Irrigation Infrastructure and Farm Income Dynamics: A Comparative Economic Assessment of the Underground Pipeline Project in Surendranagar District

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Abstract:

Traditional ways of watering crops using open canals and partially lined channels are being criticized more and more. The problems with these systems include a lot of water being lost during transport, farms being broken up into small pieces, maintenance causing disruptions, and big differences in how well farmers at the beginning and end of the canal system do. To deal with these issues, the government of Gujarat started the Underground Pipeline project in the area covered by the Sardar Sarovar Project. This change in policy involves replacing the usual open canals with underground pipes that have low pressure at the smaller canal level.

This study looks at how the UGPL project has affected people and farming in the semi-arid area of Surendranagar District, Gujarat. It uses a special framework to compare and analyze data from a survey of 600 farming households, with 300 of them having UGPL infrastructure and the other 300 relying on open surface channels. The goal is to understand the social and economic impacts of the project on these farming communities. By comparing the two groups, the study aims to provide insights into the benefits and challenges of the UGPL project in this region. The research focuses on the differences between farmers who have access to the project's infrastructure and those who do not, in order to identify areas of improvement and opportunities for growth.

The results show that putting UGPL networks underground can save 2.5% to 3.5% of good farmland that was previously wasted on open canals. Also, using closed pipes to distribute water makes the whole system more efficient, reducing the time it takes for water to get where it needs to go by about 40%. This means that farmers can get the right amount of water when they need it, which helps them switch from low-value crops like cereals to more valuable crops like cotton, wheat and cumin. As a result, the diversity of crops grown has increased significantly, with the crop diversification index increasing from 0.34 to 0.68. This is a big change, and it is good news for small farmers who can now grow more valuable crops and improve their livelihoods. By making these changes, farmers can earn more money and have a more stable income, which can have a big impact on their communities.

Financially, beneficiary households achieved a 18.7% reduction in seasonal operating expenses due to lower labor, energy, and fertilizer inputs. Combined with higher crop yields, this operational efficiency expanded net farm incomes by over 200%. Crucially, the UGPL layout mitigates geographical disadvantages, helping tail-end cultivators achieve income levels nearly identical to head-reach operators.

The study concludes with policy recommendations for integrating solar-powered pressurized pumping and strengthening Water Users' Associations (WUAs) to ensure long-term system sustainability.

1. Introduction:

1.1 The Crucial Role of Irrigation in Arid and Semi-Arid Agrarian Economies

In many parts of the world, especially in areas where farming is a big part of the economy, having a steady supply of water is crucial for helping rural areas grow and reducing poverty. This is particularly true in dry areas where farmers rely heavily on irrigation systems to water their crops. When these systems are reliable, farmers can plan and plant with more confidence. But in areas where farmers depend on rain to grow their crops, things can be really tough. The weather is getting harder to predict, and this can lead to bad harvests, unpredictable incomes, and a lot of financial stress for people living in these areas.

Consequently, expanding public and private canal networks has long been a core national policy for stabilizing rural livelihoods. However, the economic returns on these massive engineering investments depend entirely on how efficiently water travels from public reservoirs to private individual root zones.

1.2 The Technological Limits of Open Canal Channels

For a long time, people used surface-level gravity canal networks to move water across big areas of farmland. These canals, which are often just open ditches or partially lined trenches, don't cost a lot to build at first. But over time, we've seen that they have some major problems - they're not very good technically, they harm the environment, and they're not well-run.

When we look at open channels from an engineering point of view, it's clear that they have a major flaw - they lose a lot of water. This happens in a few ways: the sun heats up the water and it evaporates, the water seeps deep into the ground because the channels aren't lined, and it also leaks out through the sides because the banks are weak. In a lot of older systems, more than half of the water that's supposed to be delivered to farmers never actually makes it. This is a big problem because it means that a significant amount of the water that we collect and try to use is wasted before it can even be used for its intended purpose.

Beyond water loss, open channels cause significant land fragmentation. Constructing these networks requires building permanent parallel dikes and access paths across private properties. For smallholders operating on narrow margins, surrendering 2% to 4% of their farmable plots to public channels directly reduces their seasonal production capacity.

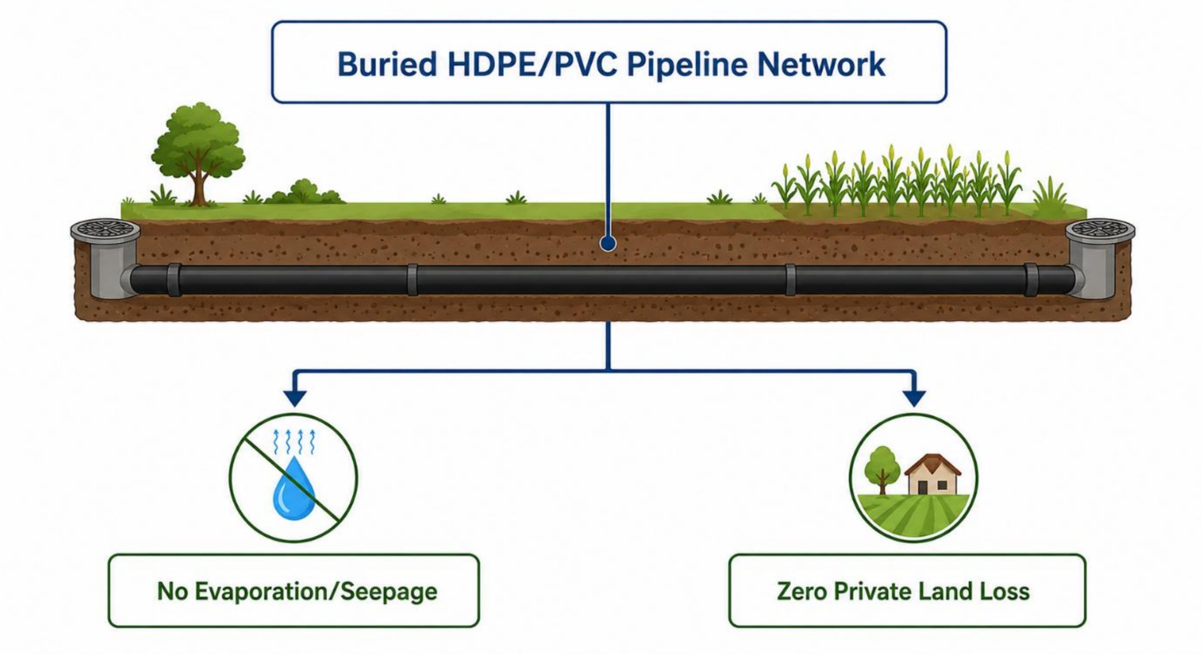
When you look at open networks, they often cause big problems between people. Farmers who are at the beginning of the network, or "head-end" farmers, usually take more water than they should, which leads to too much water in the soil, waterlogging, and salt building up in the soil. On the other hand, farmers at the end of the network, or "tail-end" farmers, often don't get enough water, and when they do, they can't predict when it will come. This makes it hard for them to grow crops, and their fields are more likely to fail.

1.3 The UGPL Project Paradigm Shift

To fix the big problems in the system, the government of Gujarat made a major change in the area where the Sardar Sarovar Project is located. They started using underground pipes instead of the usual open channels to bring water to the smaller areas.

The design of UGPL puts pipes made of HDPE or PVC really deep, about 0.9 to 1.2 meters underground. This is way below where farmers usually plow their fields. By doing this, water can flow through these closed pipes with low pressure, which means no water gets lost to evaporation and nobody can take water without permission. Plus, farmers don't have to give up their land for this system.

Figure 1: Key Physical Advantages of Buried HDPE/PVC Pipeline Irrigation Networks



1.4 Research Objectives and Scope

Engineering reports have long emphasized the water-saving characteristics of underground pipelines, but agricultural policymakers need to fully understand the economic implications. How, in particular, do these types of water savings translate into increased farm revenues?

The present study is an endeavour to answer a very significant topic by analyzing in detail UGPL project in Surendranagar District of Gujarat. It is extremely dry. The farmers water from crops consuming crops like cotton and cumin. Furthermore, it is related to the command zone of Sardar Sarovar Project, making it an intriguing case to study.

This paper evaluates:

1. The mechanical and operational advantages of UGPL networks over open channels.
2. The structural changes in crop yields and seasonal crop diversification.
3. The direct impacts on production expenses and net household income.
4. The project's success in reducing long-standing inequities between head-reach and tail-end cultivators.

2. Theoretical and Literature Review

2.1 The Political Economy of Canal Water Allocation

Managing big canal systems is a well-known problem in the field of economics that studies institutions. Researchers like Chambers and Ostrom did early work on this, back in the 1980s and 1990s. They found that public irrigation systems are a great example of what's called a Common-Pool Resource, or CPR for short. The thing is, without good rules and physical controls in place, these systems are really susceptible to something called the "tragedy of the commons." This means that when you have a shared resource like a canal network, and nobody's really in charge or making sure everyone follows the rules, it can lead to overuse and misuse, which ultimately hurts everyone involved.

In open gravity canals, this vulnerability manifests as widespread head-end water appropriation. Because downstream enforcement is difficult, upstream farmers often over-irrigate their fields. This excessive watering depreciates upstream soil quality through waterlogging while depriving downstream users of essential water access.

Easter (1993) discovered that these patterns of unequal distribution impact the overall economic effectiveness of irrigation networks and decrease the total return on public infrastructure expenditures.

2.2 Engineering Perspectives: Open Channels vs. Closed Conduits

The literature on hydraulic engineering clearly indicates the significantly lower efficiency of open channels compared to closed pipelines. Merriam and Keller (1978) found open earthen ditches lose large quantities of water to weed growth, bank breaches, silt accumulation and soil absorption. Concrete lining of channels reduces seepage but does not prevent direct surface evaporate and leaves the network subject to breaking under high summer temperatures.

Conversely, research by Shkuropat (2011) confirms that closed sub-surface pipelines operate with nearly 98% hydraulic conveyance efficiency. By sealing the distribution network, these systems eliminate evaporation and transit filtration, ensuring that the water volume released at the main turnout matches the volume delivered to individual fields.

Table 1 : Comparative Conveyance Efficiency of Different Irrigation Water Distribution Systems	
Irrigation Distribution Type	**Measured Conveyance Efficiency**
Unlined Open Earthen Ditches	40% – 55%
Concrete-Lined Open Channels	65% – 75%
Sub-surface UGPL Closed Conduits	95% – 98%

2.3 Agronomic and Socioeconomic Impacts of Irrigation Upgrades

In recent years, experts who study the economics of farming have been looking at how updating irrigation systems affects the money farmers make. Some researchers, like Birthal et al., found out in 2015 that having a reliable way to water crops often can reduce the risks that come with farming. When farmers know they will have enough water, they are more likely to invest in better seeds, fertilizers, and equipment, which can lead to higher profits. This is because they can focus on growing more valuable crops and using the best tools to help them grow, rather than just trying to get by with limited water. By having a steady supply of water, farmers can make more informed decisions about how to run their farms, and this can lead to bigger harvests and more money in their pockets.

Furthermore, pan-Asian empirical reviews by Barker et al. (2004) indicate that secure irrigation access is a primary driver of crop diversification. It allows farmers to shift away from low-value, drought-resistant subsistence grains and embrace lucrative, multi-seasonal horticulture and commercial cash crops.

But most research doesn't look at how things change in specific areas over time. This study fixes that by closely examining how UGPL is being used in Surendranagar District, giving us a clear picture of what's happening on the ground.

3. Contextual Profile of Surendranagar District

3.1 Geographical and Climatic Challenges

Surendranagar District is located in the northeastern portion of the Saurashtra peninsula in Gujarat, a region characterized by semi-arid climate patterns. The territory faces severe environmental challenges:

Erratic Rainfall Patterns: The district receives low annual precipitation, typically ranging between 450 mm and 600 mm, concentrated entirely within a brief 60-day monsoonal window.

Extreme Thermal Volatility: Summer temperatures routinely exceed 44oC, causing high potential evapotranspiration rates that rapidly deplete surface soil moisture.

Degraded Groundwater Quality: Deep, high-salinity underground aquifers characterized the local hydrogeological setting. Continuous tube-well pumping brings up brackish water, which, over time, deteriorates soil structures, making imports of surface canal water important to agricultural life.

3.2 The Agricultural Framework

Despite these difficult climatic conditions, agriculture is the main economic driver of Surendranagar, employing over 65% of the local labour force. The two high-value agricultural commodities that underpin the region's farming system are the following:

Kharif Season (Monsoon) The long-staple Bt cotton crop demands close supervision of soil moisture during early boll development.

Rabi Season (Winter): Cumin (Cuminum cyminum) and mustard are the most popular crops. Cumin is a high-value but highly sensitive spice crop and may lead to total failure under waterlogging or irregular intervals of irrigation.

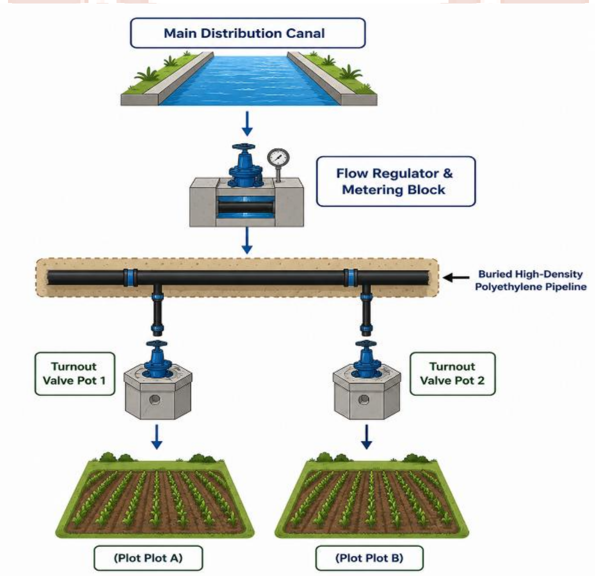
Because local cash crops are highly sensitive to watering conditions, Surendranagar served as a critical testing ground for the rollout of the Sardar Sarovar Project's UGPL infrastructure.

4. Design and Institutional Policy of the UGPL Initiative

4.1 Technical and Structural Specifications

The Underground Pipeline (UGPL) design used across the Sardar Sarovar command network replaces traditional open concrete or earthen ditches with a buried, low-pressure pipeline distribution system.

Figure 2: Schematic Layout of an Underground Pipeline Irrigation Distribution Network



The engineering specifications follow a precise layout:

- Pipeline Material: Fabricated using industrial-grade High-Density Polyethylene (HDPE) or Polyvinyl Chloride (PVC) designed to withstand continuous internal pressures of 0.4 to 0.6 MPa.
- Installation Depth: Pipelines are buried in machine-excavated trenches at a depth of 0.9 to 1.2 meters. This keeps the entire network safe from heavy tractor plowing and mechanical soil preparation.
- Delivery Interface: Water access is managed via surface-level "turnout pots" or hydrants equipped with manual alpha-valves. These delivery points are positioned to distribute water directly to small group of farm plots (chaks) averaging 5 to 8 hectares.

4.2 The Co-Management Institutional Framework

"The UGPL project works so well because it uniquely incorporates the private and public sectors. The project does not just rely on the government but has a three-part system in which the government, industry-leading construction companies, and local communities work collaboratively. Local communities are grouped into groupings called Water Users' Associations, or WUAs. The cooperation method helps to share the duties, causing the project to be more successful. By working together, government, private firms, and local communities can ensure that the project is successful and advantageous to everyone affected.

This co-management model operates with clear structural rules:

The government helps pay for most of the costs of building and installing pipelines, covering 97.5% of the expenses. The farmers who benefit from these pipelines have to pay the remaining 2.5% upfront. This way, the farmers have a small financial stake in the project, which helps them feel more invested in taking care of the pipelines and prevents them from being damaged on purpose.

Operational Handover:

Once installation is complete, the physical operation and water allocation schedules are transferred entirely to the local WUA.

Here's how it works: when it comes to keeping everything running smoothly, there's a system in place. The company that built it gives a five-year guarantee for any big repairs that need to be done. For regular, everyday upkeep, the people in charge of the water - the WUA - use money from the fees they collect from delivering water to homes and businesses in the area.

5. Research Methodology

5.1 Sampling Design and Survey Framework

This research takes a closer look at how the UGPL project affects people's lives and the economy. To do this, we collected information directly from the field over a whole year of farming in Surendranagar District.

Sampling Method: A stratified random sampling strategy was implemented to ensure balanced representation across diverse farming conditions.

Geographical Stratification: Sampling sites were chosen from villages across four major agricultural blocks (talukas) in Surendranagar: Wadhwan, Limbdi, Dasada, and Dhrangadhra.

Sample Allocation Matrix: To create a mathematically rigorous comparative model, 600 households were selected and split into two distinct analytical groups:

To make a fair comparison, the two groups were chosen from areas with similar soil and access to the same main water channels. They also had similar types of farms, including small, medium, and large ones. This helps to ensure that the comparison is valid and not influenced by differences in these factors.

5.2 Econometric and Mathematical Modeling

A. Volumetric Conveyance Efficiency Metrics

To measure the hydraulic performance improvements of the pipeline network, conveyance efficiency (n_c) was calculated using inflow-outflow measurements at delivery junctions:

$$\eta c = \left(\frac{\text{Vfield}}{\text{Vcanal}}\right) \times 100$$

Where:

Vfield represents the total water volume successfully delivered to the farm plot boundary (measured in liters via ultrasonic flowmeters).

Vcanal represents the total water volume released at the primary canal turnout gate.

B. Crop Diversification Quantification

To assess structural changes in regional crop choices, the Herfindahl-Hirschman formulation was adapted to compute a comprehensive Crop Diversification Index (CDI):

$$\mathbf{CDI = 1 - \sum_{i=1}^{N} \left(\frac{Ai}{ATotal}\right)^2}$$

Where:

- Ai represents the land area allocated to a single crop variety i.
- Atotal represents the total cultivated farm area across all growing seasons.

A CDI value near 1.0 indicates a highly diversified cropping pattern, while a value near 0 signifies total single-crop monoculture.

C. Financial Accounting and Net Revenue Models

Net Farm Income (Inet) per hectare was calculated using standard farm cost accounting structures:

$$I_{net} = \sum_{k=1}^{M} (Yk \times Pk) - [\mathrm{Cseed} + \mathrm{Cfert} + \mathrm{Cwater} + \mathrm{Cenergy} + \mathrm{Clabor} + \mathrm{Cmaint}]$$

Where:

- Yk represents the total harvested yield of crop k per hectare.
- Pk represents the realized market price per unit of yield (including state minimum support prices).
- Cseed represents total seed purchase costs.
- Cfert represents fertilizer and pesticide expenditures.
- Cwater represents official state irrigation usage fees.
- Cenergy represents fuel and electricity costs for field pumping.
- Clabor represents total wages paid to hired farm labor.
- Cmaint represents seasonal maintenance fees paid to local Water Users' Associations.

6. Empirical Results and Economic Analysis

6.1 Land Reclamation and Physical Conveyance Efficiency

Reclaiming Arable Land Surface Traditional open canals require digging surface ditches and building wide dirt embankments. This infrastructure removes valuable land from production and divides fields, hindering the use of large farm machinery.

The primary survey confirms that burying distribution lines underground reclaims significant amounts of farmable land:

Reclaimed Land Area Component ≈ 2.9% to 3.6% of Total Farm Size

Across a typical village command zone covering 1,500 hectares, this 3% land reclamation effectively adds 45 hectares of high-quality arable land back into production at zero additional acquisition cost.

Water Velocity and Conveyance Efficiency Improvements

The comparative hydraulic data reveals a significant performance gap between the two distribution models. Open earthen field channels in Surendranagar show high water loss rates, with conveyance efficiency (nc) averaging just 54.2% due to rapid soil absorption and bank erosion.

In contrast, the sealed UGPL networks maintain an average conveyance efficiency of 96.4%. By preventing water loss, these closed conduits cut the average time needed to irrigate one hectare of wheat from 7.2 hours down to 4.1 hours, significantly reducing evaporation and soil saturation risks.

Figure 3 : Irrigation Conveyance Efficiency Comparison (%)

6.2 Agronomic Performance: Yields and Crop Diversification

Crop Yield Response Profiles

By providing consistent water volumes and regular delivery schedules, the UGPL network significantly improves crop yields across all major regional varieties. This improvement is especially pronounced for sensitive cash crops that require precise watering schedules.

Table 2 : Impact of UGPL Irrigation on Crop Productivity in the Study Area

Crop	Control Group Yield (Quintals/ha)	Beneficiary Group Yield (Quintals/ha)	Increase (%)
Bt Cotton	11.4	19.8	73.70%
Wheat	28.6	41.2	44.10%
Cumin	5.1	8.9	74.50%
Mustard	14.2	19.5	37.30%

The 74.5% increase in cumin yields demonstrates the value of reliable, on-demand irrigation. Cumin has delicate root structures that rot quickly under the erratic, high-volume flooding typical of open canals. The controlled, low-volume deliveries of the UGPL system provide optimal soil moisture without waterlogging, protecting crops and maximizing yields.

Measuring Crop Diversification

The survey data shows a strong correlation between reliable water access and crop diversification. Non-beneficiary farmers, face highly unpredictable water delivery timelines, often forcing them into low-risk, single-crop grain cultivation during the winter season.

Thanks to the UGPL system's dependable water supply, farmers who benefit from it are now more confident to try new things on their land. As a result, they've been able to diversify their crops more. In fact, the Crop Diversification Index, which is a way to measure how many different crops a farmer is growing, went up to 0.68 for these farmers, compared to just 0.34 for farmers who didn't have the UGPL system. This means they're now growing a wider variety of crops, including vegetables like tomatoes, green chilies, and cluster beans, which can be sold for a good price. They're also growing high-yield alfalfa, a type of fodder that's perfect for the local dairy herds.

Figure 4 : Crop Diversification Index (CDI) Score

6.3 Financial Evaluation: Input Costs and Revenue Profiles

The financial performance of modern agriculture relies heavily on optimizing production costs. A detailed look at the input data reveals that the UGPL network creates significant operational efficiencies, reducing costs in several key categories:

Traditional open channels require constant manual monitoring to clear silt, remove weeds, and rebuild fragile soil banks. The automated, closed-valve design of the UGPL network eliminates these tasks, reducing seasonal labor costs by an average of 44%.

Using closed pipelines can actually help farmers save energy. By keeping water pressure constant and preventing water from being wasted during transport, they can irrigate their fields much faster. This means they use less electricity and diesel to power their pumps, which can reduce their energy consumption by about 32%. It's an easy way to make a big difference.

Using a better irrigation system can really help your plants grow. When you use the old way of watering the fields, a lot of fertilizer can wash away. This is a waste of money and is not good for the environment. But with the UGPL system, the flow of water is controlled, so the soil does not get too wet. This means that the fertilizer stays where it is needed, around the roots of the plants, and works more effectively. This is a simple change that can make a big difference in the growth of your crops.

The table below provides a detailed financial breakdown of the average input costs, total income and net profit per hectare for both the groups surveyed in Surendranagar district.

Table 3 : Comparative Financial Performance of Control and UGPL Beneficiary Farmers

Financial Indicator (Per Hectare / Annum)	Control Farmers (Open Canals)	Beneficiary Group (UGPL Network)	Financial Shift
Gross Agricultural Revenue	$1,310	$2,340	+$1,030 (+78.6%)
High-Yielding Seed Inputs	$215	$245	+$30 (+13.9%)
Chemical Fertilizer & Nutrients	$180	$155	−$25 (−13.8%)
Base Water Delivery Tariffs	$75	$55	−$20 (−26.6%)
Pump Energy (Electricity/Diesel)	$210	$142	−$68 (−32.3%)
Seasonal Manual Labor Wages	$260	$145	−$115 (−44.2%)

Table 3 : Comparative Financial Performance of Control and UGPL Beneficiary Farmers			
Financial Indicator (Per Hectare / Annum)	**Control Farmers (Open Canals)**	**Beneficiary Group (UGPL Network)**	**Financial Shift**
Institutional WUA Maintenance Fee	$10	$35	+$25 (+250.0%)
Total Operational Cost (Cost C)	**$950**	**$777**	**−$173 (−18.2%)**
Net Household Farm Income	**$360**	**$1,563**	**+$1,203 (+334.1%)**

Financial analysis demonstrates a strong double economic benefit. Gross revenues increased 78.6% due to the increase in yields and the change in the composition of cash crops to more productive and profitable ones. At the same time, considerable operational savings in manpower and energy reduced total production costs by 18.2%.

These shifting curves of revenues and costs raised the average net farm income of beneficiary families from $360 to $1,563 per hectare.

Figure 5: Net Annual Profit per Hectare Comparison (USD)

6.4 Regional Equity along the Canal Network

A long-standing problem in canal-irrigated agriculture is the stark inequality between head-reach and tail-end farmers. Under traditional open gravity systems, upstream farmers often use excessive amounts of water, leaving downstream fields frequently dry.

The chart below shows how the UGPL pipeline network fixes this imbalance, mapping net farm income based on a farm's location along the canal network.

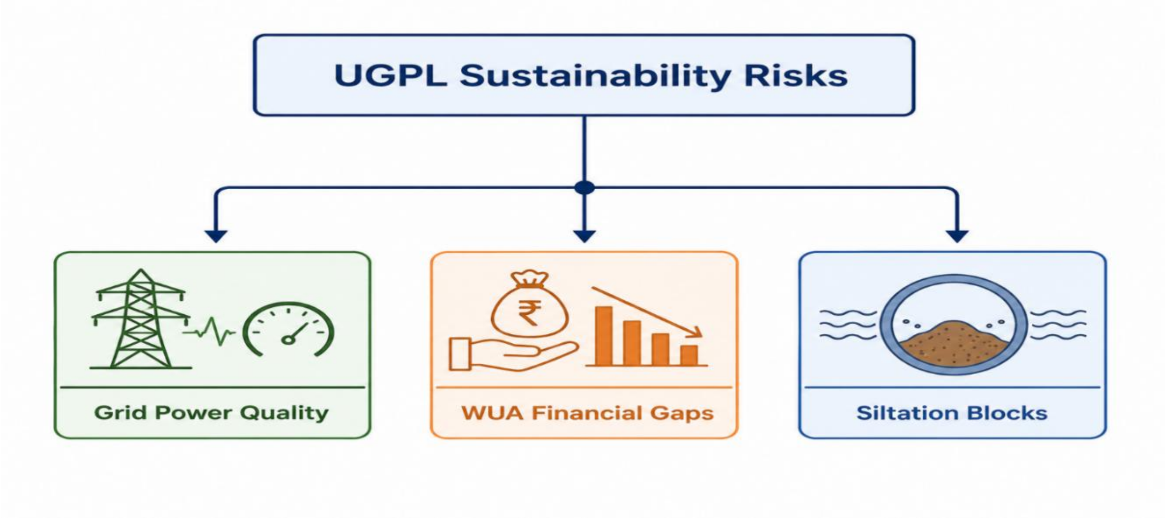
Table 4: Comparative Net Farm Income across Canal Reach Locations for Beneficiary and Control Farmers			
Location along the Canal Network	**Control Group Net Annual Farm Income (USD/ha)**	**Beneficiary Group Net Annual Farm Income (USD/ha)**	**Net Profit Growth (%)**
Head-End Reach	$580	$1,610	177.50%
Middle Reach	$390	$1,570	302.50%
Tail-End Section	$110	$1,510	1272.70%

While head-end and middle-reach farmers enjoy strong double-digit income growth, tail-end farmers experience a massive 1,272% jump in net income. By replacing unreliable open channels with a sealed, pressurized pipeline, the UGPL project successfully delivers consistent water volumes to the furthest fields. This eliminates geographic disadvantages and establishes true economic equity across the entire agricultural command zone.

7. Policy Challenges and Long-Term Sustainability

The UGPL project has economic benefits in the short term, whereas field surveys reveal that its long-term sustainability will be dependent on tackling a number of new technology-related, financial and institutional challenges.

Figure 6 : Major Sustainability Risks Associated with UGPL Irrigation Systems



7.1 Power Grid Quality and Pumping Infrastructure

The force of gravity fed pipes can work alone on hilly terrains, while flat terrains require the mechanical pumping of the system for the generation of the pressure needed. In Surendranagar, this reliance is seriously hampered by a faulty local power grid characterized by frequent outages, rapid voltage reductions and restricted supply periods.

Whenever the grid goes down there is an instantaneous loss of pressure in the pipeline network. This results in delivery delays which upset local farming and irrigation schedules. Future project phases should prioritize the incorporation of dedicated, off-grid solar-powered pumping systems to provide long-term operational resilience.

7.2 Financial and Administrative Challenges in WUAs

The operational and financial health of the local water users associations (WUAs) is critical to the long-term survival of the UGPL network. However, field surveys identify two major, recurring administrative risks:

- Revenue collection deficits: Many associations face problems in collecting seasonal water fees from all members, which leads to immediate budget deficits and hinders regular maintenance.
- Internal governance failures: Uneven distribution of water and extended delays in maintenance of key infrastructure are typically the product of local political and community disputes.

To preserve these networks, state agencies need to move from passive oversight to active capacity building. This entails teaching WUAs organized governance, providing them with transparent means of financial audit, and giving them the legal ability to enforce bylaws and to hold emergency reserve monies.

7.3 Physical Obstructions and Sediment Management

The system takes water from rivers and open storage reservoirs which carry significant fine sediments and organic waste during monsoon season. In the event of damage or bypassing the main intake filtration systems, this silt is released straight into the network and is deposited inside the underground pipes.

Clearing these internal blockages is a complicated procedure that requires specialist equipment to flush the lines under high pressure, as the infrastructure sits underground. Future infrastructure designs should require automatic multi-stage filtering basins at all key canal intake locations to collect silt before to entry into the pipeline network, thus permanently reducing this risk.

8. Strategic Interventions for Public Investment

To enhance the long-term impact of public investments in underground pipeline (UGPL) networks, agricultural policymakers must make four fundamental strategic decisions:

8.1 Transition to solar-powered pressurized pumping

To reduce reliance on the unstable local power grid, state agencies should invest in large-scale solar-powered irrigation infrastructure. Installing high-capacity solar arrays at primary pumping stations ensures a stable, clean, and predictable energy supply during peak daylight hours. This transition allows the pipeline network to maintain constant pressure, automate water distribution, and significantly reduce operational overhead for local farmers.

8.2 Integration of micro-irrigation technologies

To harness the water-saving potential of the UGPL network, public programs should encourage farmers to connect modern drip and sprinkler systems directly to surface turnout valves. Combining sub-surface pipeline conveyance with root-zone micro-irrigation maximizes water-use efficiency on the farm. This integrated approach allows communities to expand total irrigable land while proactively protecting vulnerable local groundwater tables.

8.3 Strengthening WUA Governance with Digital Tools

State departments should work to encourage water user associations (WUAs) to use digital management systems, in order to foster transparency and operational efficiency. Administration is streamlined by mobile platforms for water fee collecting, digital scheduling logs for water distribution, and mobile-based maintenance tracking. These methods cut down on accounting errors, manage distribution conflicts and ensure stable income for the necessary system maintenance.

8.4 Establishment of Regional Technical Support Centers

State irrigation authorities should set up regional technical assistance centers to prevent long system shutdowns during major operational disruptions. Such centres have to preserve a strategic store of critical spare parts and have mobile response teams with specific pipeline inspection equipment and high-pressure washing devices. With the localization of these technological resources, bottlenecks and structural faults are quickly remedied, preventing crop stress and protecting seasonal yields.

9. Conclusion

The examination reveals that the underground pipeline project is a beneficial solution to upgrade canal-irrigated agriculture. The project eliminates the disadvantages of surface irrigation systems by using underground pipes instead of open channels. It prevents land disputes, stops significant water loss during conveyance, and returns valuable land to farmers. The system is really effective and can make a major impact on how we manage water for agriculture. For example, it helps to reduce the wastage of water and free more land for crop cultivation. In summary, the underground pipeline project is a sensible approach to improve and make canal-irrigated agriculture efficient. This improved water infrastructure has led to a fundamental change in rural lives in the semi-arid climate of Surendranagar district. The dependable and predictable nature of water supply has enabled farmers to abandon low-value subsistence crops and to take up cash crops and commercial horticulture, which yield substantial profits. This agricultural shift delivers a tremendous economic double whammy, sharply cutting seasonal expenses on labor, energy, and fertilizers while improving crop yields and total income. Most crucially, the UGPL design provides real economic equality across the canal system so that populations at risk of being left behind have the same financial security and earning power as those upstream. And as we face the repercussions of climate change—extreme weather and changes in monsoon patterns—it is indeed necessary to build systems that use water wisely. It is vital to ensure the long-term safety and security of rural communities. Most crucially, the UGPL design provides real economic equality across the canal system so that populations at risk of being left behind have the same financial security and earning power as those upstream. And as we face the repercussions of climate change—extreme weather and changes in monsoon patterns—it is indeed necessary to build systems that use water wisely. It is vital to ensure the long-term safety and security of rural communities.

References

- Barker, R., Dawe, D., & Inocencio, A. (2004). The economics of water productivity in agriculture: A review of concepts and empirical evidence. *Water International*, 29(1), 87-93.
- Birthal, P. S., Negi, D. S., Khan, M. T., & Agarwal, S. (2015). Is Indian agriculture becoming resilient to droughts? Evidence from rice production. *Food Policy*, 56, 1-12.
- Chambers, R. (1988). *Managing Canal Irrigation: Practical Analysis from South Asia*. Cambridge University Press.
- Easter, K. W. (1993). Economic failure of irrigation projects: The linkage between design, incentives, and institutional arrangements. *Food Policy*, 18(1), 56-61.
- Government of Gujarat. (2014). *Revised Policy Guidelines for Underground Pipeline (UGPL) Sub-Minors in Sardar Sarovar Project Command Area*. Water Resources Department, Gandhinagar.
- Jamod, M. K. (2024). *An Economic Evaluation of Underground Pipeline (UGPL) Scheme under Sardar Sarovar Project: A Comparative Study of Beneficiary and Non-Beneficiary Farmers in Surendranagar District*. Department of Economics, Veer Narmad South Gujarat University, Surat.
- Merriam, J. L., & Keller, J. (1978). *Farm Irrigation System Evaluation: A Guide for Management*. Utah State University.
- Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.
- Palanisami, K. (2002). Sustainable management of tank irrigation systems in India. *Water Policy*, 4(4), 289-302.
- Panwar, P., Singh, R., & Kumar, S. (2021). Economic viability of underground pipeline irrigation system projects in Punjab. *Indian Journal of Soil Conservation*, 49(2), 112-120.
- Shkuropat, A. (2011). *Hydraulic Efficiency of Low-Pressure Closed Conduit Distribution Networks*. Academic Press.
- Vansiya, Y. N. (2023). *Institutional Paradigms in Command Area Development: Analyzing Public-Private-Community Partnerships*. Gujarat Economic Association Conference Proceedings, 44-59.