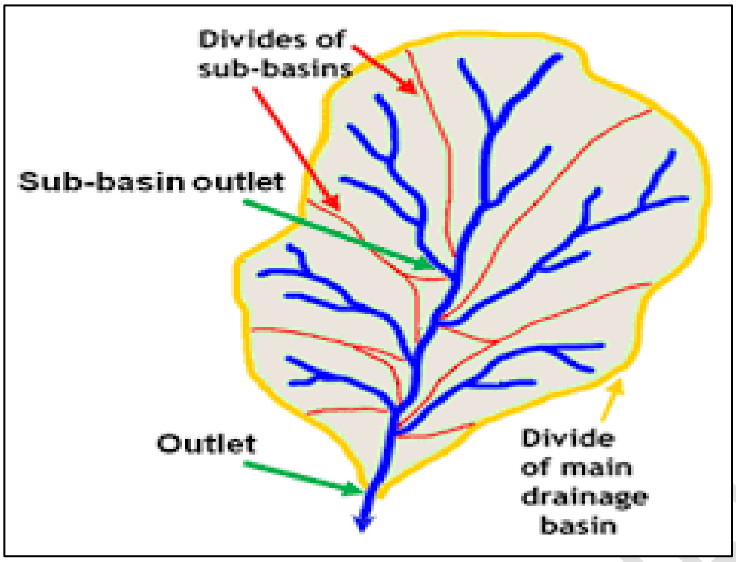


Fig. 1: Diagram of watershed

Why need of watershed?

Watershed management serves as a critical framework for achieving sustainable and holistic development, particularly in regions reliant on rainfed agriculture. The need for watershed management arises from various factors, including the importance of proper rainwater management, the implementation of conservative measures, and the development of water resources, all of which are essential for agricultural sustainability and rural livelihoods. Moreover, government intervention and projects play a pivotal role in catalyzing and sustaining watershed development initiatives.

1. **Framework for Sustainable and Holistic Development**: Watershed management provides a comprehensive framework for addressing the complex interplay between land, water, and socio-economic factors within a specific geographical area. By considering the entire watershed as a unit of management, this approach enables integrated planning and implementation of interventions that enhance agricultural productivity, natural resource conservation, and community well-being. Sustainable watershed management aims to balance ecological integrity, economic viability, and social equity, ensuring the long-term resilience and prosperity of rural communities.
2. **Proper Rainwater Management and Conservative Measures**: Effective watershed management involves adopting measures to optimize the utilization and conservation of rainwater, especially in rainfed agricultural regions where water scarcity is a prevalent challenge. By implementing soil and water conservation practices such as contour bunding,

terracing, and afforestation, watershed managers can mitigate soil erosion, improve soil moisture retention, and enhance groundwater recharge. These conservative measures not only safeguard soil fertility and crop yields but also contribute to ecosystem resilience and water security, thereby supporting sustainable agricultural production systems.

3. **Development of Water Resources**: Watershed management facilitates the development and utilization of water resources in a manner that is ecologically sustainable and socially equitable. This includes the construction of water harvesting structures such as check dams, farm ponds, and percolation tanks to capture and store rainwater for agricultural, domestic, and livestock use. Additionally, watershed-based interventions promote the rehabilitation and restoration of degraded water bodies, wetlands, and riparian zones, enhancing biodiversity, water quality, and ecosystem services. By harnessing the potential of local water resources, watershed development fosters self-reliance and resilience in rural communities, reducing dependence on external sources of water.
4. **Implementation and Intervention of Government Projects**: Government intervention is essential for catalyzing and sustaining watershed development initiatives through policy support, institutional mechanisms, and financial investments. National and regional governments play a key role in formulating and implementing watershed management policies, strategies, and programs that align with broader development objectives such as poverty alleviation, food security, and environmental sustainability. Government-led projects often involve multi-stakeholder collaborations, including government agencies, non-governmental organizations, research institutions, and local communities, to ensure participatory decision-making, resource mobilization, and capacity building. Moreover, government support is crucial for providing technical assistance, infrastructure development, and financial incentives to incentivize farmers' adoption of sustainable land and water management practices within watersheds.

Delineation and classification of watersheds

Precise delineation of watersheds is crucial for hydrological planning and design. In 2018-19, the Soil and Land Use Survey of India compiled a Watershed Atlas, categorizing India into distinct hydrological units. This atlas delineates the country into six major water resource regions, 37 river basins, 117 catchments, and further into 588 sub-catchments and 3,854 watersheds. At a finer scale, it identifies 49,618 sub-watersheds and 3,21,324 micro-watersheds, facilitating both macro and micro-level watershed delineation for effective water resource management and development planning. The techniques adopted by the Soil and Land Use Survey of India have been given in the table 1.

Table 1: Technique adopted by SLUSI for classification of watersheds

S. no.	Category of Hydrological units	Size range
Macro delineation		
1.	Regions	270-1130 lakh ha
2.	Basin	30-300 lakh ha
3.	Catchments	10-50 lakh ha
4.	Sub-catchments	2-10 lakh ha
5.	Watersheds	0.2-1.5 lakh ha
Micro delineation		
6.	Macro-watersheds	>50,000 ha
7.	Sub-watersheds	10,000-50,000 ha
8.	Milli-watersheds	1000-10,000 ha
9.	Micro-watersheds	100-1000 ha
10.	Mini-watersheds	1-100 ha

Watershed management

Watershed management is a systematic approach aimed at the sustainable utilization of soil and water resources within a defined geographical area to foster agricultural productivity while mitigating floods and conserving natural resources. This strategy entails the rational utilization of land and water resources to optimize production while minimizing risks to the environment.

The Government of India has undertaken various watershed management initiatives as part of its developmental programs. Notable among these are the Drought Prone Area Development Programme (DPAP) and the Desert Development Programme (DDP), which embraced the watershed development approach as early as 1987. Additionally, the Integrated Watershed Development Project (IWDP), initiated by the National Wasteland Development Board (NWDB) in 1989, focused on rehabilitating wastelands on a watershed basis. Another significant program, the National Watershed Development Programme for Rainfed Areas (NWDPRA) under the Ministry of Agriculture, targets rainfed regions. The Ministry of Rural

Development under DPAP, DDP, and IWDP provides funding for watershed development schemes.

Watersheds are classified based on their size into micro, small, and large categories. Micro watersheds encompass areas ranging from a few hectares to several hundred hectares and can be delineated within crop fields. Small watersheds cover a few thousand hectares, while large watersheds encompass entire river basins.

Principles of watershed management

Principles guiding watershed management include utilizing land based on its capability, safeguarding fertile topsoil, minimizing silting of reservoirs and fertile lands, maintaining vegetative cover year-round, conserving rainwater in situ, diverting surface runoff safely to storage structures, stabilizing gullies, constructing check dams to enhance groundwater recharge, increasing cropping intensity through intercropping and sequential cropping, adopting alternative land use systems for marginal lands, harvesting water for supplemental irrigation, ensuring ecosystem sustainability, maximizing farm income through diversification into agricultural-related activities, improving infrastructure for storage, transportation, and agricultural marketing, establishing small-scale agro-industries, and enhancing the socio-economic status of farmers.

Objectives of watershed management

Watershed management objectives encompass recognizing watersheds as units for development and land use planning, controlling floods through multipurpose reservoirs and water storage structures, ensuring adequate water supply for domestic, agricultural, and industrial needs, reducing soil pollution, promoting efficient utilization of natural resources to improve agriculture and allied occupations, enhancing socio-economic conditions of local residents, and expanding recreational opportunities.

The POWER acronym encapsulates the objectives of watershed management:

P= - Production of food, fodder, fuel, fruit, fiber, fish, and milk sustainably

- Pollution control

- Prevention of floods

O= - Overexploitation of resources minimized

- Operational practicability ensured

W= - Water storage for various purposes

- Wild animal and indigenous plant conservation

E= - Erosion control

- Ecosystem safety

- Economic stability

- Employment generation

R= - Recharge of groundwater

- Reduction of drought hazards

- Reduction of siltation in multipurpose reservoirs

- Recreation opportunities

Steps in watershed management

The action plan for watershed development involves several steps:

1. Identification and selection of watersheds: Watershed boundaries are delineated through field surveys, marking from the lowest point of water courses to the ridge line, with areas ranging from 100 hectares to 10,000 hectares.
2. Description of watersheds: Basic information is gathered on location, area, shape, slope, climate, soil, vegetation, land capability, land use patterns, cropping systems, farming practices, socio-economic data, and infrastructure.
3. Analysis of problems and identification of solutions.
4. Designing technology components: This includes soil and moisture conservation measures, runoff collection, storage, and recycling, optimal land use and cropping systems, alternative land use systems, livestock development, and groundwater recharge.
5. Preparation of base maps: Maps incorporating geological, hydrological, physiographical, and soil features, along with proposed development measures, are created for each part of the watershed.

6. Cost-benefit analysis: Estimation of costs and benefits associated with various components and activities.
7. Fixing timeframes: Setting start times, project durations, and completion timelines for each activity.
8. Monitoring and evaluation: Continuous assessment of project progress and modification recommendations.
9. On-farm research: Identifying site-specific solutions to problems.
10. Organizational requirements: Establishing watershed development agencies with multidisciplinary staff, providing training to personnel and farmers, facilitating credit, fostering farmer forums or village associations, engaging non-governmental organizations.

Components of watershed management

The main components of watershed management programmes include:

1. Soil and water conservation: Soil and water play an important role in meeting essential needs such as food, fibre and fodder. Soil when exposed to rain and streams are subjected to erosion, which is a major cause for land degradation. Erosion of top fertile soil leads to reduction in crop productivity which adds up to the crop losses due to uncertainty of rainfall in rainfed areas. There are two types of measures which helps to improve the moisture availability in the soil and surface for supplemental irrigation.

   i. Mechanical measures: These measures are provided for improvement of relief, physiography and drainage features of watershed, also known as permanent measures.

      a) Using land according to its capability: It underscores the importance of utilizing land according to its optimal suitability to maximize yields while preventing degradation. The USDA categorizes land into eight capability classes, labeled with Roman numerals I to VIII, based on their inherent limitations. Classes I to IV are deemed suitable for cultivating crops. Classes V to VIII are deemed suitable for alternative land use systems.

      b) Contour bunding and Field bunding: This method entails creating low embankments along the contours of the land, dividing steep slopes into smaller segments. Each embankment serves to slow down the flow of runoff, enabling more water to seep into the soil. This enhances soil moisture levels and mitigates erosion. The dimensions and intervals between embankments are typically determined by factors such as soil composition, slope gradient, and soil depth. It's generally advisable not to employ this technique in areas with slopes exceeding 20%.

c) Bench terracing: In hilly regions, an essential mechanical technique involves transforming steep slopes, typically ranging from 16% to 33%, into a series of steps with flat or nearly flat platforms. This method effectively reduces the gradient of the terrain and promotes even distribution of soil moisture.

d) Stone terracing: These structures, alternatively referred to as stone wall terraces, are essentially modest embankments crafted from stones positioned along the contours of hillsides. They prove particularly suitable for slopes abundant in stones, serving as a practical solution for their utilization.

e) Graded bunding: These structures are designed to safely manage and dispose of excess rainwater. They are typically built in regions with moderate to high levels of rainfall, where the annual precipitation exceeds 600 mm, and in areas with soil that doesn't allow water to penetrate easily. Channels with a gradual slope are created on the upstream side of these structures to guide the water at non-damaging speeds, directing it towards secure discharge points.

f) Wind breaks: Wind breaks serve as barriers that disrupt the flow of wind, thereby diminishing its speed and mitigating both soil and wind erosion. These structures can take the form of hedges, fences, or rows of trees, either living or artificial. By creating a line of defense, wind breaks effectively shield against the damaging effects of strong winds, safeguarding agricultural land and other vulnerable areas from erosion.

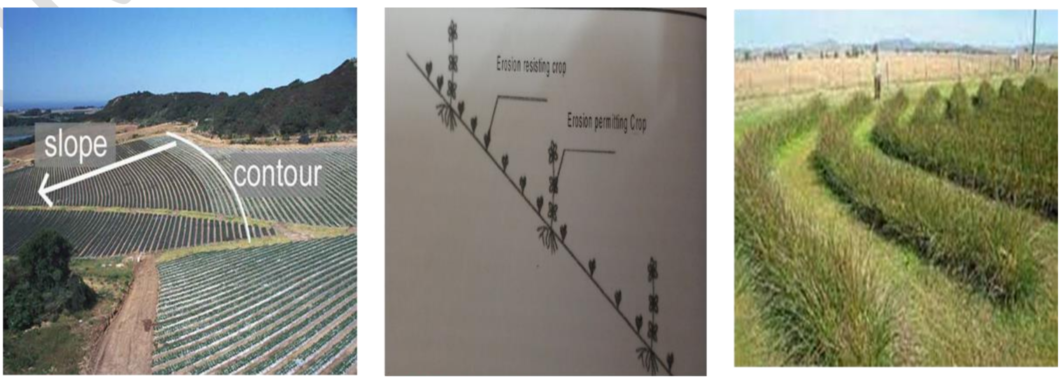
Fig. 2: Mechanical measures for soil and water conservation

ii. Biological measures: Temporary methods for in situ moisture conservation, which involve biological measures, are simplistic and require annual renewal or renovation. These approaches are characterized by their straightforwardness and the need for regular maintenance to sustain effectiveness.

a) Contour cultivation: Contour lines mark points of equal elevation on a landscape. Cultural practices such as ploughing, sowing, and inter-cultivation are executed perpendicular to the slope, aiding in the mitigation of soil and water loss. This method ensures that each ridge formed by furrows and each row of crops serve as barriers to runoff, allowing more time for water to infiltrate the soil, thereby reducing erosion. Ideal for medium slopes, contour cultivation is particularly effective with crops like maize, sorghum, and pearl millet.

b) Strip cropping: The agricultural technique involves cultivating regular crops in narrow, perpendicular strips across the slope of the land. This method entails planting rows of erosion-resistant crops such as cowpea, black gram, and green gram interspersed with erosion-permitting crops like maize, sorghum, and pearl millet, all arranged on contour lines. The primary aim is to mitigate soil loss and runoff by breaking up long slopes. By closely planting erosion-resistant crops, the flow and erosive force of water are impeded, thereby encouraging water retention within the field.

c) Vegetative barriers: In agricultural settings, rows of closely planted grass or shrubs are strategically positioned along the contours of the land to prevent erosion. These rows serve to slow down the velocity of runoff water and effectively trap sediment, acting as barriers against its movement. Among the various plant options, Khus grass (*Vetiveria zyzynoides*) is highly recommended for its effectiveness in this erosion control method.



a.) Contour cultivation   b.) Strip cropping   c.) Vegetative barriers

Fig. 3: Biological measures for soil and water conservation

2. Water harvesting and water management: Despite India's relatively high average annual rainfall of 1194 mm, surpassing the global average, the country often faces water scarcity due to inadequate realization of the value of rainwater. The rainfall pattern in India is characterized by short, intense spells, which lead to rapid runoff, leaving minimal opportunity for groundwater recharge. Consequently, many regions experience scarcity even for basic domestic needs. Effective rainwater harvesting is essential to address this challenge, emphasizing the importance of maximizing the utility of every raindrop received. The necessity for implementing water harvesting techniques underscores the importance of effectively conserving rainfall within a region. This involves the utilization of suitable structures to capture rainwater and runoff, storing it for various purposes either above, below, or on the ground, or recharging it into groundwater reservoirs. Water harvesting encompasses the collection and storage of rainwater or runoff, which can then be utilized for additional irrigation, household needs, and replenishing groundwater sources.

Fig. 4: Structures used for water harvesting

3. Alternate land use systems: An enduring system designed to alter or substitute current land utilization patterns can be described as an alternate land use system. Its primary objective is to produce reliable income with minimal risk through the efficient exploitation of existing resources. In regions reliant on rain for agriculture, where land is scarce, labor abundant but less productive, and resources limited, adopting alternate land use systems that align with the land's capacity presents an optimal solution. Such systems not only facilitate the creation of essential off-season employment opportunities but also enable the harnessing of off-season rainfall that would otherwise be wasted.

i. Agroforestry: An alternate land use system, designed to transform or replace current land utilization practices, aims to generate consistent income with reduced risk by effectively utilizing available resources. Particularly in areas dependent on rainfall for farming, where land is scarce, labour plentiful but less efficient, and resources constrained, adopting such systems tailored to the land's capabilities offers an ideal solution. These approaches not only facilitate the generation of crucial off-season employment but also allow for the harnessing of otherwise unused rainfall during non-agricultural periods.

a) Agri-silviculture: Combining agricultural crops with trees for a symbiotic system.
b) Silvi-pastoral: Incorporating pastureland and/or livestock with tree cultivation.
c) Agri-silvi-pastoral: Creating a holistic system by integrating crops, pasture, and/or livestock with tree cultivation.
d) Agri-horticulture: Uniting agricultural crops with fruit-bearing species for enhanced cultivation.
e) Silvi-horti-pastoral: Intertwining livestock, pastureland, and fruit-bearing species within a tree-based environment.

Fig. 5: Different types of agroforestry systems

ii. Medicinal and aromatic plants: Cultivation high-value, low-volume crops for dyes, medicines, and aromatics proves economically feasible in rainfed regions while also aiding in the rehabilitation of degraded lands. Noteworthy plants for dye production in such areas include Indigo (*Indigofera tinctoria*) and Henna (*Lawsonia innermis*). Additionally, medicinal plants like Ashwagandha (*Withania somnifera*), lemongrass

(*Cymbopogan winki*), palmarosa (*Cymbopogan martini*), and sweet basil (*Ocimum basilium*) play crucial roles in this regard.

iii. Livestock husbandary: Raising livestock is crucial within rainfed agricultural systems. To effectively manage livestock numbers and enhance their productivity, several targeted measures can be implemented:
   - Implementation of dairy farming practices.
   - Encouragement of backyard poultry.
   - Promotion of rabbit husbandry.
   - Cultivation of fodder crops alongside traditional crops as part of mixed farming.
   - Support for sericulture through mulberry cultivation and silkworm rearing.
   - Expansion of fish farming in ponds, lakes, and rice fields.

4. Capacity building: Improving the skills and capacity of individuals or groups to efficiently manage their tasks and guide farmers towards self-sufficiency and sustainability. The primary objective is to strengthen the capacity to assess and manage programs and project implementation methods by comprehensively understanding the strengths, requirements, and perspectives of stakeholders.

Planning of watershed

Effective watershed planning necessitates a comprehensive understanding of the physical landscape, encompassing factors such as geographical features, soil composition and gradient, precipitation patterns, distinctive flora, current land usage, as well as the social and cultural dynamics of local communities alongside pertinent governmental institutions and policies. Such planning demands a seamless integration of both agricultural and non-agricultural regions, involving collaborative efforts among government agencies, research institutions, and the local populace. Local stakeholders, although pivotal, cannot solely undertake watershed planning, necessitating external support in terms of financial resources and technical expertise. A holistic approach to watershed planning is indispensable, requiring active engagement from a spectrum of professionals including agricultural engineers, agronomists, soil scientists, hydraulic engineers, forestry and animal husbandry experts, as well as outreach specialists.

1. Phase 1: Planning phase
   i. Stage 1: Get familiar with watershed
      - Understand people, their interest and institutions

- Determine size, boundaries, soils, rainfall, geography and other features
- Understand the existing farming system and find ways for its diversification
- Identify various ways to use existing resources in the village in a sustainable manner
- Understand how watershed is used at present

ii. Stage 2: Determine priorities for action

- Gather and analyse the data
- Assemble maps and data
- Evaluate water quality
- Assess land use
- Identify and analyse the problems and their causes
- Alternative solutions of these problems
- Identify various other livelihood support used as occupation by people such as handicrafts, iron smiths and tourism

iii. Stage 3: Ensure people's participation

- Identify and contact stakeholders
- Form different groups at village level for implementation of programmes
- Divide work and responsibility
- Identify and manage various differences

2. Phase II: Implementation phase

i. Stage I: Provide assistance

- Provide technical assistance
- Provide financial assistance

ii. Stage II: Ensure implementation

- Proceed with an integrated approach
- Select the best watershed management alternatives
- List various ways and plans for implementation
- Integrate Indigenous Technical Knowledge with Exogenous Technical Knowledge
- Implement the selected alternative
- Identify various methods to measure progress

3. Phase III: Evaluation phase
    - Install a mechanism to monitor and evaluate
    - Prepare a monitoring and evaluation team
    - Visit the area at regular intervals
    - Interact with local leaders to inquire about any problems
    - Ask local authorities to prepare progress report on a regular basis
    - Ensure all factors that sustain watershed and people are properly working

Review of literature

Rashid et al. (2016) evaluated the effectiveness of terrace structure for improvement of crop and soil productivity and reported that significantly higher grain yield, organic matter and soil moisture content was found in the treatment with Recommended rate of fertilizer with terrace structure (RFWS) as compared to all other treatments (RRFWOS: Recommended rate of fertilizer without terrace structure, FPRS: Farmer practice with terrace structure, FPWOS: Farmer practice without terrace structure) as shown in figure 6.

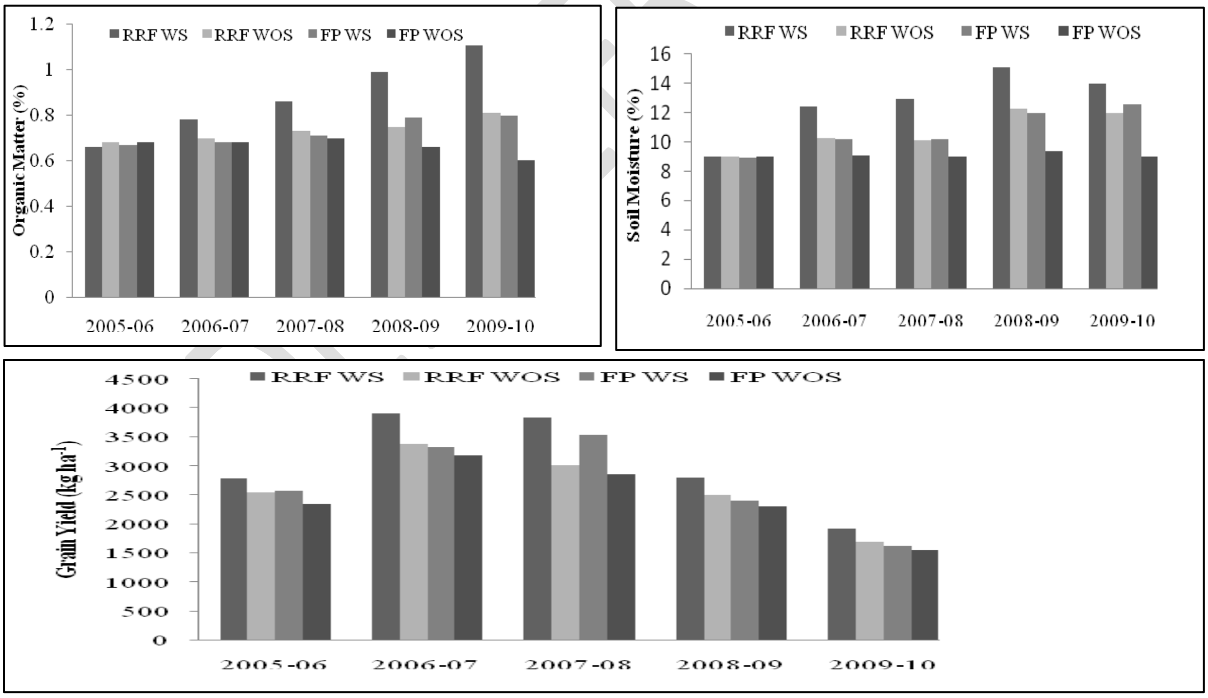


Fig. 6: Effectiveness of terrace structures for improvement of crops and soil productivity (Rashid et al., 2016)

Li et al. (2017) studied the effect of different ridge-to-furrow ratio in ridge-furrow mulching systems for improving water conservation in maize and reported that maize yields were increased by 26.1, 36.4, and 50.3 per cent under RFMS40 (Ridge-furrow mulching system with ridge/furrow ratio of 40:70 cm), RFMS55 (Ratio of 55:55 cm) and RFMS70 (Ratio of 55:55 cm) treatments, respectively than conventional flat planting, Water use efficiency were enhanced by 25.7, 38.7, and 53.9% in RFMS40, RFMS55, and RFMS70, respectively, compared with conventional (table 2).

Table 2: Effect of different ridge-to-furrow ratio in ridge-furrow mulching systems for improving water conservation in maize (Li et al., 2017)

Treatments	**Grain yield (t ha^{-1})**	**WUE (kg ha^{-1} mm^{-1})**
Conventional Flat	8.3 d	19.7 d
RFMS40	10.7 c	25.7 b
RFMS55	11.5 b	27.5 b
RFMS70	12.5 a	30.4 a

Zemadim et al. (2017) studied the impact of contour bunding on runoff, soil erosion and crop yield and found that there was increase of 24% and 49% in cotton and millet yield treated with contour bunding as compared to the no contour bunding (table 3). Also, Runoff rate ranged from 39 to 43% in no contour bunding fields and 24 to 26% in the contour bunding fields.

Table 3: Impact of contour bunding on runoff, soil erosion and crop yield (Zemadim et al., 2017)

Techniques	**Crop species**	
	Cotton (kg ha^{-1})	Millet (kg ha^{-1})
Contour bund(CB)	1998	1322
No contour bunding (NCB)	1617*	890**
*($p<0.05$), **($p<0.01$)		

Fig. 7: (Millet field)

Sudhishri et al. (2008) studied the conservation potential of vegetative barriers for rehabilitation of degraded hill slopes in eastern India and revealed that sambuta and vetiver barriers reduced runoff and soil loss by 63.4 and 68.6%, respectively, over control (table. 4). However, the sambuta barriers resulted in increased yield of finger millet, enhanced organic carbon accumulation in the soil when compared with rest of the conservation measures (table 5).

Table 4: Effect of conservation measures on average run off, average soil loss and average organic carbon loss (Sudhishri et al., 2008)

Treatments	**Avg. Run off %**	**Avg. Soil loss (t/ha)**	**Avg. O.C. loss (kg/ha)**
Stone bund	11.9	5.64	71.33
Hill broom	13.64	6.7	84.82
Vetiver	8.84	4.04	51.52
Sambuta	9.48	4.39	56.0
Control	25.88	13.96	175.12

Table 5: Effect of conservation measures on finger millet yield (Sudhishri et al., 2008)

Treatments	**Average yield (q ha^{-1}) of finger millet**		**% increase in grain yield over control**
	Grain	Straw	
Stone bund	10.87	28.42	60.79
Hill broom	10.21	26.88	52.03
Vetiver	12.26	32.99	80.62
Sambuta	12.31	32.48	82.10
Control	6.76	17.97	

In a recent study led by Mazahreh et al. (2018), an analysis employing Geographic Information Systems (GIS) was conducted to assess the suitability of various Land Utilization Types (LUTs). The results indicated that approximately 89% of the total area under investigation exhibited favorable conditions for rangeland utilization. Furthermore, 55% of the surveyed region demonstrated high potential for irrigation purposes, while 54% was deemed suitable for implementing water harvesting techniques. Moreover, about 70% of the study area was found to be conducive to runoff generation. Additionally, a minor proportion, accounting for 5% of the total area, was identified as suitable for cultivating field crops (table 6). These findings underscore the diverse potential applications of the land and provide valuable insights for informed land management decisions.

Table 6: Potential suitability for different Land Utilization Types (Mazahreh et al., 2018)

Land use	Area (ha)	% area of total geographical area
Rainfed agriculture (Field crops)	100.5	4.8
Irrigation	1156.6	55.0
Rangeland	1871.5	89.0
Runoff	1464.4	69.6
Water harvesting	1130.7	53.8
Not suitable	2.1	0.1

Adgo et al. (2013) studied the Impacts of long-term soil and water conservation on agricultural productivity in Ethiopia and reported that soil and water conservation had improved crop productivity. The average yields, water productivity and net returns on terraced fields for teff, barley and maize were significantly higher than un-terraced fields (table 7 and figure 6).

Table 7: Impacts of long-term soil and water conservation on agricultural productivity (Adgo et al., 2013)

Crop/system	Total rainfall (mm growing season^{-1})	Water productivity (kg mm^{-1})
Teff		
Terraced	933	**1.01**
Un-terraced	933	0.52
Barley		
Terraced	1358	**1.35**
Un-terraced	731	0.86
Maize		
Terraced	1445	**1.21**
Un-terraced	1445	0.56

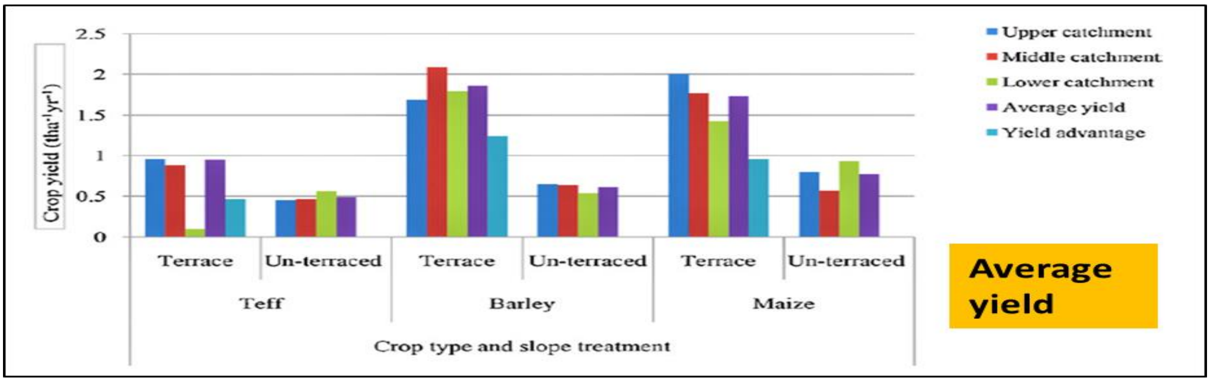


Fig. 7: Effect of terraced and un-terraced system on crop yield (Adgo et al., 2013)

Dass et al. (2009) conducted research on the impact of various agronomic techniques within the Kokriguda watershed, noting a significant expansion in the cultivation areas of various crops. Notably, the acreage dedicated to cash crops saw a remarkable increase from 1.25 hectares to 18 hectares by the project's conclusion. Moreover, the study identified a favorable influence of these agronomic practices on soil fertility. A table accompanying the study illustrates the alterations in organic carbon (OC) and the availability of nitrogen, phosphorus, and potassium (NPK) from the project's outset to its completion (table 8).

Table 8: Soil fertility improvement in the watershed (Dass et al., 2009)

	Pre-projected period	**Post-projected period**
Organic C (%)	0.46	0.48
N (kg/ha)	221.16	236.0
P (kg/ha)	6.86	7.62
K (kg/ha)	295	313.5

Chander et al. (2020) found a notable decrease of 34.6% in runoff and 48.8% in soil loss within the treated watershed zone compared to the untreated region, indicating substantial effectiveness in mitigating environmental impacts. Hedge and Raju (2018) conducted a study examining the impact of watershed management on agricultural practices, particularly the shifting cropping patterns. Their findings revealed a notable increase in the cultivation of commercial crops, pulses, flowers, and fruit crops within the watershed area. Conversely, there was a discernible decrease in the cultivation of cereals, vegetables, and oilseed crops. These findings suggest a significant shift in farming preferences, indicating a transition away from cereals, vegetables, and oilseed crops towards the cultivation of commercial crops, pulses, flowers, and fruit crops among the local population.

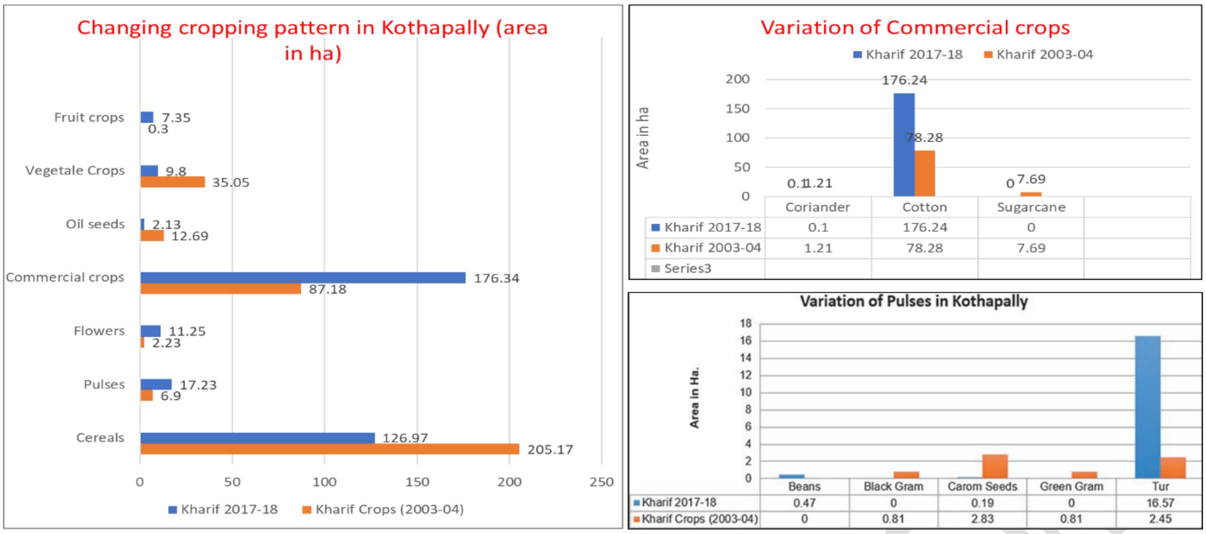


Fig. 8: Changing of cropping pattern due to watershed management (Hedge and Raju, 2018)

In 2013, Pathak et al. conducted a study on the impact of watershed management on land use dynamics. Their findings revealed a notable 66 per cent rise in irrigated land area following the implementation of watershed interventions (table 9). Subsequently, upon the conclusion of the watershed initiative, there was observed an increase in the per capita availability of both food grains and vegetables.

Table 9: Effect of watershed management on the changes in land use pattern (Pathak et al., 2013)

Land use pattern	Before watershed interventions area (ha)	After watershed interventions (ha)	Change (%)
Irrigated	207	343	66
Rainfed	327	209	-36
Pasture	167	114	-32
Horticulture	Nil	35	
Forest	360	360	0
Dwelling & River	294	294	0
Total	1355	1355	

Singh et al. (2008) conducted research on the impact of enhanced land and water management on crop output within the Sujala watersheds of Karnataka. Their findings demonstrated that the implementation of conservation furrows led to notable improvements in maize, soybean, and groundnut yields. Specifically, maize yield saw an increase of 15%, while soybean and groundnut yields experienced enhancements of 20% and 16%, respectively, compared to conventional farming practices employed by local farmers (table 10). These results underscore the effectiveness of adopting conservation furrows in bolstering crop productivity within the studied region.

Table 10: Effect of improved land and water management on crop productivity (Singh et al., 2008)

Sub Watershed Area	Crop	Grain yield (t ha^{-1})		
		Farmers' practice	Conservation furrows	% increase in yield
Haveri	Maize	3.57	4.10	15
Dharwad	Soybean	1.50	1.80	20
Kolar	Groundnut	1.05	1.22	16
Tumkur	Groundnut	1.29	1.49	15

Conclusion

The presence of yield gaps in rainfed agriculture arises from numerous challenges faced by these regions. However, implementing watershed management (WM) emerges as a promising avenue for the comprehensive enhancement of rainfed areas. By employing techniques such as broad bed and furrows (BBF), ridge-furrow mulching, various vegetative barriers, terrace structures, contour bunding, check dams, and farm ponds, water availability can be augmented while minimizing soil erosion. Additionally, strategies like crop diversification, adoption of improved varieties, and alternate land use systems hold potential to elevate farmers' income within rainfed regions. Furthermore, WM serves as a holistic approach to mitigate the adverse impacts of climate change. In essence, through the application of WM practices, rainfed farming stands poised for rejuvenation, ensuring sustainable agricultural development in these vital areas.

Future thrust

In the realm of watershed development aimed at revitalizing rainfed farming, future efforts will concentrate on exploring the adoption of indigenous materials tailored to specific watershed contexts, fostering sustainable resource management through localized technology transfer initiatives, and advocating for value-added solutions to enhance the economic well-being of local communities. Moreover, advancements in modern technology, such as remote sensing, will play a pivotal role in meticulously delineating watershed boundaries over time, facilitating a comprehensive assessment of their condition and guiding the implementation of tailored solutions accordingly.

Literature cited

Adgo E, Teshome A and Mati B. 2013. Impacts of long-term soil and water conservation on agricultural productivity: The case of Anjenie watershed, Ethiopia. *Agricultural Water Management* 117: 55-61

Chander G, Wani SP, Sudi R, Pardhasaradhi G and Pathak P. 2020. Soil management for Sustained and Higher Productivity in the Adarsha Watershed. *Community and Climate Resilience in the Semi-Arid Tropics: A Journey of Innovation* 49-63

Dass A, Sudhishri S, Patnaik US and Lenka NK. 2009. Effect of agronomic management on watershed productivity, impact indices, crop diversification and soil fertility in Eastern Ghats of Orissa. *Journal of Soil Water Conservation* 8(3): 34-42

Li W, Wen X, Han J, Liu Y, Wu W and Liao Y. 2017. Optimum ridge-to-furrow ratio in ridge-furrow mulching systems for improving water conservation in maize (*Zea mays* L.) production. *Environmental Science and Pollution Research* 24: 23168-23179

Mazahreh S, Bsoul M and Hamoor DA. 2019. GIS approach for assessment of land suitability for different land use alternatives in semi-arid environment in Jordan: Case study (Al Gadeer Alabyad-Mafraq). *Information Processing in Agriculture* 6(1): 91-108

Pathak P, Chourasia AK, Wani SP and Sudi R. 2013. Multiple impact of integrated watershed management in low rainfall semi-arid region: A case study from eastern Rajasthan, India. *Journal of Water Resource and Protection* 5(1): 27-36

Rashid M, Alvi S, Kausar R and Akram MI. 2016. The effectiveness of soil and water conservation terrace structures for improvement of crops and soil productivity in rainfed terraced system. *Pakistan Journal of Agricultural Sciences* 53(1)

Singh P, Pathak P, Wani SP and Sahrawat KL. 2009. Integrated watershed management for increasing productivity and water-use efficiency in semi-arid tropical India. *Journal of Crop Improvement* 23(4): 402-429

Sudhishri S, Dass A and Lenka NK. 2008. Efficacy of vegetative barriers for rehabilitation of degraded hill slopes in eastern India. *Soil and tillage research* 99(1): 98-107

Zemadim B, Dembele CO, Dicko M, Traoré K, Samake O and Tabo R. 2017. Evaluating the impact of contour bunding technology on runoff, soil erosion and crop yield in southern Mali.