Watershed Management for Sustainable Development

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***Abstract—* Effective management of watersheds is essential for the conservation of undeveloped areas, including forests, rangelands, and alpine vegetation. It is a fundamental component of rural development and worldwide natural resource management. Watershed management is complex because of the varied and sometimes contradictory requirements imposed on these systems, resulting in an unequal allocation of advantages and disadvantages among many users. Gradually, watershed management strategies have shifted from a predominantly technical emphasis to one that prioritizes social organization and community involvement. Nevertheless, these culturally motivated approaches may not necessarily be readily reproducible in other settings. The objective of this study is to offer a thorough examination of hydrological principles and their implementation in modern engineering methods, with a specific emphasis on watershed management, water harvesting systems, and the design of associated structures.**

***Index Terms-* Watershed, Watershed Management, Catchment.**

I. INTRODUCTION

Land and water are critical natural resources that necessitate careful conservation, preservation, control, and maintenance through advanced engineering practices. A watershed, also known as a drainage basin, is a geographical area that collects and channels precipitation, including rainfall and snowfall, into a single stream or common outlet, such as a reservoir. Watersheds naturally evolve to manage runoff efficiently, incorporating all surface water bodies—such as lakes, streams, reservoirs, and wetlands—as well as groundwater and aquifers within their boundaries.

Precipitation, which accumulates on the surface and within subsurface layers, primarily drives the hydrological dynamics within a watershed. However, not all precipitation leaves the watershed as streamflow; some evaporates and transpires, some infiltrates into the soil, and some human activities consume it. The boundaries of watersheds are defined by drainage divides, typically represented by ridges or hills, which direct water flow into separate watersheds, thus preventing it from converging at a single outlet.

Effective watershed management is a key component of the multi-barrier approach used to ensure the provision of safe drinking water. This approach underscores the importance of protecting both surface and subsurface water supply sources. When studying watersheds, several critical features must be considered:

1. Size: Watersheds vary in scale, and larger watersheds exhibit distinct characteristics due to their capacity to drain more extensive areas.2. Drainage Divide: The watershed boundary, which is often a mountain range or similar topographical feature, plays a critical role in determining the direction of water flow, either towards or away from a specific area.3. Topography: The terrain within a watershed significantly influences hydrological processes. Steep terrain can lead to rapid water movement, increasing the risks of flooding and erosion, while flatter terrain typically results in slower river flows.4. Soil Type: The permeability of soils within a watershed affects water infiltration and runoff dynamics. For instance, sandy soils, which absorb water quickly, contrast with clay soils that are less permeable, thereby impacting erosion rates and groundwater recharge.

Watersheds serve as essential sources of drinking water and provide water for various other uses, including recreation, irrigation, and industrial activities. Additionally, they play a crucial role in supporting biodiversity, as they provide vital resources such as food and water for a wide range of plant and animal species.

This analysis highlights the multifaceted nature of watersheds and underscores the importance of integrating hydrological principles with contemporary engineering practices for effective watershed management. Understanding these dynamics is essential for developing strategies that ensure water resource sustainability and ecological system protection.

1.1 AIM:

This study aims to improve the overall health and sustainability of the watershed by increasing usable water yield, protecting and improving aquatic and terrestrial ecosystems, and safeguarding soil and water resources. This study will achieve this by combining advanced construction techniques, stabilization practices, and educational outreach to minimize erosion. The study also focuses on reducing harmful concentrations of copper, iron, bacteria, and nutrients in the creek to preserve recreational use. Additionally, the study aims to strengthen the vegetative buffer, encourage the educational use of the Wal-Mart wetland mitigation area, and install interpretive signs to promote awareness of watershed health and historical heritage.

1.2 SCOPE OF THE STUDY:

Addressing Natural Disasters: In India, natural conditions such as floods and droughts pose significant challenges. Floods result in rainwater loss, affecting human life and causing severe damage to agricultural fields and crops. Conversely, droughts lead to water scarcity, threatening livelihoods. Watershed management offers a viable solution to mitigate the impacts of both floods and droughts, providing relief to affected communities.

Government Initiatives: To address water scarcity in rural areas, government authorities are increasingly implementing watershed management projects. These initiatives aim to overcome the difficulties faced by villages due to inadequate water sources, thereby improving agricultural productivity and ensuring water security.

Soil and Water Conservation: Crops require both water and fertile soil to thrive. However, drought can degrade soil, runoff can erode it, and heavy rains can lead to flooding, all of which threaten crop viability.

The Adarsha "broad bed furrow" system protects soil and conserves water. This method involves plowing wider than usual plant beds separated by shallow furrows, effectively reducing soil erosion and improving water retention in agricultural fields.

These strategies highlight the critical role of watershed management in addressing future challenges related to water scarcity, soil degradation, and agricultural sustainability.

1.3 OBJECTIVES:

1. Stabilize soil and water flows: Implement strategies to stabilize soil and regulate water flows within the watershed. Ensure long-term protection and effective management of soil and water resources.
2. Minimize downstream impacts: Minimize the adverse effects of upstream activities on downstream areas, including reducing the risk of flooding, sedimentation, and water pollution. Enhance the resilience of downstream communities and ecosystems.
3. Protection of Upland Watershed: Focus on protecting upland areas of the watershed to prevent erosion and reduce the amount of sediment entering water bodies. Implement soil conservation techniques and vegetation management to maintain the integrity of upland areas and reduce sedimentation in lower-lying areas.
4. Develop land use practices: Promote land use practices that improve productivity in upland areas while simultaneously protecting downstream regions from adverse impacts. Encourage sustainable agricultural practices, reforestation, and responsible land management to enhance overall watershed health.
5. View or Delineate Watershed Boundary: It is crucial to precisely identify the watershed's limits, comprehend its sphere of influence, and handle it efficiently. Utilize geographic information systems (GIS) and other tools to map and monitor watershed boundaries for better planning and management.

6. Evaluate past or present initiatives within the watershed: Review and analyze past and ongoing efforts in watershed management to identify successful strategies and areas needing improvement. Build on previous initiatives to create a more comprehensive and effective watershed management plan.
7. Determine the designated uses for the watershed. Identify and prioritize the designated uses of the watershed, such as drinking water supply, agriculture, recreation, and wildlife habitat. Ensure that watershed management practices align with and support these designated uses.
8. Identify Impairments in the Watershed: Conduct thorough assessments to identify existing impairments within the watershed, such as pollution sources, habitat degradation, and hydrological alterations. Focus on addressing these impairments to restore and enhance the watershed's overall health and functionality.
9. Determine the data requirements for the watershed management plan. Identify and collect the necessary data to inform and develop a comprehensive watershed management plan. Ensure that data collection efforts cover critical areas such as water quality, soil conditions, land use patterns, and ecosystem health.

These objectives aim to create a robust framework for effective watershed management, ensuring the protection, restoration, and sustainable use of water and soil resources within the watershed.

II. CLASSIFICATION OF WATERSHED

Watershed classification is essential for understanding and managing water resources effectively. The classification helps in assessing hydrological dynamics, determining management practices, and implementing conservation strategies. This section outlines the classification of watersheds based on their size and area, highlighting the distinctions between different categories and their implications for watershed management.

A. Classification by Size:
1. Micro Watersheds: Micro watersheds are characterized by their very small size, where overland flow is the primary contributor to peak runoff. In these watersheds, the characteristics of channels have minimal impact on the overall flow dynamics. These watersheds typically span from 0 to 10 hectares (ha). Due to their size, micro watersheds often require focused management strategies to control runoff and prevent soil erosion. The influence of channel characteristics is minimal, making overland flow management crucial.

2. Small Watersheds: These are those where overland flow significantly contributes to peak runoff, but channel characteristics have a limited effect on flow dynamics. Small watersheds typically span from 10 to 40 hectares (ha). Management in small watersheds must account for both overland flow and minor channel characteristics. Effective strategies may include vegetation management and runoff control measures to mitigate peak flows and reduce erosion.
3. Large Watersheds: Channel characteristics and basin storage greatly influence peak flows in large watersheds. Overland flow is not the sole determinant of runoff dynamics. Large watersheds, typically larger than 40 hectares (ha), encompass a range of sizes, including mini, sub, and macro watersheds, as well as river basins. The management of large watersheds involves comprehensive strategies that address channel dynamics, basin storage, and overall hydrological patterns. This often includes advanced engineering solutions and large-scale conservation practices.

B. Classification by area the classification of watersheds based on area provides a more granular understanding of their size and management requirements. The categories are as follows:

Table No.2.1. Type of Watersheds:

Sr. No	Type of Watershed	Area Covered
1	Micro Watershed	0 to 10 ha
2	Small Watershed	10 to 40 ha
3	Mini Watershed	40 to 200 ha
4	Sub Watershed	200 to 400 ha
5	Macro Watershed	400 to 1000 ha
6	River basin	above 1000 ha

2.1 Objectives of watershed management:

Watershed management aims to integrate various strategies to ensure the sustainable use of water resources and the protection of ecological systems within a watershed. The primary objectives of watershed management include:

1. Control damaging runoff and degradation: The study aims to lessen the adverse impacts of excessive runoff and environmental deterioration, emphasizing the preservation of soil and water resources. Implement erosion control measures, such as contour plowing, check dams, and vegetative cover, to stabilize soil and manage runoff effectively.
2. Manage and Utilize Runoff Water: To harness and make beneficial use of runoff water for various purposes, enhancing water resource efficiency. Develop and promote water harvesting techniques, such as rainwater collection systems and retention basins, to optimize the utilization of runoff water for irrigation, groundwater recharge, and other uses.
3. Protect, Conserve, and Improve Land for Production: the study aim to protect and improve the land in the watershed to facilitate more effective and long-lasting farming and land utilization methods. Employ sustainable land management practices, such as agroforestry, crop rotation, and conservation tillage, to improve soil health and productivity while conserving natural resources.
4. Protect and enhance water resources: The goal is to safeguard and improve the water resources that originate from the watershed. The goal is to implement measures that prevent pollution, safeguard water quality, and promote the restoration of natural water bodies and riparian zones.
5. Investigate soil erosion and reduce sediment production. The goal is to regulate soil erosion and reduce the influence of sediment production on the watershed, which in turn safeguards water quality and land productivity. Introduce erosion control practices, such as terracing, vegetative buffers, and sediment traps to reduce soil loss and manage sediment transport within the watershed.
6. Rehabilitate deteriorating land: The study aims to restore and rehabilitate lands that have undergone degradation or are facing environmental decline. Initiate land restoration projects, such as reforestation, soil remediation, and the re-establishment of natural vegetation, to improve land condition and ecosystem function.

These objectives aim to promote effective watershed management practices that ensure the sustainable use of resources, protect environmental health, and support community well-being.

III. CASE STUDY

3.1 Location

Vadawali, identified with watershed number WF-30/VIII/2-b, is a village situated in the Bhiwandi Taluka of Thane District, Maharashtra. The village is located approximately 18 kilometers from Bhiwandi and 38 kilometers from Thane, with convenient access to the National Highway 3 (NH-3). The total area of the watershed encompassing Vadawali is 1,115 hectares (ha), of which the village itself occupies 188 hectares. The remaining 927 hectares of the watershed area include lands from neighboring villages.

The watershed is situated at a mean sea level of 58 meters, and the terrain exhibits a gentle slope with a gradient ranging from 4% to 5%. This topographical characteristic influences the hydrological dynamics within the watershed, affecting water flow and soil erosion patterns. Understanding the location and physical attributes of Vadawali is crucial for developing effective watershed management strategies, as it provides insight into the areas water resource distribution and land use characteristics.

3.2 Land use and land cover:

The Vadawali watershed categorizes land use into several distinct types, reflecting the diverse ways in which people utilize and manage the area. Villagers primarily use 426 hectares (ha) of land for agricultural and residential purposes. Forested areas in the watershed span 377.70 ha, contributing to the region's ecological health by providing habitat, reducing soil erosion, and influencing water cycles. Additionally, non-agricultural lands cover 205 hectares, which may include urban development, infrastructure, and other uses unrelated to farming. Competent authorities reserve a substantial portion of the watershed, 4,025 hectares, likely for conservation, protection, or regulated use, ensuring the preservation of critical natural resources and ecological balance. Open areas within the watershed, totaling 305 hectares, are typically characterized by their undeveloped or minimally used state, potentially serving as buffer zones or land with limited immediate human activity. These varied land use types collectively shape the watershed's hydrological and ecological dynamics, underscoring the importance of a comprehensive management approach to balance human needs with environmental conservation.

3.3 TOTAL LAND DISTRIBUTION:

Vadawali village, covering a land area of 188 ha, divides its land distribution into various uses and types. The non-forest area of the village spans 80.4 hectares. Agricultural activities, residential development, and other non-forestry uses likely occupy this portion. The remaining 20.10 hector. The village designates the remaining 20.10 hectares as forest areas, which contribute to its ecological balance and environmental sustainability. ts the proportion of land dedicated to forest conservation compared to other uses, providing a basis for assessing land management and conservation strategies within the village.

3.4 Water sources of village:-

The primary water sources in Vadawali village fall into the following categories:

1. Open Wells: There are five open wells in the village, which serve as a traditional and accessible source of groundwater for a variety of uses, including drinking, irrigation, and domestic activities.
2. Bore Wells: The village has 20 bore wells, which provide a more reliable and deeper source of groundwater compared to open wells. Bore wells are crucial for meeting the water needs of the village, particularly in times of low rainfall or during dry periods.
3. Others: This category includes any additional water sources that may be present in the village, such as surface water bodies, rainwater harvesting systems, or other unconventional sources. Specific details about these sources would provide a comprehensive understanding of the village's water supply system.

These diverse water sources play a vital role in supporting the daily needs of Vadawali's residents and contribute to the overall water resource management within the village.

3.5 POPULATION FORECASTING: -

To project the future population of Vadawali village, the arithmetic increase method is utilized. This method estimates future population based on the current population, the number of decades into the future, and the average increase in population per decade.

Using the arithmetic increase formula:

P_n= P_0+nx

Where:

Po is the current population,

n is the number of decades into the future,

x is the average population increase per decade.

For Vadawali village:

Current Population (Po): 2,855

Number of decades (n): 1

Average increase per decade (x): 100

Substituting these values into the formula:

Pn=2,855+ (1×100)

Pn=2,955

Thus, the forecasted population of Vadawali village for the next decade is 2,955. This forecast helps in planning for future needs in infrastructure, resources, and services.

Table No.3.5.1. Population Forecasting.

Name of village	Population before 10 years	Present population	Population after 10 years
Vadawali	2755	2855	2955

3.6 water requirement of village: -

1)For domestic used: -

Per capita demand in lit/day/head = total yearly water required of the village in lit. x 365 x design population

Water demand = 135 x 365 x 2855

=140.68 x 106 lit

2)Water requirement for cattle: -

Per capita demand is taken as 115 lit/capita/day

Cattle water req. = 115 x 365 x 175

= 7.346 x106 lit

3) Water requirement for crops:-

Adopting duty for vegetables as 700 ha/cu.m

Base period of vegetables as 120 days

Area under cultivation = 1 ha

Q = area under crop (ha) / duty

Q = 1/700

Q = 1.42 x 10-3

Quantity of water requirement = 8.64 x Q x B (base period)

= 14.81 x 106 lit

3.7 Advantages of the case study:

Strong Rapport with Villagers: The project implementation agency has established a positive relationship with the local community, ensuring effective collaboration and support for the project.

Disciplined Service Societies: Well-organized village-level Seva Sanghs contribute to efficient project management and resource utilization.

Well-Treated Stream Courses: Despite some needed repairs, the stream courses have been well managed, supporting water quality and ecological health.

3.8 Challenges Identified in the case study:

1. Steep Slope and Heavy Rains: The watershed is characterized by a steep slope and intense rainfall, resulting in a significant level of soil erosion. This combination, by exacerbating the loss of topsoil and nutrients, adversely affects land productivity and heightens the danger of sedimentation in aquatic bodies. In order to address these issues and avoid more land deterioration, it is crucial to implement adequate erosion control techniques.

2. Intermediate and Acidic Soils: The soils in the watershed exhibit substandard quality and acidity, mostly as a result of insufficient management operations. Insufficient implementation of soil conservation and enhancement measures has led to a decline in soil fertility and productivity. Ensuring soil health by implementing effective management strategies, such as amendments and erosion control, is essential for improving soil quality and increasing agricultural productivity.

3. Lack of Adoption of New Practices: Insufficient extension work and outreach attempts have resulted in a significant resistance to the adoption of new practices. This hesitation impedes the implementation of novel and efficient watershed management approaches. To encourage the adoption of new technologies and practices, it is imperative to enhance extension services and streamline contact with local populations.

4. Erroneous Land Use and Cropping: Inappropriate land use and cropping practices plague the watershed, primarily due to a lack of education and awareness. Suboptimal land utilization and agricultural techniques result in moisture wastage and diminished biomass production. Strengthening education and awareness initiatives is crucial to educate land users on optimal methods and to maximize land and water resources for improved agricultural and ecological results. Tackling these issues necessitates a holistic strategy that integrates soil conservation methods, enhanced extension services, and educational programs to encourage sustainable land and water management practices.

3.9 Solutions :

1. Rainwater Velocity Management: Rainfall Harvesting: Installing rainwater harvesting systems to collect and retain rainfall for future utilization. Implementing this method effectively mitigates surface runoff and facilitates groundwater reserve restoration. Bunds (earth embankments) and boundary cultivation are used to decelerate and sequester rainwater, thereby mitigating erosion and increasing soil moisture. Implementing contour trenching and bunding methods in conjunction with vegetation planting can manage runoff, mitigate soil erosion, and enhance water penetration.

2. Tree Selection: Harnessing Deeper Nutrients: Cultivating trees with extensive root systems that can reach and exploit nutrients from deeper levels of soil, thereby improving soil fertility and stability. Commercial benefits refer to the selection of tree species that provide commercial advantages, such as timber, fruit, or nuts, thereby generating supplementary money for landowners. We should prioritize the selection of trees that can fulfill the specific needs for fuel and feed in the local area, thereby reducing the burden on other land resources and fostering sustainable living.

3. Appropriate Land Use: Implementing a green cover plan to enhance vegetation cover, thereby mitigating soil erosion, preserving moisture, and promoting biodiversity. Enhanced Crop Management: Implementing advanced crop management techniques, such as crop rotation and conservation tillage, to optimize soil health, boost productivity, and maximize water resource utilization.4. Pragmatic Pathways: ensuring that the solutions offered are uncomplicated, comprehensible, replicable, and economically viable. This methodology enables extensive acceptance and

reproducibility in comparable situations. We should adopt a strategy of 50% labor equity in watershed management efforts to ensure community participation and fair distribution of benefits from the implemented improvements. The proposed solutions aim to tackle the recognized problems by utilizing achievable and enduring approaches, thereby improving the overall efficiency of watershed management and making a positive contribution to the management of land and water resources.

IV. RESULT AND DISCUSSION

1. Reduction in Total Arid Land: Initially, the watershed encompassed 30 hectares of arid land, characterized by low moisture content and limited vegetation. Targeted watershed management strategies have effectively reduced this arid land by 18 hectares. Consequently, the current arid land area now stands at 12 hectares. This reduction demonstrates the successful application of soil and water conservation techniques, which have improved soil moisture and mitigated the extent of arid conditions.

2. Expansion of Cultural Command Area: The cultivable command area within the watershed has increased to 910 hectares. Improved land management practices have converted 18 hectares of previously categorized arid land into productive use, contributing to this expansion. The increase in cultivable area underscores the effectiveness of the watershed management interventions in enhancing land productivity and providing more space for agricultural activities. This expansion facilitates better utilization of land resources and contributes to the overall improvement in agricultural output.

3. Groundwater Level Improvement: Before Watershed Management: Prior to the implementation of management practices, the groundwater level was recorded at 15 meters below the surface. This depth made it difficult to access groundwater for agricultural and domestic purposes. After Watershed Management: Post-implementation, the groundwater level has risen substantially to 3 meters below the surface. This significant improvement of 12 meters in groundwater depth reflects the success of watershed management strategies in enhancing groundwater recharge and availability. The increase in groundwater levels indicates that the management practices have effectively bolstered water resources, ensuring a more accessible and sustainable water supply for the community.

In summary, the results highlight the significant impact of watershed management efforts on land and water resources. The reduction in arid land and expansion of cultivable area demonstrate improvements in land use and productivity. The substantial rise in groundwater levels illustrates the successful enhancement of water resource management, ultimately contributing to greater agricultural potential and improved water availability within the watershed.

CONCLUSION

In India, the seasonal variation in rainfall presents both opportunities and challenges for effective water management. Given that constructing large-scale dams is not always feasible, alternative methods for managing rainwater are crucial. Small-scale structures such as loose boulder check dams, farm ponds, small barrages, and bandharas (water harvesting structures) offer practical solutions for capturing and retaining rainwater. These structures play a significant role in enhancing soil moisture, thereby benefiting agricultural activities and other human uses.

This paper has explored the concept of watershed management and its importance in efficiently utilizing rainwater, particularly in regions prone to high water wastage. We can achieve significant benefits for farming, domestic use, and other purposes through proper management practices, such as the construction of small water-harvesting structures.

The study demonstrated that effective watershed management led to an 18-hectare increase in the cultivable command area and a 3-meter improvement in the groundwater table. These outcomes underscore the effectiveness of the management strategies implemented and highlight the potential for similar projects to provide substantial benefits. Therefore, we recommend the practices and approaches outlined in this paper for future watershed management efforts, as they provide viable solutions for improving water resource utilization and supporting sustainable development.

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