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Role of Water Resource Management in Achieving Sustainable Agriculture in Arid and Semi-Arid Zones

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Abstract: Planned management of natural resources with the goal of maximizing their usefulness, efficient use in their original application, reuse, and recycling is known as resource conservation. The goal is to reduce energy consumption and waste at every step, starting with manufacturing and continuing all the way to disposal. Reduce your environmental footprint with the help of a resource conservation system that makes smart use of Earth's natural resources. In dry regions, variability in soil, temperature, and socioeconomic elements is significant, making each place unique; hence, the appropriate selection of technology tailored to individual locales is essential. In order to achieve this goal, there has to be a more effective management of natural resources in order to reduce the environmental impact of the goods throughout their entire lifecycle, from sourcing of raw materials to final disposal. Predominantly agricultural systems can only achieve agricultural development that is ecologically sustainable if they guarantee in protecting, improving, and overseeing their water and land resources while simultaneously improving farmers' productivity, profitability, and prosperity.

Keywords: Water Resource Management, Arid and Semi-Arid Zones, Agriculture, Sustainable

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INTRODUCTION

Approximately 97.5% Salt water makes up the majority of Earth's water resources; it covers 70% of the planet's surface. Surface water and extra freshwater, which all living things may access, make up only 1.2% of the remaining 2.5% of the water type categorized as freshwater. As a result, there is a lack of renewable freshwater resources and an unequal distribution of these resources across different areas. While the world's population is growing at a rate of around 73 million years each year, the extraction of freshwater is increasing at a rate of 64 km^3 per year, having tripled since 1965. Along with being an environmental, social, and economic concern, aridity affects people all around the world. It is a major obstacle to sustainable development, social and economic stability, ecological preservation, and food security on a worldwide scale.

Throughout the 21st century and beyond, they will undoubtedly be the most pressing issues facing humanity. Water resources are influenced by land use changes and climate shifts caused by the burning of fossil fuels, although aridity occurs naturally. The documented example of the Aral Sea's drying up began during the Soviet Union period. The ecological, economic, and social impacts of the Aral Sea's recession are immense and far-reaching increasingly worse.

We believe that A manufacturing approach that is only concerned with financial indicators, including market share and large profits, is a human action that worsens drought. and requires careful consideration.

Such models may provide profits in the short to medium term, but may become detrimental in the long run due to resource depletion. Agriculture entails an intense consumption of input resources, which include soil, water, and plant parts. Contamination of water sources, depletion of aquifers, salinization of land, and deforestation, eventually leading to habitat deterioration on Earth.

LITERATURE REVIEW

Jiang et.al. (2024) Water is a vital an essential component for human survival, economic growth, and social progress; vital for the maintenance of balanced ecosystems and all kinds of life. Water resources are dwindling as a result of factors such as the unceasing growth of populations, economies, and land areas, as well as the enduring effects of climate change. An increasingly complex web of tensions and contradictions is emerging in semi-arid and dry regions around the interdependence of water, energy, food, and ecological security forming or deepening, alongside rising levels of uncertainty and risk. The techniques of water consumption and management are becoming more intricate and critical, necessitating novel and inventive strategies for conservation and prudent usage. Extensive research on the topic of sustainable water resource management has been carried out in prestigious forums, and the topic has been the focus of worldwide study for some time. Using a review technique, this study analyzes relevant articles on water resources management, suggests better ways to manage water resources in a sustainable way, and suggests areas where more research may be beneficial in this domain.

Kinzelbach et.al. (2010) The expanding worldwide population is perpetually increasing strain on water supplies, particularly on dry and semi-dry land Currently implemented management approaches are often unsustainable, resulting in significant water-related issues such as aquifer depletion, the buildup of toxic compounds, water disputes, and economically unfeasible expenditures. This article presents numerous case stories to demonstrate these issues. The northwest Sahara aquifer system exemplifies the repercussions of excessive groundwater extraction. An exemplary upstream–downstream issue is examined via the case of the Okavango Delta. As an additional case study, the Yanqi basin in China is considered. A basin in Yanqi exemplifies how improper irrigation techniques may result in soil salinization and ecological issues downstream. The discussion encompasses potential solutions to these issues as well as the use of numerical modeling in developing long-term plans for management. Common issues in establishing dependable models are identified, along with proposed solutions to solve these challenges. This chapter concludes with a discussion of techniques to bridge the cognitive divide as well as those in charge of making decisions. To manage water resources in a way that doesn't deplete them permanently while also protecting related components like soils and ecosystems is the goal of sustainable water management to provide services, including ecological benefits.

Samanta et.al. (2024) Water is essential to agriculture, functioning as the vital component of global food production systems. Issues like water shortage, intensified by urbanization, population increase, and climate change, highlight the pressing need for creative and sustainable water management strategies, especially within the agricultural sector. Comprehensive strategies for water management are crucial to reduce the harm that climate change will do to water supplies and quality. Sustainable water management is a comprehensive strategy to save water and preserve water quality for future generations. Advanced irrigation technology, agronomic methods for soil moisture preservation, rainfall collecting, and water quality control are tactics that enhance sustainable water management in agricultural ecosystems. Nonetheless, the journey toward attaining sustainable management is fraught with challenges. Numerous technical constraints, the socio-economic status of farmers, insufficient awareness, and policy deficiencies are significant impediments to progress. Nonetheless, several holistic and integrative methodologies are facilitating progress. The future of sustainable water management in agriculture offers potential for improving water security, fostering food sovereignty, and strengthening the robustness and longevity of agricultural systems around the world.

Huo et.al. (2022) Evapotranspiration (ET) is a crucial element Considering the water budget, which is characterized by complex spatiotemporal changes, especially in agricultural areas that rely on irrigation. Much work has to be done to understand how evapotranspiration is affected by various hydrological processes and human activities. The case study site for this research was a typical agricultural irrigation zone with arid weather conditions and shallow groundwater. After regional ET was estimated using the Surface Energy Balance Algorithm for Land (SEBAL) model with Moderate Resolution Imaging Spectroradiometer (MODIS) data, the impact of supplied irrigation water, shallow groundwater, crop planting patterns, and weather conditions on ET was evaluated. The results show that during the last fifteen years, the regional evapotranspiration in Hetao has been steadily declining. Due of the favorable correlation between ET and water input (precipitation and water diversion), it is suggested that reducing water diversion contributes to the reduction of ET, subsequently leading to a decline in groundwater levels. Capillary pressures and root absorption caused the shallow groundwater to rise, compensating for the soil's water deficit to meet crop water demands. Moreover, we assessed the impact of shallow groundwater on regional evapotranspiration and determined Because throughout the era of water-saving irrigation, the contribution from shallow groundwater increased from 5% to 15%. During the crop growth season, a soil water deficit occurred due to the extended drop in irrigation water supply and groundwater levels. Additionally, changes in crop planting patterns significantly reduced evapotranspiration (ET). since a result, shallow groundwater's effect on regional water usage must not be disregarded, since groundwater is critical for the sustainable growth of agriculture in semiarid and dry areas overlooked.

Das et.al. (2019) The arid and semiarid regions of the nation, significantly affected by persistent drought, are under heightened economic and environmental pressure mostly due to water constraint. Owing to the scarcity of surface water, groundwater has become the only sustainable source for water delivery and irrigation in this region. However, it’s very varied presence and potential throughout time and geography need its demarcation, development, conservation, and safeguarding from overexploitation and pollution. Research and practical experiences indicate that integrated water resource management, which includes conjunctive usage and rainwater collecting within watershed development, may guarantee water security and justice. Science and technology have a significant part in water resource management, which is crucial for the region's economic prosperity. This article recounts and examines current initiatives aimed at enhancing and preserving limited water supplies via community involvement in this region.

ARID ZONE CLIMATE

The desert region of India has an area of 38.7 million hectares, with 31.7 million hectares classified as a hot, dry zone and a cold, dry zone covering 7 million hectares. A large chunk of northwestern India

(28.57 Mha) is inside the hot, dry area that extends from 22°30' to 32°05' N and from 68°05' to 75°45' E. Western Rajasthan (19.6 Mha, or 69%), northwestern Gujarat (6.22 Mha, or 21%), and the southwestern portions of Haryana and Punjab (2.75 Mha) are all part of this area. Solar radiation from a clear sky, substantial temperature changes throughout the day and year, unpredictable rainfall both annually and interannually, lengthy dry seasons, and strong winds are the defining characteristics of the climate of India's hot desert zone. Cloud cover is minimal for the most of the year, allowing the incoming radiation to range day, between 15.12 and 26.50 MJ m-2. An annual precipitation of 100–500 mm with a coefficient of variation of 40–80% is possible, say Rao and Singh (1998). Precipitation processes are often initiated by convective clouds, which are characterized by a high level of intensity, a short duration, and a limited geographical coverage. Local topography has a substantial impact on the dispersion of precipitation. It is common to see rainwater evaporate before to reaching the surface because of the flat terrain and lack of topographical variety. The wet season in arid Rajasthan may last anywhere from fifty to eighty days, depending on where you are in the area. Western disturbances cause a little amount of precipitation, around 7-10 percent of the annual total, to fall throughout the winter.

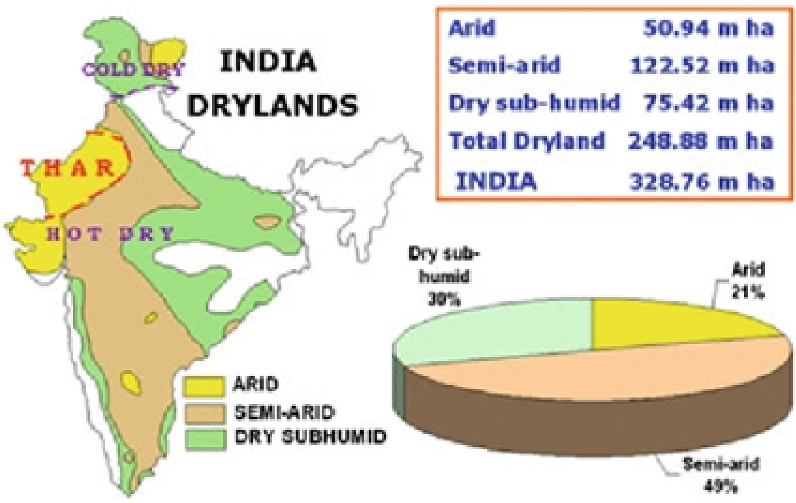

Figure 1: The distribution of India's dry regions

Based on models that predict the distribution of rainfall in Jodhpur over a period of 97 years, 52 years had ordinary to above-average rainfall (ranging from 350 to above 400 mm), suggesting that the area gets significant rainfall around every other year. Approximately 19 years documented precipitation levels ranging from 250 to 350 mm. Suitable agricultural production systems may sustain levels of yield in those years. Only around 250 millimeters fell over the other 26 years of precipitation, indicating the need for particular technologies to address rainfall deficits. Research on the potential for water harvesting in the districts of Nagaur and Jodhpur was found to be highest in their eastern portion's superior capacity for effective water collection to enhance agricultural production. The average excess water in these locations, as determined by water balance studies, was more than 100 mm in Nagaur district and 50 to 100 mm in Jodhpur district.

WATERSHED DEVELOPMENT AND MANAGEMENT

Watershed Developing and managing a drainage system entail using technology while preserving its natural features basin. Water conservation and rainfall collection are most effectively implemented at the watershed level. The watershed, as a hydrological unit, indicates that any efforts to retain rainfall or manage runoff are more effective when implemented on a watershed level.

The principle of Achieving sustainable production without reducing the resource base or causing ecological imbalances should be the goal of watershed development and management, according to "integrated watershed development. The objective is to avert watershed degradation caused by the interplay of physiographic characteristics, eradicate using land in an unscientific manner by means of appropriate cropping patterns; reducing soil erosion; improving and maintaining resource production; raising incomes and living standards in the watershed area (Table 1).

Table 1. Socio-economic impact of watershed management project

Parameters	**Year of survey**		**Increase**
	1983	**1990**	**(%)**
Change of cropping pattern (ha)			
Wheat	83	117	41
Sesamum	9	82	811
Castor	0	9	
Irrigation resources:			
Area under irrigation (ha)	31	112	261
Number of wells	72	110	53
Water lifting device	10	15	50
Recharging of water (ha-m)			
(a). Winter	31.1	112	260
(b). Summer	4.6	45	878
Agricultural income (Rs. in lakhs)	22.83	46.81	105

The following are some strategies for sustainable water management: (i) collecting rainwater in farm ponds and check dams to stabilize drinking water and irrigation wells and increase groundwater recharge; (ii) using water wisely in areas that are irrigated by canals and reducing water loss; (iii) restoring bodies of water; (iv) using drip and sprinkler irrigation, which save a lot of water, more widely; and (v) building community wells to encourage the combined use of surface and groundwater.

WATER CONSERVATION

We may learn a lot about how to save water and store it from our old religious writings and epics that existed throughout that era. Throughout the year, increasing populations, heightened industry, and expanded farmland have escalated the need for water. Initiatives have been undertaken to procure water via a number of countries have attempted water recycling and desalination; others have built reservoirs and dams and dug wells. It is now critical to save water. The concept of groundwater replenishment by rainwater harvesting is becoming more significant in several urban areas.

DRY FARMING

Crop production is poor and yields vary greatly from year to year in dry farming. Even when there is enough rain to grow crops in dry farming zones, how the rain falls affects harvest yields. Erratic rainfall distribution throughout crucial phases significantly impacts yield owing to dry periods. In rainfed regions, not all precipitation is accessible to crops, since a substantial portion is lost as runoff. This creates the opportunity to collect runoff, store it in a pond, and use it for essential irrigation.

The country's annual average rainfall is 1,140 mm, equivalent to around 400 m ha-m. Of this, 180 million hectare-meters are lost by river flow, whereas around 150 million hectare-meters infiltrate the soil. The remaining 70 million hectares-meter is lost due to evaporation. Of the 180 million hectares of runoff, 20 million hectares are used, while the remainder is lost.

Approximately 63% of the total net planted area (142 million hectares) yields approximately 45% of cereals and encompasses nearly 90% of the area dedicated to oilseeds and pulses. Despite reaching the maximum irrigation potential of 113.5 million hectares, over 50 million hectares will continue to be rainfed in 2025.

Gujarat has around 2.5 million hectares of irrigated land, constituting 26% of the total cultivated area. Of this, 80% is watered by wells, 18% by canals, and 2% by other sources, mostly tanks. Consequently, in Gujarat, 74% of agriculture relies on the caprices of weather, compared to 70% at the national level. The issue intensifies due to the unpredictable rainfall characterized by a high coefficient of variation (CV%). All of this underscores the need of effective rainfed water management technologies for this state. Gujarat comprises around 20% of the nation's arid regions and 9% of its semi-arid areas. This region is mostly located in Gujarat, next to Rajasthan. Saurashtra is classified as dry to semi-arid, with a potential evapotranspiration of 1,873 mm, and has low and unpredictable rainfall averaging 761 mm, with a coefficient of variation of 55%.

RAINWATER HARVESTING

Agricultural growth is at a pivotal juncture now. Some challenges to agricultural transformation have emerged in the second generation, despite the fact that the developing world had an agricultural revolution in the first that benefited farmers, consumers, and economies greatly. Issues including unequal access to agricultural development, food security, poverty, diminishing variety, stagnating production in certain crops, leading to an increasing ecological imbalance and the rise of unsustainable agricultural methods. Ironically, many people living in rural regions don't get to reap the advantages of the agricultural revolution because they live in places with poor soil and unpredictable rainfall, which puts them distant from agricultural services and markets.

An on-farm water reservoir can be used for future productive applications, or "water harvesting" can be used to collect and concentrate runoff water from a runoff area into a run-on area. The collected water can then be used in the cropping area or kept in the soil profile for immediate crop use. In addition to its usage for surface water recharge, the collected water has potential use in aquifer storage and groundwater recharge. Typically, rainfall falls below 50% of the area mean and occurs every 3 to 5 years. The groundwater level drops when precipitation is insufficient because changes in the water-table levels are contingent upon precipitation, at which point both surface and groundwater availability becomes crucial. Drought becomes predominant, resulting in challenges in meeting water demand throughout this time. Likewise, in many regions, water scarcity is seen just before to the onset of the rainy season. Both issues may be addressed by the systematic implementation of appropriate soil and moisture conservation techniques on a watershed scale.

Water conservation in agriculture is crucial, since for plants to grow, water is essential. The rising salinity and falling water table caused by the overapplication of chemical fertilizers and pesticides have exacerbated the situation. Diverse techniques for water collecting and recharge have been used globally to address the issue. In regions characterized by poor precipitation and limited water resources, the inhabitants have adopted rudimentary methods tailored to their environment to mitigate water demand.

GROUNDWATER RECHARGE

When circumstances are conducive, recharging groundwater is preferable than constructing surface ponds for storage. This method reduces evaporative losses and often enhances water quality (Table 2). Recharge structures may range from a little pit excavated into the earth to a borewell repurposed for recharge purposes. Recharge structures are beneficial on inclined terrains where water would otherwise lack sufficient time to infiltrate the soil before runoff occurs. The buildings must be situated in relatively low-lying areas to facilitate natural water flow into them. A favourable position is situated behind a check dam, allowing the water to decelerate and facilitating infiltration. Meticulous attention must be devoted to preventing silt and debris from infiltrating the recharge structure; failure to do so will obstruct water penetration. This may be accomplished by constructing smaller pits to facilitate the settling of silt prior to the water entering the actual recharge structure. Utilizing a borewell for recharge, the development of the well (injecting air or water under pressure) will facilitate the loosening of the surrounding soil and enhance permeability. Whenever feasible, open recharge structures should be covered or treated to mitigate mosquito reproduction, using neem juice or fish that consume mosquitoes.

CREATING A FARM POND OR TANK

Deep plowing is used to fracture hardpan and enhance dark soils' physical characteristics. A tractor plough must be used for deep plowing, which must reach a depth of 22 cm. in Vertisols, which will eliminate detrimental weeds and give increased crop production. This may be conducted once every three years (Table 4).

Table 4. Influence of harvesting methods on groundnut production.

Treatment	Pod yield(kg/ha)	Haulm yield(kg/ha)
CT (cultivator + blade harrowing)	862	1,828
Ploughing followed by CT	914	1,913
Tillage through rotavator	852	1,751
CT + subsoiling between rows	902	1,900
CT + broad bed and furrow	1,078	2,035
No tillage	709	1,652
CD (P=0.05)	171	234

CHISEL PLOUGHING

Chisel ploughing is advised at least once every three years to disrupt the hard pan in the subsoil and facilitate the infiltration of rainwater into the subsoil.

Subsoiling: Soil compaction is a prevalent issue in arid agriculture. The presence of hard pan or plow pan in the subsoil might exacerbate the situation by impeding the infiltration and retention of precipitation, as well as hindering root penetration. Non-inversion tillage, such as sub-soiling, decreases bulk density and enhances the penetration of precipitation into the soil, reduces runoff losses, and thus increases moisture retention in the soil profile and root development. This technique involves using a sub-soiler to fracture the dense and impermeable subsoil, hence enhancing soil physical conditions to retain greater amounts of rainwater. This procedure, which avoids soil inversion and enhances moisture infiltration, reduces both runoff and soil erosion. The sub-soiler operates spaced 90–180 cm apart and at a depth of 30–60 cm (Tables 5 and 6).

Table 5. The impact of water-saving methods on groundnut harvest and profit margins

Treatments	Pod yield(t/ha)	Net returns (Rs/ha)
Flat bed	1.423	20.06
Alternate between row sub-soiling	1.545	21.91
Between row sub-soiling	1.740	25.54
In row sub-soiling	1.564	21.81
Broad bed and furrow	1.713	24.83
CD (P=0.05)	0.116	2.30

Table 6. Impact of water-saving techniques on pigeonpea harvest and financial returns

Treatments	Pod yield(t/ha)	Net returns (Rs/ha)
Flat bed	1.233	13.84
Alternate between row sub-soiling	1.286	14.34
Between row sub-soiling	1.318	14.46
In row sub-soiling	1.452	16.88
Broad bed and furrow	1.463	17.06
CD (P=0.05)	0.095	1.70

CONCLUSION

A water management system has to be sustainable in the long run, affordable, and thoughtful to society for it to be a success. A major problem for society, corporations, and National Agricultural Research Systems (NARS) is the hunt for innovative solutions to improve integrated water resource management at large. The limited natural resources of this delicate ecosystem have been put under stress by the rising strain from the population. Arid zones throughout the globe are now being prioritized for food production due to the heavy cultivation of suitable lands. Adopting appropriate watershed management technologies and taking a scientific approach to comprehending the challenges faced by dry regions may go a long way towards fulfilling the aspirations of those living there in the long run. To achieve this, natural resources must be handled more effectively to mitigate the environmental impact of goods, including raw materials, manufacture, distribution, and final disposal. To achieve agricultural development in an environmentally sustainable way while simultaneously increasing farmers' productivity, profitability, and prosperity in an agricultural system, land and water resources must be carefully conserved, developed, and managed.

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