JOURNAL OF
Climate Change Sustainable Development Research

Journal of Climate Change and Sustainable Development Research, 1(2),18-37, 2026
Homepage:https://JCCSD.com

The Role of Integrated Watershed Management in Reducing the Impacts of Drought and Enhancing Sustainable Resilience in Iran

Ehsan Fathi [1*], Mohammadreza Ekhtesasi[2]

Received: 23 July 2026 · **Revised:** 4 September 2026 · **Accepted:** 15 September 2026
Early online: 23 September 2026 · **Published:** 8 October 2026

ABSTRACT

Drought, particularly in arid and semi-arid climates, is a destructive phenomenon with profound hydrological, ecological, economic, and social consequences. The increasing frequency and severity of drought events, driven by natural processes and further intensified by human activities, necessitate a fundamental reassessment of existing management approaches. Integrated watershed management, through its holistic approach to managing water resources, soil, vegetation, and human interactions at the natural watershed scale, has been recognized as one of the most effective strategies for mitigating the impacts of drought. This review was conducted to provide a comprehensive understanding of the role of integrated watershed management in reducing vulnerability and enhancing resilience to drought. First, the key concepts of watershed management and the various dimensions of drought are introduced, followed by a discussion of the mechanisms linking drought to the hydrological characteristics of watersheds. Subsequently, the wide-ranging impacts of drought at different levels are examined, followed by a comprehensive analysis of the strategic role of various watershed management interventions including soil and water conservation, vegetation restoration, surface and groundwater resources management, land-use adaptation, and the strengthening of local community participation in mitigating the impacts of drought. The findings of this review demonstrate that the watershed management approach, with its emphasis on ecosystem-based and community-based strategies, can enhance water storage capacity within watersheds, reduce soil erosion and land degradation, improve the sustainability of agricultural and livestock production, and ultimately strengthen the long-term resilience of coupled human–natural systems against future water scarcity challenges. Accordingly, it is proposed to simultaneously and integratively implement vegetation conservation and restoration measures, small-scale floodwater storage and spreading structures, and management and participatory approaches; prioritize watersheds facing severe groundwater crises and recurrent droughts; and employ remote sensing, Geographic Information Systems (GIS), and hydrological modeling to effectively target and monitor interventions. Furthermore, empowering local communities and establishing economic incentives for active participation of stakeholders should be regarded as one of the key pillars of integrated watershed management.

Keywords:

Resilience, Soil conservation, Sustainable development, Watershed management, Water resources management

[1] *Postdoctoral researcher in Comprehensive Watershed Management, Faculty of Natural Resources and Desert Studies, Yazd University. Yazd. Iran.*
[2] *Professor, Rangeland and Watershed Department, Faculty of Natural Resources and Desertology, Yazd University. Yazd. Iran.*

[*]*Corresponding Author: Email: ef.ehsan2012@gmail.com/ ORCID:*

1. Introduction

Drought is a natural hazard characterized by a slow onset and a creeping nature, occurring in nearly all climatic regions. Over a relatively long period, it exerts substantial impacts on climate, water resources, agriculture, the environment, and even the social and economic sectors of society (Navabi et al., 2021). A deficiency in precipitation relative to the long-term average represents a simple and seemingly harmless definition of drought; however, the dimensions and consequences of this phenomenon are far more extensive and multifaceted. Due to its gradual development, the impacts of drought are often imperceptible in the short term and therefore tend to receive limited attention. Furthermore, the inability to precisely determine its onset and termination, together with the extensive geographical areas it affects, distinguishes drought from other natural hazards (Foroudi Sefat et al., 2025). Owing to its high potential to disrupt ecosystem functioning, its persistence across short- to medium-term timescales, and its widespread spatial impacts, drought is recognized as one of the most complex climatic hazards (Gazol et al., 2025). Drought can reduce river flows, substantially lower groundwater levels in wells and qanats, cause the degradation and desiccation of rangeland and forest vegetation, markedly diminish agricultural production, intensify dust storms and airborne particulate matter, and ultimately lead to the forced migration of rural populations and the expansion of urban marginal settlements. Iran, along with many regions located within the world's arid and semi-arid belt, has been persistently affected by this phenomenon. Moreover, climate projections indicate that both the frequency and severity of drought events are expected to increase in the coming decades.

Drought is a phenomenon that occurs in nearly all climatic regions worldwide. The impacts of this slow-onset and creeping hazard are particularly severe in arid and semi-arid regions due to the low amount and uneven annual distribution of precipitation. Therefore, continuous monitoring and effective management of drought are of paramount importance (Rafiei Sardooi et al., 2026). A watershed is defined as a distinct geographical area in which all precipitation-derived runoff converges toward a common outlet, such as a river, lake, or sea. Watershed management refers to the planning and implementation of a coordinated set of measures for the management of water resources, soil, vegetation cover, and land use within a watershed to achieve sustainable environmental, economic, and social objectives, without compromising one objective at the expense of another. Unfortunately, many traditional drought management policies in Iran and other developing countries have been predominantly reactive, focusing primarily on emergency relief measures, such as water supply by tanker trucks, compensation payments to farmers, and the drilling of new deep groundwater wells. Such an approach not only fails to address the underlying causes of the problem but also often exacerbates the crisis by creating dependency and increasing the exploitation of groundwater resources. In contrast, watershed management provides a proactive and nature-based approach to mitigating drought and its associated impacts. This approach seeks to enhance the watershed's natural hydrological processes by conserving and strengthening its ecological functions, thereby increasing water storage capacity in the soil and groundwater aquifers, reducing evaporation and surface runoff, and ultimately improving the system's resilience to precipitation deficits. The primary objective of this study is to elucidate the specific mechanisms through which effective watershed management can mitigate the severity and impacts of drought. These mechanisms include enhancing groundwater recharge, increasing the soil's water-holding capacity, conserving vegetation cover and controlling soil erosion, reducing the risk of destructive post-drought floods, and ultimately empowering local communities to actively participate in water resources management. A considerable number of studies have investigated drought assessment in Iran (Table 1) as well as in other parts of the world (Table 2).

Integrated watershed management, by taking into account the complex interactions between socio-economic systems and ecosystems, plays a pivotal role in mitigating the impacts of drought and enhancing long-term resilience (Beheim et al., 2012; Qi & Altinakar, 2013). This approach enhances adaptive capacity to water scarcity by conserving and restoring ecosystem health, biodiversity, and productivity, while integrating economic and social needs (Homauonfar et al., 2016). In Iran,

characterized by an arid and semi-arid climate, the uneven spatial distribution of water resources, excessive groundwater extraction, declining vegetation cover, soil erosion, and recurrent floods have made drought one of the most frequent natural hazards, exerting severe impacts on water resources, agricultural production, and the livelihoods of local communities.

Table 1. Studies Conducted on Drought Assessment in Iran

No.	Study	Reference
1	Investigation of the Temporal and Spatial Variations of Meteorological and Hydrological Drought in the Zohreh–Jarahi Watershed	Razavizadeh &) (Dargahian, 2021
2	Assessment of Groundwater Drought Conditions in the Mehran Plain, Ilam, Using the Groundwater Resource Index (GRI)	(Abbasinia et al., 2021)
3	Monitoring Agricultural Drought at the Farm Scale Using Remote Sensing–Based Soil Moisture Microwave Imagery	(Fashaee et al., 2022)
4	Investigation and Assessment of Ecological Risk in the Dried Sediments of the Hoor Al-Azim Wetland	(Namjoofar et al., 2025)
5	Zoning the Severity of Hydrogeological Drought in the Garmsar Plain and Its Relationship with Meteorological Drought	Noori and Malekian,) (2023
6	Regional Analysis of Hydrological Drought in the Halil-Rud Watershed Using the Baseflow Index (BFI)	(Daemi et al., 2024)
7	Implementation of comprehensive watershed management and sediment control approaches in Anzali wetland protection	(Ravanbakhsh et al., 2024)
8	Assessment of Drought-Induced Changes in Tree Density Across Dryland Ecosystems of Southeastern Iran	(Shamshiri et al., 2026)
9	Evaluation of Remote Sensing–Based Indices for Drought Monitoring Using MODIS Imagery in the Bam Plain	(Rafiei Sardooi et al., 2026)
10	Watershed management measures affecting local inhabitants livelihood improvement in the Baghamch Watershed, Chenaran County	(Bidaki, 2025)
11	Assessment of the Applicability of the Groundwater Resource Index (GRI) for Groundwater Drought Monitoring in the Qazvin Plain	Jamshidi & Hashemi,) (2025

Table 2. Studies Conducted on Drought Assessment in Other Countries

No.	Study	Reference
1	Assessment of Drought Characteristics Based on the Standardized Precipitation Index (SPI) in the Huaihe River Basin, China	(Yan- jun et al., 2012)
2	Analysis of the Temporal and Spatial Variability of Hydrological Drought in the Iberian Peninsula, Spain	Lorenzo-Lacruz et al.,) (2013
3	Assessment of Water Level Trends Under Climate Change Using the Modified Mann–Kendall Test and Sen's Slope Estimator in Southern Australia	Le Brocqueet al.,) (2018
4	Impact of Drought on Vegetation Cover Conditions in the Damqu Basin, China	(Zhao et al., 2018)
5	Drought Prediction Using the Composite Evapotranspiration Index in the Ganga River Basin	(Elbeltagi et al., 2021)
6	Integrated watershed management on soil quality, crop productivity and climate change adaptation, dry highland of Northeast Ethiopia	Mekonnen et al.,) (2021
7	Analysis of Drought Trends in Europe Using the SPI and SPEI Indices	(Dukat et al., 2022)
8	Assessment of Hydrological Drought in Africa	(Odongo et al., 2023)
9	Assessment of the Impact of Precipitation on the Aquifer Using the SPI and GRI Indices in the Purulia Region, West Bengal, India	Sarkar & Chinnasamy,) (2023
10	Drought prediction using artificial intelligence models based on climate data and soil moisture	Oyounalsoud et al.,) (2024
11	Drought Prediction in Morocco Using the SPI and SPEI Indices and Machine Learning Algorithms	(En-Nagre et al., 2024)
12	Watershed management, groundwater recharge and drought resilience: An integrated approach to adapt to rainfall variability in northern Ethiopia	Woldearegay et al.,) (2024

Under such conditions, integrated watershed management enhances groundwater recharge, increases soil moisture storage, controls surface runoff, and improves vegetation cover, thereby not only mitigating the severity of drought but also strengthening the long-term resilience of both natural and human systems to prolonged dry periods. Unlike the prevailing fragmented and uncoordinated sectoral policies, this approach integrates environmental, social, and economic dimensions at the watershed scale, thereby providing a foundation for ecosystem restoration, reducing local vulnerability, and achieving sustainable development in the face of drought.

Integrated watershed management, as a holistic and sustainable approach to addressing the growing challenges associated with water and soil resources, has received increasing attention in many countries over recent decades. This approach is founded on the principle of managing natural resources within natural spatial units, namely watersheds, with the objective of achieving a balance between resource utilization and the conservation of natural resources. Watersheds are social–ecological systems (SES) in which humans and other living organisms interact with the physical environment as well as with one another (Cabello et al., 2015; Gari et al., 2018). These hydrological response systems constitute the most appropriate units for water resources assessment, land-use planning, and integrated resource management (Wang et al., 2016). Integrated watershed management considers the interactions among the ecological, social, and economic components of a watershed and seeks to enhance resource productivity while preventing environmental hazards through the active participation of stakeholders, particularly local communities.

Drought is one of the most significant natural hazards, characterized by its gradual, slow-onset nature, and exerts widespread impacts on various dimensions of human life. As an adverse climatic phenomenon, drought directly affects societies by limiting access to water resources and imposes substantial economic, social, and environmental costs (Goddard et al., 2001).

Based on its assessment criteria and associated impacts, drought can be classified into the following categories; meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought. Meteorological drought is defined by a reduction in precipitation relative to the long-term average of a given region and is commonly identified using indices such as the Standardized Precipitation Index (SPI). Hydrological drought occurs when precipitation deficits lead to reductions in surface water resources (e.g., rivers and reservoirs) and groundwater supplies. This type of drought typically develops with a time lag following meteorological drought and has more pronounced impacts on water resources available for human use.

Agricultural drought occurs when soil moisture within the root zone is insufficient to meet crop water requirements, resulting in reduced crop yields or even crop failure. This type of drought is influenced by meteorological drought, soil characteristics, and the water requirements of crops. Finally, socioeconomic drought refers to the economic and social consequences arising from water shortages associated with the other types of drought. These consequences include declines in agricultural and livestock production, unemployment, migration, increased prices of agricultural inputs and products, and social conflicts over water resources. These classifications demonstrate that drought is not a linear or one-dimensional phenomenon; rather, it is a complex, multidimensional process whose various dimensions interact and exert interconnected impacts on one another.

The concept of resilience in the management of environmental and social crises refers to the capacity of a system whether ecological, social, economic, or an integrated social–ecological system to absorb and withstand stresses or disturbances, maintain its essential structure and functions, adapt to changing conditions, learn from past experiences, and, when necessary, reorganize and recover while preserving its core identity.

In the context of drought, resilience encompasses four principal components: resistance (the capacity to withstand adverse impacts without significant damage), absorption (the ability to absorb shocks while maintaining essential functions), adaptation (the capacity to modify behaviors and system structures to reduce vulnerability), and recovery (the ability to restore or even improve system performance following disturbance).

Based on the reviewed literature, drought is a climatic phenomenon with hydrological, agricultural, economic, and social dimensions, whose severity and frequency have increased under the influence of climate change. Studies indicate that drought is not merely a natural hazard; rather, the extent of societal vulnerability to drought also depends on anthropogenic factors and inadequate water resources management. In this context, reactive and exclusively short-term approaches to drought management have proven ineffective, underscoring the necessity of adopting proactive and ecosystem-based adaptation strategies. The literature review emphasizes that integrated watershed management can significantly mitigate the impacts of drought and enhance the long-term resilience of both natural and human systems by improving groundwater recharge, controlling floods, reducing soil erosion, and enhancing vegetation cover. These findings highlight the pivotal role of integrated watershed management as an effective framework for reducing drought vulnerability and achieving sustainable development. The primary objective of this study is to provide a comprehensive and in-depth analysis of the role of integrated watershed management in mitigating the adverse impacts of drought and enhancing long-term resilience in arid and semi-arid regions. To this end, the study first presents the theoretical concepts related to watershed management, drought, and resilience. Subsequently, the major impacts of drought at different levels are evaluated, followed by a detailed examination of the mechanisms through which various watershed management measures contribute to mitigating each of these impacts. Finally, the study concludes by summarizing the key findings and proposing practical strategies to strengthen and more effectively operationalize the integrated watershed management approach within national and regional planning frameworks aimed at enhancing drought adaptation.

2. Data and Methodology

The present study was conducted using a descriptive–analytical approach, based on a review and analysis of the scientific literature. The main objective of this study was to investigate the role of integrated watershed management in mitigating the impacts of drought and enhancing long-term resilience, with emphasis on hydrological, ecological, economic, and social dimensions. In this regard, studies addressing drought, climate change, the impacts of drought on water resources and ecosystems, as well as studies focusing on watershed management and strategies for drought adaptation and impact mitigation, were reviewed.

To identify relevant sources, a comprehensive search of the scientific literature was conducted in national databases, including the Islamic World Science Citation Center (ISC), the Scientific Information Database (SID), and specialized scientific journal databases, as well as international databases, including Web of Science, Scopus, ScienceDirect, and Google Scholar, without any restriction on publication year. The search was conducted using Persian keywords and their English equivalents, including drought, climate change, watershed management, integrated watershed management, watershed conservation, drought resilience, soil and water conservation, aquifer recharge, water resources management, runoff control, floodwater spreading, and vegetation restoration. Furthermore, to broaden the search coverage, various combinations of keywords were used with the Boolean operators AND and OR.

The identified studies were screened based on their titles, abstracts, and, where necessary, the full texts. The primary criterion for selecting the sources was their relevance to the objectives and main themes of the study. Accordingly, studies that examined the nature, trends, severity, and impacts of drought; the effects of climate change on drought and water resources; or the role of watershed management in reducing vulnerability and enhancing resilience to drought were included in the review, provided that they contained relevant information. Studies addressing water and soil resources management, aquifer recharge, runoff and flood control, vegetation conservation and restoration, land use management, improvements in water-use efficiency, and local community participation were also reviewed when their relevance to drought impact mitigation or adaptation to climate change could be established. Duplicate sources, as well as studies that lacked a meaningful connection to the objectives and main themes of the research or did not provide sufficient information for analysis, were excluded from the final review.

Following the screening of the sources, relevant information on the type and characteristics of drought, its hydrological, ecological, economic, and social impacts, the characteristics of the watershed, and the types of management interventions and their effects was extracted and categorized. The findings of the selected studies were then comparatively analyzed using a descriptive–analytical approach and synthesized around the main themes of the research, including soil and water conservation, enhanced infiltration and aquifer recharge, runoff and flood management, vegetation conservation and restoration, water and soil resources management, climate change adaptation, and local community participation. In this process, studies focusing on drought and climate change were primarily used to characterize the context, trends, and impacts of drought, whereas studies related to watershed management were used to examine strategies for mitigating drought impacts and enhancing resilience. Finally, the available evidence from both domestic and international studies was synthesized to identify the key mechanisms, management interventions, and conditions required for the effectiveness of integrated watershed management in addressing drought. To provide an overview of the diversity and breadth of the scientific literature used in this study, examples of national and international journals in which the reviewed studies were published are presented in Table 3.

Table 3. Examples of journals used in the present study

No.	Journal Type	Names of the Journals Used
1	Domestic Journals	Iranian Water Research Journal, Physical Geography Quarterly, Water and Soil Management and Modelling, Watershed Engineering and Management, Journal of Range and Watershed Managment, Agricultural Extension and Education Research, Journal of Watershed Management Research, Journal of Water and Soil, Journal of Environmental Management, Journal of Environmental Research and Technology, Iran Nature and ….
2	International Journals	*Journal of Hydrology*, Ecology and Society, *Nature Communications, Nature*, *Meteorology and Atmospheric Physics*, *Water, Groundwater for Sustainable Development*, *Environmental Science and Pollution Research*, Global Change Biology, Water Science, *Agricultural Systems*, *International Soil and Water Conservation Research* and …

3. Results

Integrated watershed management, as an integrated and ecosystem-based approach, has a high potential to reduce the adverse impacts of drought and enhance sustainable resilience in arid and semi-arid regions. The findings obtained from the literature reviewed in this study clearly indicate that the effectiveness of watershed management is achieved through several major pathways, each of which contributes, in different ways, to improving hydrological, ecological, and socioeconomic indicators. The most important of these mechanisms are discussed in detail below.

3.1. Impacts of Drought at the Watershed Scale

Drought, as an anomalous and hazardous phenomenon, exerts substantial adverse impacts on water resources, agriculture, economic sectors, and the environment (Ali et al., 2021; Jahangir et al., 2022; Farhadinejad et al., 2024). At the watershed scale, drought gives rise to a wide range of impacts that can be broadly classified into four main categories:

Hydrological Impacts

Decline in surface water resources: Reduced precipitation leads to decreased inflows to rivers, reservoirs, and other surface water bodies.

In many watersheds, baseflow which is primarily sustained by groundwater discharge—also declines, and in severe cases, this may lead to the complete drying of streams and rivers during the warm season or prolonged periods of drought.

Decline in groundwater levels: Reduced infiltration of water into aquifers, coupled with increased groundwater extraction from wells to compensate for surface water shortages, results in a significant

decline in groundwater levels. This phenomenon can lead to the drying up of wells, qanats, and springs, land subsidence, and, in coastal regions, the intrusion of saline water into coastal aquifers.
Deterioration of water quality: The concentration of pollutants in reduced water volumes (due to decreased streamflow and increased evaporation), elevated water salinity (particularly in groundwater), and higher water temperatures (which reduce dissolved oxygen concentrations) are among the principal water quality impacts of drought.
Increased erosion and sedimentation: During the post-drought period, the first intense rainfall events can trigger severe soil erosion, as the dry and degraded soil becomes highly susceptible to erosion. These sediments reduce the storage capacity of reservoirs and check dams and adversely affect aquatic ecosystems. The findings of Wada et al. (2013) in their study of hydrological drought worldwide showed that water consumption is one of the most important mechanisms intensifying hydrological drought and will remain a major factor affecting the severity and frequency of drought in the coming decades (Wada et al., 2013).

Ecological and Environmental Impacts

Degradation of vegetation cover: Soil moisture and water shortages limit plant growth, leading to the deterioration of rangeland and forest vegetation, reduced forage production, and increased susceptibility to wildfires. This degradation, in turn, creates a vicious cycle that further intensifies soil erosion and desertification.
Loss of biodiversity: Drought and habitat degradation threaten many plant and animal species, particularly those that are highly dependent on water resources (such as aquatic species and migratory birds).
Increased desertification and dust storms: Wind and water erosion of exposed soils leads to the expansion of desertification and an increase in the occurrence of dust events (sand and dust storms), which affect air quality, human health, and the agricultural sector.
Soil erosion and land degradation: Drought, particularly when combined with strong winds and intense rainfall, intensifies erosion processes and can lead to the permanent degradation of land quality and a decline in its productive capacity. Drought is one of the most important climatic hazards that has significant effects on the growth, productivity, structure, composition, and functioning of plant ecosystems and can lead to a decline in the quantity and quality of vegetation cover (Xiao et al., 2023).

Economic Impacts

Reduced agricultural and livestock production: Water shortages for irrigation, insufficient soil moisture, and reductions in the quality and quantity of forage directly have negative impacts on the productivity of agricultural crops, horticultural crops, and livestock. This leads to a reduction in the income of farmers and livestock producers.
Decline in water-related revenues: Watersheds whose economies depend on water resources (such as water-based tourism and fish farming) experience a decline in revenues during periods of drought.
Increased crisis management costs: Governments and communities incur substantial costs to provide emergency water supplies, compensate farmers for their losses, and implement long-term drought adaptation projects.
Impacts on industry and energy: Water shortages can disrupt water-dependent industrial production as well as electricity generation from hydropower plants.

Social Impacts

Migration and population displacement: Reduced employment and income opportunities in the agricultural and livestock sectors, particularly in rural areas, can lead to widespread migration to urban areas and exacerbate urban challenges.
Increased poverty and inequality: Drought disproportionately affects the more vulnerable segments of society and can exacerbate economic and social inequalities.

Social and political tensions: Competition over limited water resources, particularly among different water-use sectors (agriculture, industry, and domestic use) or between upstream and downstream regions, can lead to increased tensions and, in severe cases, social conflicts.
Impacts on public health: Shortages of safe drinking water, poor air quality (caused by dust), and stress resulting from the economic crisis can all have negative effects on the physical and mental health of the population.

3.2. Watershed Management Measures for Drought Mitigation

Watershed management, through the implementation of a set of technical, biological, and managerial interventions, helps mitigate the impacts of drought at different levels. These measures can be classified into the following main categories:

Technical and Engineering Measures (Watershed Management Structures)

These measures are implemented with the aim of controlling hydrological processes and conserving water and soil resources:
Sediment control and groundwater recharge structures: Construction of small storage dams, earthen check dams, gabion structures, stone–masonry check dams, and contour pits in waterways and ephemeral streams. These structures reduce the flow velocity of water, thereby enhancing its infiltration into the soil and promoting groundwater recharge, while preventing the transport of large volumes of sediment to downstream areas.
Terracing and bench terracing: The implementation of these structures in sloping areas, by creating level surfaces, reduces the velocity of surface runoff, enhances water infiltration into the soil, and prevents surface erosion. Bench terraces (such as semi-circular or strip bench terraces) are particularly effective for implementing vegetation restoration projects in arid and semi-arid regions.
Flood spreading: Implementation of channels and diversion structures to direct seasonal floodwaters to broader areas of the plain in order to increase soil moisture and promote artificial groundwater recharge. This method is particularly applicable in areas prone to wind erosion and deficient in soil moisture.
Protection of riverbanks and stream channels: Implementation of stabilization structures along riverbanks and water bodies to prevent bank erosion and shoreline retreat, which becomes increasingly important under conditions of water scarcity and increased evaporation.

Biological Measures and Vegetation Restoration

Vegetation plays a vital role in regulating the water cycle, reducing erosion, and conserving biodiversity. Measures in this regard include:

- Rangeland restoration: Rangeland restoration: Implementation of management programs, including grazing exclusion (restriction or prohibition of livestock grazing during specified periods), grazing capacity control, seed broadcasting, and planting drought-resistant rangeland species. These measures lead to increased vegetation cover, improved soil structure, enhanced soil infiltration, and reduced erosion.
- Afforestation and forest restoration: Planting tree and shrub species adapted to the local climate, particularly in the upstream areas of the watershed, helps stabilize the soil, reduce wind velocity, enhance water infiltration, and improve microclimatic conditions.
- Cultivation and development of medicinal and industrial plants: Replacing or supplementing traditional crops with plant species that require less water or possess higher economic value can reduce pressure on water resources while contributing to the diversification of farmers' livelihoods.
- Crop residue management: Leaving crop residues on the soil surface after harvest helps conserve soil moisture, prevent erosion, and improve soil structure.

Water and Soil Resources Management:

This category of measures focuses on the sustainable and efficient use of water and soil resources:
Improving irrigation efficiency: Upgrading irrigation systems from traditional, water-intensive methods to modern, water-efficient techniques (such as drip, tape, and sprinkler irrigation) can substantially reduce water consumption.
Integrated groundwater resources management: Determining permissible groundwater abstraction rates, controlling the drilling of unauthorized wells, preventing excessive declines in groundwater table levels, and, where feasible, implementing artificial groundwater recharge projects.
Agricultural land management: Implementing conservation agriculture practices, crop rotation, reduced tillage, and the application of organic fertilizers to improve soil quality and enhance its moisture retention capacity.
Runoff and flood management: In addition to water storage structures, the use of distributed water management practices to capture, distribute, and promote the infiltration of rainfall at or near the point where it falls, such as terracing, contour farming (contour strip cropping), and similar measures.
Wastewater treatment and reuse: Where wastewater resources (municipal or industrial) are available, treating and reusing them for non-potable purposes (such as agriculture or landscape irrigation) can reduce pressure on freshwater resources.

Socioeconomic Management and Stakeholder Participation
Livelihood diversification: Supporting the development of non-agricultural economic activities in rural areas (such as handicrafts, rural tourism, and service-based businesses) can reduce household dependence on water resources for their livelihoods.
Education and extension: Conducting educational and extension programs for farmers, livestock breeders, and local communities on the sustainable management of water and soil resources, drought-adaptive practices, and the importance of watershed management measures.
Community participation: Establishing and strengthening community-based organizations (such as water user associations, production cooperatives, and village councils) to actively participate in the planning, decision-making, implementation, and maintenance of watershed management projects. This enhances stakeholders' sense of ownership and responsibility.
Insurance and financial support: Establishing mechanisms to provide insurance coverage for agricultural and livestock production against drought and facilitating access to financial credit for the adoption and implementation of modern management practices.
The conceptual model presented in Figure 1 illustrates the four main pathways through which watershed management contributes to drought resilience. The first pathway (technical and engineering measures) includes structures such as gabion check dams, flood spreading systems, and terracing, which primarily enhance groundwater recharge by reducing runoff velocity and increasing the opportunity time for water infiltration. The second pathway (biological measures and vegetation restoration) enhances rangeland canopy cover and reduces soil erosion through grazing exclusion, afforestation, and the cultivation of drought-tolerant plant species.
The third pathway (water and soil resources management) focuses on improving irrigation efficiency, implementing artificial groundwater recharge, and promoting conservation agriculture, thereby enhancing the sustainable use and productivity of water and soil resources. The fourth pathway (socioeconomic management and stakeholder participation) enhances the adaptive capacity of local communities through livelihood diversification, education, and insurance support mechanisms. What is particularly important in this model is the synergy among these four pathways. For example, without the participation of local communities (the fourth pathway), technical and engineering measures (the first pathway) may be subject to damage or inadequate maintenance. Ultimately, the convergence of these four pathways within the framework of sustainable resilience indicates that successful drought management requires an integrated and balanced approach that combines structural, non-structural, and social interventions.

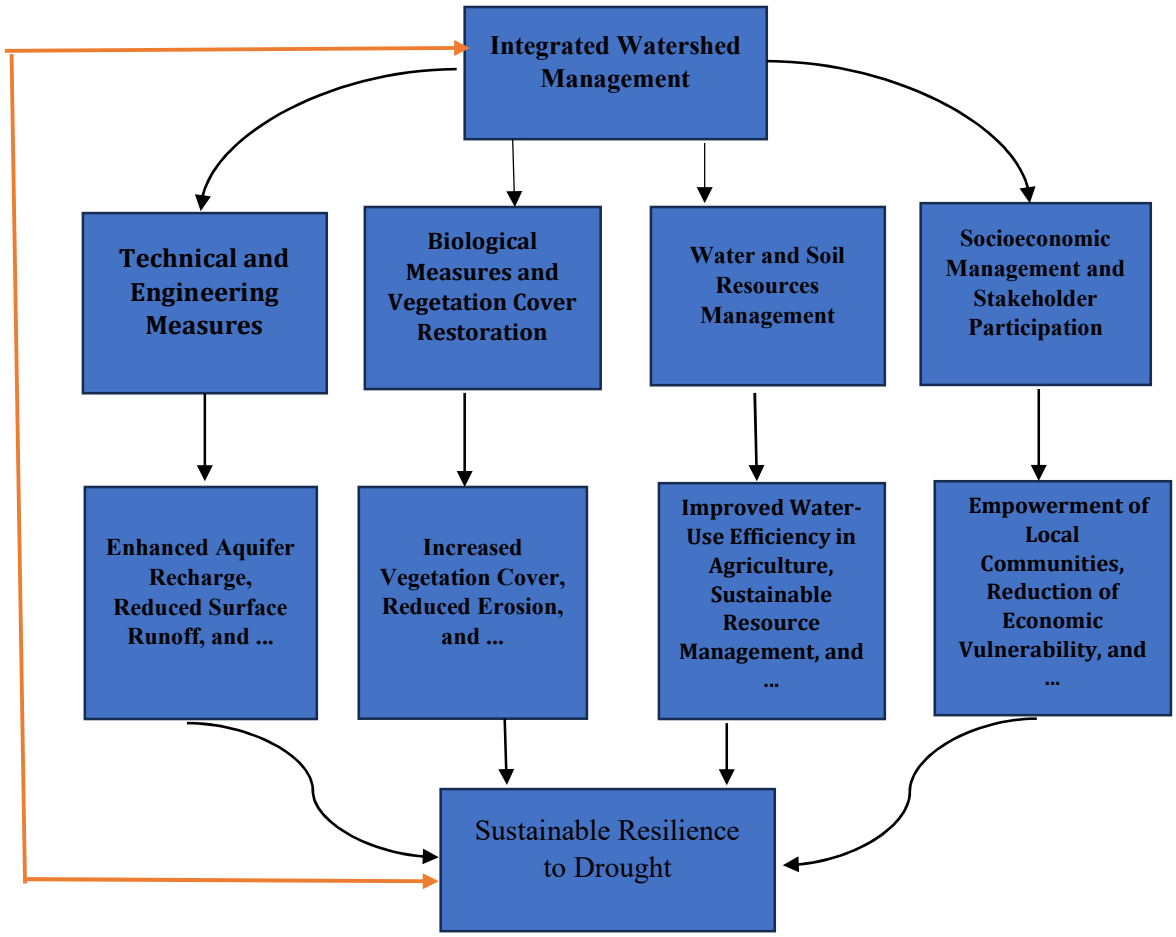


Figure 1. Conceptual model of the mechanisms of the effect of integrated watershed management on reducing the impacts of drought and enhancing sustainable resilience.

3.3. Groundwater Recharge and Storage

The first, and perhaps the most fundamental, mechanism is the enhancement of natural and artificial groundwater recharge. In recent decades, the expansion of agriculture and population growth have led to declining groundwater levels across most plains of Iran (Abbasi Jondani et al., 2016). In regions characterized by arid climates and low precipitation, groundwater constitutes the primary source of water supply for a wide range of socioeconomic activities (Abiye et al., 2018). Under normal conditions, a substantial proportion of precipitation infiltrates into the soil, thereby recharging groundwater aquifers. However, in degraded watersheds lacking adequate vegetation cover and characterized by compacted soils resulting from overgrazing and eroded drainage channels, more than 70% of the precipitation is rapidly lost as surface runoff leaving the watershed, while a considerable proportion is also lost through evaporation. Numerous studies have shown that the construction of small earthen and gabion (wire-mesh rock) check dams in second- and third-order drainage channels reduces flow velocity and increases the time of concentration. By temporarily storing water upstream, these structures provide sufficient time for infiltration into the deeper soil layers, thereby enhancing groundwater recharge. Soleimanpour et al., in their study on the analysis of groundwater drought conditions in the Daranjir watershed, proposed that, in order to cope with this natural phenomenon, both short-term and long-term programs should be

implemented through measures such as expanding the cultivation area of greenhouse crops, using drought-resistant cultivars with high water-use efficiency, developing pressurized irrigation systems to replace traditional irrigation systems in orchards and agricultural fields, and implementing projects effective in increasing the storage of groundwater and surface water resources for irrigation, including masonry check dams, earthen dams, and flood-spreading systems in the study area (Soleimanpour et al., 2024).

3.4. Vegetation Conservation and Desertification Prevention

The second key mechanism is the conservation of natural vegetation cover and the prevention of desertification. Severe climate change profoundly affects the composition, structure, and functioning of ecosystems and alters vegetation cover (Frank et al., 2015; Greve et al., 2017). Drought, as a particular type of extreme climatic condition, can occur periodically yet extensively, leading to reduced plant productivity, increased tree mortality, declining agricultural yields, and famine, ultimately resulting in ecosystem degradation (Ciais et al., 2005; Zhao et al., 2010; Van der Molen et al., 2011; Anderegg et al., 2015; Schwalm et al., 2017). Drought itself weakens vegetation cover; however, when combined with anthropogenic pressures such as overgrazing, tree cutting, and deliberate wildfires, the land rapidly becomes denuded and highly susceptible to both wind and water erosion. Such lands lose their capacity to recover to their original condition after the drought has ended, and the process of desertification occurs in an irreversible manner. Participatory watershed management prevents this destructive process by determining the carrying capacity for grazing, implementing seasonal grazing exclusion (exclosure), and restoring degraded habitats through the planting of native and drought-resistant species. This phenomenon can influence regional-scale carbon sequestration capacity through its effects on vegetation growth and ecosystem processes (Liu et al., 2023). Recent studies have demonstrated that increasing drought frequency and severity, particularly the occurrence of rapid-onset and extreme droughts, lead to reductions in vegetation cover and delays in vegetation recovery across many ecosystems (Chai et al., 2025), reduce vegetation resistance and increase its sensitivity in different regions (Tang et al., 2024), and further indicate that vegetation responses to drought may exhibit a time lag, with significant impacts on ecosystem functioning occurring not only during drought events but also throughout the post-drought recovery period (Muthuvel & Qin, 2025). Studies conducted in the forest ecosystems of northern Iran have shown that one hectare of natural forest can retain up to 500 cubic meters more rainfall than one hectare of abandoned agricultural land. Therefore, conserving upstream vegetation cover constitutes a direct investment in mitigating the impacts of drought in downstream areas.

3.5. Post-Drought Flood Control

The third mechanism, which is often given less attention, is the control of destructive floods following the end of drought periods. A relatively common climatic paradox is that prolonged droughts are often terminated by short-duration, high-intensity rainfall events (torrential rainfall). Under such conditions, the dry and cracked soil initially has little capacity to absorb water; an impermeable surface crust forms, and nearly all the rainfall is converted into surface runoff. The result is a devastating flood that not only causes substantial human and economic losses but also rapidly exits the watershed, thereby playing no role in compensating for the depletion of reservoirs and groundwater aquifers. In contrast, a properly managed watershed functions in the opposite manner: sediment-retention structures, masonry check dams, and gabion structures constructed within drainage channels reduce flood-flow velocity; terraces and contour furrows distribute water across hillslopes; and subsurface dams (underground structures constructed within riverbeds) store baseflow and prevent the rapid outflow of water. As a result, floods are transformed from a natural hazard into an opportunity for groundwater recharge. A representative example of this mechanism can be observed in the Garbayegan Flood Spreading Watershed in Fasa. Following several consecutive years of drought, an intense rainfall event occurred within a single day, causing severe damage to houses and livestock in the surrounding areas. However, within the flood-spreading and watershed-managed area, a large proportion of the floodwater infiltrated into the soil, resulting in a noticeable rise in the groundwater level of downstream wells. In a study investigating the

flood–drought paradox in a rural area on the outskirts of Ahvaz, researchers found that restoring traditional water management practices—particularly Goorabs and water reservoirs—could provide storage capacity equivalent to up to 10% of the region's average flood volume within the Goorab network, thereby reducing water shortages for agricultural and livestock activities. In addition, approximately 17,000 m^3 of treated water would be stored in water reservoirs to meet the annual drinking water demand of 464 residents of the village. The findings of the study showed that this bottom-up approach operates in a gradual, sustainable, and highly effective manner and, by strengthening the resilience of the local community to environmental challenges, contributes to the long-term adaptation and self-recovery of the region (Raoufi and Tsubaki, 2025).

3.6. Local Community Empowerment and Participatory Management

The fourth mechanism is the empowerment of local communities and the reduction of water demand through participatory management. No technical or engineering solution can succeed without changing users' behavior and ensuring the active participation of stakeholders. The community-based watershed management approach has demonstrated highly promising results in recent years. This approach includes training farmers in the use of pressurized irrigation systems (drip and sprinkler irrigation) and irrigation scheduling based on the actual water requirements of crops rather than traditional flood irrigation; establishing water users' associations to ensure the equitable distribution of water during drought periods; creating economic incentives for the use of treated domestic wastewater in landscape irrigation; and promoting public awareness to reduce water losses within water distribution networks. Community empowerment is considered one of the most important components of participatory natural resource management programs (Emami et al., 2018). Preto and Lingo (2012) concluded that community empowerment is the key to the success and long-term sustainability of development initiatives in natural resource management. Similarly, in California, water management during drought periods relies on pricing incentives, water conservation measures, water recycling, and water transfers to address reductions in water supply (Langridge et al., 2012).

3.7. Complementary Mechanisms of Integrated Watershed Management in Reducing the Impacts of Drought

In addition to the four main mechanisms, namely groundwater recharge, vegetation cover protection, post-drought flood control, and local community empowerment, a review of the studies indicates that the effectiveness of integrated watershed management in addressing drought also depends on a range of complementary measures. These measures play an important role in enhancing watershed resilience by reducing the degradation of fundamental resources, increasing adaptive capacity to climate change, improving forecasting and preparedness, reducing water consumption, and strengthening the economic security of resource users.

Soil Erosion and Sediment Control: Protecting the Productive Capacity of the Watershed

One of the major consequences of watershed degradation is increased soil erosion and the transport of sediment into waterways and reservoirs. Soil erosion is recognized as the most important driver of land degradation worldwide (Duan et al., 2020), threatening ecosystems, agricultural soil health, and wildlife habitat security (Kang et al., 2021). Drought increases the susceptibility of the land surface to erosion by reducing vegetation cover and soil moisture, while intense rainfall following dry periods can lead to increased runoff and sediment production.

Therefore, erosion control through vegetation restoration, grazing management, the use of plant residues, terracing, and the construction of sediment-control structures should be an integral part of drought mitigation strategies. Research evidence also confirms the effectiveness of these measures. In the Bushy Creek watershed in Texas, simulations using the APEX model showed that no-till farming, compared with conventional tillage, reduced soil evaporation, runoff, and soil erosion by 46–52%, 27–33%, and 55–

59%, respectively, and also reduced runoff and sediment losses under conditions of heavy rainfall (Samanta et al., 2025). Furthermore, a study conducted in the Baitarani watershed in India using the SWAT model showed that the combined implementation of management measures can reduce sediment yield at the watershed scale by up to 80%, while simultaneously increasing groundwater recharge, baseflow, and deep percolation (Uniyal et al., 2020). These findings indicate that erosion and sediment control, in addition to protecting soil resources, can contribute to enhancing watershed resilience to drought by improving components of the water balance.

Climate Scenario-Based Management: Moving from Reaction to Foresight

The increasing uncertainty associated with climate change has heightened the need for forward-looking approaches to watershed management. Integrating climate scenarios with hydrological models can help assess the potential impacts of climate change on runoff, soil moisture, erosion, and sediment yield, thereby providing a basis for selecting appropriate adaptive management measures. Studies conducted in the Taleghan watershed (Haji Mohammadi et al., 2025) and central Oklahoma (Lee et al., 2025) have shown that climate change can increase soil erosion and sediment yield, while measures such as seeding, pitting, contour farming, construction of sediment-trapping structures, the use of cover crops, and no-till farming can be effective in mitigating these impacts. Therefore, integrating climate scenarios, watershed modeling, and management measures enables a transition from reactive management toward forward-looking planning that is adaptive to future conditions.

Early Warning Systems: Strengthening Drought Preparedness

Research studies also indicate that the effectiveness of early warning systems increases when the information generated is directly made available to resource users and decision-makers, thereby enabling timely responses. A systematic review conducted across 19 African countries showed that seasonal climate forecasts and early drought warnings can help reduce production risks and strengthen farmers' resilience, particularly through adjustments in planting dates, crop selection, and diversification of agricultural activities; however, their effectiveness depends on the economic and institutional capacity to take action based on the information received (Jisow, 2026). Furthermore, studies conducted in Indonesia emphasize the need to integrate information and modern technologies with integrated watershed management, local community participation, and coordination among stakeholders. Therefore, early warning systems can play an effective role in drought management when they are incorporated into an integrated decision-making and management system, and the information they provide leads to practical actions at the farm, sub-watershed, and watershed scales (Supangat et al., 2023).

Crop Pattern Optimization: Reducing Pressure on Water Resources

Various studies have also emphasized the importance of crop pattern optimization and crop diversification as key strategies for adapting to climate change and drought. Agriculture plays a crucial role in ensuring and maintaining the country's food self-sufficiency, while its sustainable development depends largely on transforming existing cropping structures and patterns (Nosrati et al., 2022). In a study conducted in southwestern Ethiopia, changes in planting dates and crop diversification were identified as among the most important adaptation strategies adopted by farmers. Participation in watershed management activities was also reported as an effective factor in enhancing the adaptive capacity of rural communities (Wolka et al., 2023). Furthermore, a study conducted in agricultural watersheds in Japan showed that climate change can affect the optimal timing of crop cultivation and irrigation water-use patterns and, under certain conditions, may constrain farmers' capacity to adapt (Yoshida & Takada, 2025). These findings indicate that crop pattern optimization should be considered in an integrated manner, taking into account climatic conditions, water resource availability, and crop water requirements. Accordingly, crop selection and planting dates should be aligned not only with maintaining agricultural production and farmers' incomes but also with the actual constraints of available water resources.

Financial and Insurance Mechanisms: Strengthening the Economic Capacity for Adaptation

Studies have emphasized the role of insurance and financial mechanisms in strengthening farmers' adaptation to drought. Agricultural insurance is particularly important in Iran due to its location in one of the world's dry regions, as the agricultural sector faces greater exposure to risks associated with recurrent droughts (Ghasemi & Davarzani, 2021). Index-based agricultural insurance, based on indicators such as precipitation or vegetation cover, can reduce part of the economic risk associated with drought; however, its effectiveness depends on data quality and the selection of an appropriate index (Tsegai & Kaushik, 2019). Furthermore, the findings of studies indicate that well-designed insurance schemes can reduce production risks while preventing increased dependence on groundwater resources and water-intensive crops, thereby encouraging resource users to adopt less water-intensive options (Kalthof et al., 2026). Therefore, insurance can serve not only as a means of compensating for losses but also as a tool for reducing risk and strengthening sustainable adaptation to drought.

4. Discussion

Overall, the findings of this review indicate that integrated watershed management, through a combination of hydrological, ecological, managerial, and economic measures, plays an important role in reducing the impacts of drought and enhancing long-term resilience. These measures include groundwater recharge and protection, vegetation cover conservation, erosion and sediment control, flood mitigation, climate scenario-based management, early warning systems, crop pattern optimization, local community empowerment, and financial and insurance mechanisms. The synergy among these measures can reduce pressure on water and soil resources while strengthening the productive capacity and adaptive capacity of local communities. However, the effectiveness and sustainability of this approach require long-term planning, sustained financial resources, coordination among responsible institutions, meaningful stakeholder participation, consideration of climate change scenarios, and the establishment of continuous monitoring and evaluation systems. Therefore, integrated watershed management should move beyond reactive and purely structural approaches toward integrated, forward-looking, participatory, and climate-adaptive management.

Despite the high effectiveness of watershed management in addressing drought, the successful and sustainable implementation of these measures faces numerous challenges, ranging from structural constraints to socioeconomic issues. The first, and perhaps the most fundamental, challenge is the long-term and high-cost nature of watershed management measures, together with short-term and insufficient budgeting, because watershed management operations generally require substantial investment and a period of three to five years for their gradual outcomes to become evident, whereas the allocated budgets are often annual, and drought crises also demand immediate solutions. Second, the absence of an integrated governing institution and the complexity of intersectoral coordination constitute a major challenge; watersheds are often shared among several provinces or even countries and are managed by multiple governmental and non-governmental organizations. This institutional fragmentation, together with overlapping responsibilities and competition over resources, makes the integrated coordination of watershed management plans extremely challenging. Third, climate change and the unprecedented increase in the severity and uncertainty of drought have, in some cases, exceeded the design capacity of watershed management structures and require flexible management approaches based on future scenarios. Fourth, opposition from local resource users and conflicts with stakeholders' interests; measures such as rangeland grazing exclusion, livestock reduction, or changes in cropping patterns may conflict with the short-term interests of some local communities and therefore require effective conflict management. Fifth, limited public participation; in many areas, the participation of local communities remains limited to merely accepting the projects, with little or no genuine involvement in planning, implementation, and maintenance. This leads to the unsustainability of project outcomes and the improper utilization of watershed management structures. Finally, the weakness of monitoring and evaluation systems should be regarded as one of the fundamental barriers; without accurate hydrometric and sediment measurement data, and more generally, without continuous and efficient monitoring systems, it is not possible to measure the actual impacts of the measures, improve the processes, or modify the projects.

5. Conclusion

The evidence synthesized in this review demonstrates that sustainable and integrated watershed management plays an undeniable and multifaceted role in mitigating the impacts of drought. This role is achieved through five principal mechanisms: enhancing groundwater recharge and mitigating groundwater level decline; increasing the soil's moisture retention capacity; conserving vegetation cover and preventing irreversible desertification; controlling destructive post-drought floods and transforming them into opportunities for aquifer recharge; and, finally, empowering local communities through education and the establishment of water users associations. Nevertheless, the success of integrated watershed management in mitigating drought depends on several fundamental prerequisites. First, interventions must be implemented as an integrated combination of green measures (vegetation restoration), blue measures (small-scale water storage and flood-spreading structures), and managerial measures (social and institutional participation), rather than as isolated actions. Second, implementation priorities should focus on watersheds experiencing severe groundwater depletion and recurrent droughts, particularly those supporting the largest populations of vulnerable rural communities. Third, the application of advanced technologies such as remote sensing, Geographic Information Systems (GIS), and hydrological modeling is essential for identifying optimal locations for watershed interventions and predicting their impacts. Fourth, public education, the empowerment of local communities, and the creation of economic incentives to encourage the active participation of resource users constitute essential and indispensable pillars of integrated watershed management. Ultimately, integrated watershed management is neither a passive defensive measure nor an idealistic concept; rather, it is a practical, preventive, and proven strategy for achieving sustainable coexistence with drought in the era of climate change. Projections indicate that the frequency and severity of droughts are expected to increase substantially in arid and semi-arid regions over the coming decades. Under such conditions, targeted and long-term investment in integrated watershed management should be regarded not as an option, but as an absolute necessity for ensuring the country's water, food, and environmental security.

Declaration of AI Use

ChatGPT was used to assist with translation from Persian into English, rewriting, grammar correction, English language editing, and improvement of academic writing style. The authors reviewed and verified all AI-assisted content and take full responsibility for the accuracy, originality, interpretation, and conclusions of the manuscript.

Authors' Contribution

All authors contributed to the conceptualization, methodology, investigation, writing, and editing of this manuscript.

Funding

This article is the result of independent research conducted by the authors and has not been supported by any organization.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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