Canal Irrigation and Sustainable Agriculture in Gujarat: A Study in the Context of Sustainable Development Goals

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Abstract:

Canal irrigation is an important component of agricultural development, particularly in regions where rainfall is seasonal, uncertain and unevenly distributed. In Gujarat, the development of major and medium irrigation projects has contributed to the expansion of irrigated agriculture, increased cropping intensity, crop diversification and reduction in dependence on monsoon rainfall. However, the sustainability of irrigation development cannot be assessed only through the expansion of irrigated area or agricultural production. It must also be examined in terms of water-use efficiency, equity, soil health, groundwater sustainability, environmental protection and farmers' livelihoods. This paper examines the relationship between canal irrigation and sustainable agriculture in Gujarat within the framework of the Sustainable Development Goals (SDGs). Particular attention is given to SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 15 (Life on Land). The study is based on secondary data and a descriptive-analytical research approach. The analysis suggests that canal irrigation can enhance agricultural productivity, improve farm-income opportunities, support multiple cropping and strengthen rural livelihoods. At the same time, inefficient irrigation can contribute to waterlogging, salinity and inefficient use of water resources. The study argues that sustainable canal irrigation in Gujarat requires participatory irrigation management, micro-irrigation, conjunctive use of surface and groundwater, improved drainage, climate-resilient cropping systems and SDG-based monitoring.

1. Introduction:

Agriculture is fundamentally dependent on the availability and timely supply of water. In areas where rainfall is seasonal and uncertain, irrigation plays an important role in stabilising agricultural production and reducing production risk. Irrigation can enable farmers to cultivate additional crops, improve the productivity of existing crops and make better use of agricultural inputs such as improved seeds, fertilisers and farm machinery (Chambers, 1988; World Bank, 2007).

Gujarat provides an important context for studying the relationship between irrigation and sustainable agricultural development. The state has substantial geographical and agro-climatic diversity, with considerable variation in rainfall and water availability. As a result, irrigation development has been an important component of agricultural and regional development policies. Major irrigation systems, including the Narmada and Ukai-Kakrapar projects, have contributed to the distribution of surface water to agricultural command areas in different parts of the state (Government of Gujarat, n.d.).

The traditional objective of irrigation development has generally been to increase the availability of water for agriculture. However, contemporary development policy requires irrigation to be evaluated through a broader sustainability framework. The Sustainable Development Goals adopted by the United Nations in 2015 provide such a framework. SDG 2 focuses on ending hunger, achieving food security and promoting sustainable agriculture, while SDG 6 focuses on sustainable water management (United Nations, 2015).

The relationship between irrigation and sustainable agriculture is therefore multidimensional. Irrigation can contribute to food security and poverty reduction, but excessive or inefficient irrigation can generate environmental problems. FAO (2020) emphasises the need to improve agricultural water management because agriculture is a major user of freshwater resources. Sustainable irrigation consequently requires both adequate water availability and efficient water utilisation.

The present study examines canal irrigation in Gujarat from the perspective of sustainable agricultural development and its contribution to selected SDGs.

2. Concept of Canal Irrigation

Canal irrigation is a method of supplying water to agricultural land through an artificial network of canals constructed to convey water from rivers, reservoirs, dams or other surface-water sources.

A typical canal irrigation system may include:

(1) Main canal (2) Branch canal (3) Distributary (4) Minor canal (5)Sub-minor canal (6) Field channel

The effectiveness of a canal irrigation system depends not only on the quantity of water available at the source but also on the efficiency of conveyance, distribution and application at the farm level. Chambers (1988) argues that irrigation systems should be understood as socio-technical systems in which physical infrastructure and human institutions operate together.

Consequently, sustainable canal irrigation requires appropriate infrastructure, efficient water distribution, regular maintenance, farmer participation and effective institutional arrangements.

3. Sustainable Agriculture: Concept and Dimensions

Sustainable agriculture refers to an agricultural system that meets present food and livelihood requirements while maintaining the ecological and resource base required for future generations.

The concept has three major dimensions.

3.1 Economic Sustainability

Economic sustainability means that farming should provide adequate and reasonably stable economic returns to farmers. Irrigation can improve productivity, increase cropping intensity and create opportunities for crop diversification. Increased agricultural activity may also stimulate employment and non-farm economic activities (World Bank, 2007).

3.2 Social Sustainability

Social sustainability includes food security, employment, equitable access to productive resources and improvement in rural living standards. Irrigation can reduce the vulnerability of farmers to rainfall failure. However, equitable distribution of canal water is essential because unequal access may result in unequal agricultural benefits.

3.3 Environmental Sustainability

Environmental sustainability requires conservation of water, soil and other natural resources. Excessive irrigation without adequate drainage can result in waterlogging and soil salinity. Therefore, sustainable irrigation must be accompanied by efficient water application, drainage and soil-management practices (FAO, 2021).

4. Sustainable Development Goals and Canal Irrigation

4.1 SDG 1: No Poverty

SDG 1 aims to end poverty in all its forms. Agricultural irrigation can contribute to poverty reduction by increasing productivity, reducing crop-failure risk and creating opportunities for higher agricultural income.

Where irrigation enables farmers to cultivate multiple crops, annual returns from land may increase. Irrigation may also generate additional employment in cultivation, harvesting, transportation, storage and processing.

Thus, canal irrigation can contribute to SDG 1 through the following chain:

Reliable irrigation → Higher agricultural production → Higher employment and income → Improved rural livelihoods → Poverty reduction

However, the extent of poverty reduction depends on landholding size, access to inputs, market prices, credit and equitable water distribution.

4.2 SDG 2: Zero Hunger

SDG 2 is directly related to agriculture. It seeks to end hunger, achieve food security and promote sustainable agriculture (United Nations, 2015).

Canal irrigation can support SDG 2 through:

1. higher agricultural productivity;

2. increased cropping intensity;
3. crop diversification;
4. reduction in rainfall-related production risks;
5. improved food availability; and
6. greater agricultural income.

The SDG India Index developed by NITI Aayog includes agricultural productivity and agricultural value addition among indicators associated with Goal 2 (NITI Aayog, 2024). Therefore, irrigation development has relevance to India's SDG framework.

4.3 SDG 6: Clean Water and Sanitation

SDG 6 seeks to ensure availability and sustainable management of water and sanitation for all. Target 6.4 specifically focuses on improving water-use efficiency and ensuring sustainable withdrawals of freshwater resources (United Nations, n.d.).

This target has direct relevance to canal irrigation. Agricultural water should not merely be made available; it must be distributed and utilised efficiently.

Important measures include:

1. reducing canal conveyance losses;
2. improving canal maintenance;
3. measuring water deliveries;
4. efficient irrigation scheduling;
5. promoting drip and sprinkler irrigation;
6. conjunctive use of surface and groundwater; and
7. Preventing over-irrigation.

Molden (2007) argues that improving water productivity in agriculture is essential for addressing increasing demands for food while maintaining water-resource sustainability.

4.4 SDG 8: Decent Work and Economic Growth

Irrigation can increase the number of agricultural operations undertaken during a year. Multiple cropping and crop diversification can consequently increase demand for agricultural labour.

The benefits may extend to rural economic activities such as:

1. agricultural transport;
2. storage;
3. processing;
4. input supply;
5. machinery services; and

6. agricultural marketing.

Irrigation can therefore contribute indirectly to SDG 8 by strengthening agricultural and rural economic activity.

4.5 SDG 12: Responsible Consumption and Production

SDG 12 promotes sustainable consumption and production patterns. In agriculture, this requires efficient utilisation of water, soil, fertilisers, energy and other inputs.

Canal irrigation should therefore be integrated with:

1. drip irrigation;
2. sprinkler irrigation;
3. soil testing;
4. balanced fertilisation;
5. integrated pest management;
6. appropriate crop planning; and
7. reduction of water losses.

The objective should be to obtain **more agricultural output from each unit of water**, rather than encouraging indiscriminate expansion of water-intensive agriculture.

4.6 SDG 13: Climate Action

Climate variability presents a significant challenge to agricultural production. Irrigation can provide farmers with greater resilience to irregular rainfall and short-term dry spells.

However, irrigation systems must themselves become climate resilient. This requires efficient water allocation, improved reservoir management, water conservation and climate-smart agricultural practices.

FAO (2021) emphasises the importance of integrated management of land and water resources in responding to increasing climatic and resource pressures.

4.7 SDG 15: Life on Land

SDG 15 focuses on protecting terrestrial ecosystems, combating land degradation and promoting sustainable management of natural resources.

Canal irrigation can support land productivity, but poorly managed irrigation may contribute to waterlogging and salinity. Therefore, irrigation development should be accompanied by:

1. adequate drainage;
2. soil-health monitoring;
3. groundwater monitoring;
4. appropriate irrigation scheduling; and

5. land-conservation practices.

5. Irrigation Development in Gujarat

Gujarat has developed irrigation infrastructure through major, medium and minor irrigation projects. The state government's Water Resources Department provides project-level information regarding major and medium irrigation schemes and their command areas (Government of Gujarat, n.d.).

The Ukai-Kakrapar irrigation system is particularly important in the context of South Gujarat. The project has influenced agricultural water availability and the development of irrigated farming in its command areas.

The Narmada irrigation system has also expanded the availability of surface water across a large part of Gujarat. Such large irrigation systems have contributed to the broader transformation of agricultural production.

Nevertheless, the success of an irrigation project should not be measured solely by the command area created. Actual agricultural benefits depend on the extent to which water reaches farms, the timing of supply, the condition of distribution networks and farmers' capacity to use water efficiently.

6. Canal Irrigation and Agricultural Transformation

6.1 Increase in Cropping Intensity

Rain-fed agriculture is generally concentrated during the monsoon season. Reliable canal irrigation can enable farmers to cultivate rabi and summer crops in addition to kharif crops. Therefore:

Canal irrigation → Longer cultivation period → Multiple cropping → Higher annual land productivity

This is an important mechanism through which irrigation contributes to agricultural development.

6.2 Crop Diversification

Irrigation increases farmers' flexibility in selecting crops. Where agro-climatic and market conditions are favourable, irrigated areas may support vegetables, horticultural crops and other commercial crops in addition to traditional food crops.

However, diversification should not automatically mean a shift towards water-intensive crops. Crop choice should reflect local water availability, soil conditions and market opportunities.

6.3 Agricultural Productivity

Adequate water at critical stages of crop growth can increase crop yields. Irrigation also improves the effectiveness of other agricultural inputs.

Therefore, the relationship can be expressed as:

Water availability + Improved inputs + better farm management → Higher productivity

6.4 Reduction of Agricultural Risk

Rainfall variability is one of the major risks faced by farmers. Canal irrigation reduces dependence on rainfall and can provide an additional source of water during periods of inadequate rainfall.

This can improve production stability and encourage farmers to invest in agricultural technologies.

6.5 Rural Employment

Higher cropping intensity and diversified agricultural production can increase demand for labour. Employment may be generated in both farm and post-farm activities.

Consequently, irrigation has the potential to contribute to rural livelihood improvement beyond the direct effect on crop production.

7. Water-Use Efficiency and Sustainable Irrigation

The sustainability of canal irrigation depends heavily on water-use efficiency. Water may be lost during conveyance through canals and during field application.

Perry et al. (2009) caution that improvements in irrigation technology do not automatically result in overall water savings unless water is managed at the basin and system levels. This observation is important because field-level efficiency and basin-level water conservation are not necessarily identical.

A sustainable irrigation strategy should therefore include:

Canal efficiency + Field efficiency + Appropriate crop selection + Water accounting + Groundwater management

Micro-irrigation can be especially useful for suitable crops because it allows more controlled application of water at the farm level.

8. Participatory Irrigation Management

Participatory Irrigation Management (PIM) involves the participation of farmers in the management and distribution of irrigation water.

The approach recognises that irrigation management is not solely an engineering function. Farmers are directly involved in water use and therefore need a role in decision-making and local management (Chambers, 1988).

Participatory irrigation institutions can contribute to:

1. equitable water distribution;
2. canal maintenance;
3. local conflict resolution;
4. monitoring of water delivery;
5. farmer awareness;
6. improved communication with irrigation authorities; and
7. efficient use of irrigation water.

Government of Gujarat has promoted participatory approaches to irrigation management in the state's command areas (Government of Gujarat, n.d.).

9. Environmental Problems Associated with Canal Irrigation

9.1 Waterlogging

Excessive irrigation combined with inadequate drainage can raise the groundwater table and result in waterlogging. This can adversely affect crop growth and soil conditions.

9.2 Soil Salinity

In irrigated areas with poor drainage, salts may accumulate in the root zone. Over time, this may reduce agricultural productivity.

9.3 Groundwater Depletion

In some situations, canal water availability may coexist with excessive groundwater extraction. Sustainable irrigation therefore requires monitoring both surface-water deliveries and groundwater levels.

9.4 Canal Seepage and Water Loss

Seepage may result in water losses from conveyance systems, although in some locations seepage may contribute to groundwater recharge. Therefore, canal modernisation decisions should be based on local hydrogeological conditions rather than a blanket approach.

9.5 Water-Intensive Cropping

The expansion of irrigation may encourage farmers to cultivate water-intensive crops. If crop water requirements exceed sustainable water availability, irrigation development can create long-term resource pressure.

10.Irrigation Governance and Institutional Sustainability

The sustainability of irrigation requires effective governance. Three aspects are particularly important:

1. **Equity**

Canal water should reach farmers fairly across head, middle and tail reaches of the irrigation system.

2. **Efficiency**

Water should be delivered at the right time and in quantities appropriate to crop requirements.

3. **Accountability**

Water distribution, maintenance and irrigation charges should be managed transparently.

Participatory irrigation institutions can strengthen these dimensions by involving water users in local management.

11.Research Objectives

The study has the following objectives:

1. To examine the role of canal irrigation in agricultural development in Gujarat.
2. To analyse the contribution of canal irrigation to sustainable agriculture.
3. To examine the relationship between canal irrigation and selected Sustainable Development Goals.
4. To analyse the economic, social and environmental implications of canal irrigation.
5. To identify challenges affecting sustainable canal-water management.
6. To suggest policy measures for improving irrigation efficiency and sustainability.

12.Research Questions:

The study addresses the following questions:

1. What role does canal irrigation play in agricultural development in Gujarat?
2. How does canal irrigation contribute to sustainable agriculture?
3. What are the major linkages between canal irrigation and SDG 2 and SDG 6?
4. What environmental challenges are associated with canal irrigation?
5. How can participatory management and modern irrigation technologies improve sustainability?

13.Research Methodology

The study follows a **descriptive and analytical research design**.

The research is primarily based on secondary information obtained from government publications, international organisations, policy documents and academic literature.

Major Sources:

1. Government of Gujarat, Water Resources Department
2. Government of India, Ministry of Jal Shakti
3. Pradhan Mantri Krishi Sinchayee Yojana
4. NITI Aayog
5. United Nations Sustainable Development Goals
6. Food and Agriculture Organization
7. World Bank
8. Academic books and research literature

The study uses thematic and comparative analysis to identify the relationship between irrigation and the economic, social and environmental dimensions of sustainable agriculture.

For future empirical research, primary data from farmers in selected canal command areas can be analysed using descriptive statistics, correlation, regression and chi-square tests.

14.SDG-Based Analytical Framework

SDG	Major Objective	Canal Irrigation Linkage
SDG 1	No Poverty	Agricultural income and livelihood improvement
SDG 2	Zero Hunger	Productivity, food security and sustainable agriculture
SDG 6	Clean Water	Efficient and sustainable water management
SDG 8	Decent Work	Agricultural and rural employment
SDG 12	Responsible Production	Efficient use of water and inputs
SDG 13	Climate Action	Reduced agricultural vulnerability to rainfall variability
SDG 15	Life on Land	Soil and land-resource conservation
Source: Author's conceptualisation based on United Nations (2015) and related literature.		

15.Major Findings

The study identifies the following findings:

1. Canal irrigation can reduce farmers' dependence on uncertain monsoon rainfall.
2. Reliable irrigation can increase cropping intensity and facilitate cultivation beyond the kharif season.

3. Irrigation creates opportunities for crop diversification and commercial agricultural production.
4. Higher cropping intensity and productivity can improve agricultural income and employment opportunities.
5. Canal irrigation has a particularly strong linkage with **SDG 2**, because agricultural water availability is directly related to food production and sustainable agriculture.
6. **SDG 6** requires irrigation systems to focus on water-use efficiency rather than only expanding irrigated area.
7. Participatory irrigation management can improve local governance and farmer involvement.
8. Inadequate drainage can result in waterlogging and soil salinity.
9. Surface water and groundwater should be managed conjunctively.
10. Micro-irrigation and digital water-management technologies can improve irrigation efficiency.
11. Climate change increases the importance of efficient and resilient irrigation systems.
12. Sustainable irrigation requires integration of water management with crop planning, soil conservation, markets and farmer institutions.

16.Policy Suggestions

16.1 Strengthen Participatory Irrigation Management

Water User Associations should be strengthened through capacity building, transparent water scheduling and greater participation of farmers.

16.2 Promote Micro-Irrigation

Drip and sprinkler irrigation should be promoted where agronomically and economically suitable.

16.3 Modernise Canal Networks

Canal repair, maintenance, desilting and appropriate modernisation should be undertaken regularly.

16.4 Improve Drainage

Command areas vulnerable to waterlogging should receive priority for drainage infrastructure and groundwater monitoring.

16.5 Promote Conjunctive Water Management

Surface water and groundwater should be managed as an integrated resource.

16.6 Promote Climate-Smart Agriculture

Farmers should be encouraged to adopt climate-resilient varieties, efficient irrigation practices and suitable cropping patterns.

16.7 Use Digital Technologies

GIS, remote sensing, automated water measurement and digital water accounting can improve irrigation management.

16.8 Develop SDG-Based Irrigation Indicators

Irrigation projects should be evaluated using indicators such as:

- Irrigated area
- Cropping intensity
- Agricultural productivity
- Farm income
- Water-use efficiency
- Employment
- Groundwater status
- Waterlogging
- Soil salinity
- Farmer participation
- Equity in water distribution
- Climate resilience

17.Conclusion

Canal irrigation has significant potential to support sustainable agricultural development in Gujarat. Its contribution extends beyond increasing the availability of water. Reliable irrigation can support multiple cropping, crop diversification, agricultural productivity, rural employment and livelihood security. These outcomes are directly or indirectly connected with SDG 1, SDG 2 and SDG 8.

At the same time, irrigation development can create environmental challenges when water is used inefficiently or drainage is inadequate. Waterlogging, salinity, groundwater stress and inefficient water distribution can reduce the long-term sustainability of irrigated agriculture.

Therefore, the future strategy for canal irrigation in Gujarat should move from a narrow focus on **“irrigated area expansion”** towards **“water productivity, equity, efficiency and sustainability.”** The integration of canal irrigation with micro-irrigation, participatory irrigation management, conjunctive use of surface and groundwater, drainage management, soil conservation and climate-smart agriculture can strengthen its contribution to the SDGs.

In conclusion, canal irrigation should be considered an important component of an integrated sustainable agricultural development strategy. Its success should ultimately be measured not only by the amount of water delivered or the area irrigated, but also by whether it generates sustainable productivity, equitable farmer benefits, efficient water use, resilient livelihoods and environmental protection.

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