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Assessing the cost-effectiveness and adoption barriers of micro-irrigation (drip, sprinkler) among smallholders in Karjat (Ahmednagar District)

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Abstract

Karjat taluka in Ahmadnagar district of the state Maharashtra lies under a semi-arid drought-prone agro-climatic zone with seasonal water scarcity trade-off, which limits its agricultural productivity. Farmers have to rely on wells and traditional irrigation, with very little mechanised infrastructure. Micro-irrigation (MI), including drip and sprinkler technologies, allows improved water-use efficiency, higher yields, and income, but its range in adoption is relatively limited due to high capital costs, technical constraints and institutional bottlenecks. Evaluation of cost-effectiveness and Barriers to adoption in the study area: MI was assessed for its cost-effectiveness in Karjat by making use of the secondary data through government reports, district plans, aquifer studies, and academic literature. The economic model for the 1–3 ha holdings is based on investment and borrowing costs, PMKSY subsidies, higher yields obtained from alternate row planting systems for sorghum/pearl millet/cotton, and crop price variability. Findings demonstrate that MI can be profitable, especially for high-value crops like sugarcane, onion, and vegetables, with payback periods of 0.5 yrs to 2 years and even benefit–cost ratios over 2 throughout the life of the system; profitability is lower in cereals and pulses. Barriers to adoption are further classed as financial (excessive upfront cost, credit access), technical (design, maintenance), institutional (subsidy delays, weak coordination) and social (risk-averse, peer influence). Managing these barriers by an integrative intervention is necessary to harness the potential of MI in enhancing water productivity and resilience in the economically distressed agriculture practices of Karjat.

Key Words: *Agro Climatic Zone, Agricultural productivity, Micro-irrigation*

Introduction

Karjat taluka, situated in the Ahmednagar district of Maharashtra, falls under semi-arid and drought-prone agro-climatic zones where erratic supply of water has always kept agricultural productivity on check **(Gore & Kadam 2019).** The majority of the farmers in this region are dependent on wells and traditional hand-dug wells for irrigation without major portable, large-scale mechanised irrigation infrastructure **(Government of Maharashtra, Minor Irrigation Census 2017).** Seasonal water stress, mainly during late rabi and summer months, resulted in altered cropping patterns and lower yields **(Patil et al., 2020).** Micro-irrigation (MI) technologies, mainly drip and sprinkler systems, are increasingly advocated as a viable solution to amplify water-use efficiency, crop yields, income per unit of water, and cropping intensity **(Narayanamoorthy 2010; Kumar et al. 2021).** These are the systems that, in theory, can deliver significant benefits in water-limited Geographies like Karjat. But uptake among smallholders is frequently limited by a number of reasons. These are predominantly high capital investment required at the time of installation, continuous recurring maintenance obligation needed for proper function, inadequate technical knowledge.

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and institutional bottlenecks such as subsidy delays **(Birthal et al., 2015; GOI, 2020).** A body of local evidence suggests that traditional water sources, as well as segmental development of water management systems, dominate the subject region, indicating the potential gains and limitations of adopting MI in this region **[GOM 2017].**

2. Research methodology

This study uses secondary data, collating taluka/district reports and dashboards for Karjat and Ahmednagar (SOPPECOM water balance, CGWB aquifer report, PMKSY micro-irrigation progress, NABARD PLP, DES APY tables) along with academic/policy literature. Wells, gross cropped area, major crops, micro-irrigation coverage, subsidy levels and cost parameters will be recorded in a database. The assessment will apply an economic modelling approach for 1 ha and 2.5 ha holdings, respectively, using literature-based costs, yield gains, and local price data to estimate cost-benefit and payback periods with sensitivity for yield scenarios with a subsidy in place or none. The general concept considers that barriers will be synthesised in terms of financial, technical, institutional and social categories. The new solutions will be based on NABARD/PLP and a successful policy brief. Information regarding data sources (specific secondary sources)

3. Cost-effectiveness modelling (method, assumptions & illustrative results)

3.1 Assumptions used (drawn from literature & program documents)

Capital cost (installed) for drip: baseline gross cost ≈ INR 60,000-120,000/ha (by crop, emitter type, filters, fertigation), subsidies can substantially reduce farmer-paid costs per state/PMKSY. (Use local subsidy schedules in PMKSY / state) (PM-KISAN, extension journal.com). Capital cost (installed) for sprinkler: baseline ≈ INR 30,000–70,000/ha, depending on system size (extension journal.com). Yearly O&M: 3-7% of capital cost per year (filters, repairs, labour). Meta ranges of increases in vegetable/fruit yields were 20–40% and in many field crops, 10–20% under MI relative to furrow/flood irrigation, according to crop-specific literature. Enter 10% (low), Conservative but very realistic! 20% (medium) real-world case, and 35% (high).MI can sometimes save farmers 30–60% of water applied per ha relative to flood irrigation, but this may not translate into saving pumped groundwater if farmers expand the area under irrigation or pump more water (RCT). Consider water-saving as a lower extraction (efficiency) helper. Farm sizes: 1.0 ha (smallholder) and 2.5 ha (medium smallholder).

3.2 Simple payback formula (illustrative)

Payback (yrs) = (Farmer net installed cost) ÷ (Annual net incremental profit from MI), where incremental profit = (Yield uplift × price × yield baseline × area) − (annual O&M + extra input costs if any).

3.3 Illustrative numeric example (medium scenario) — on 1 ha (vegetable/market crop mix)

Farmer net installed cost after subsidy: INR 40,000 (drip; illustrative mid figure).
Baseline net income per ha (farming household, mixed veg): INR 80,000/yr (conservative district-level proxy).
Yield uplift: 20% → additional net income ≈ INR 16,000/yr.
Annual O&M: INR 3,000.
Annual net incremental benefit ≈ INR 13,000.
Payback ≈ 40,000 / 13,000 ≈ 3.1 years.

3.4 Sensitivity (summary)

Inexpensive case (10% yield uplift) → restitution ~6+ years (a minor compared to).
High-return scenario (35% uplift) → payback ~1.5–2 years (VERY interesting).
It may be a shorter payback time for some crops than sprinkler systems with lower capital Investment, but the yield uplift is much smaller in drip-suitable crops(fruit/vegetable) sentences-paraphrasing.
Such illustrative calculations echo findings in adoption studies; e.g., it has good potential to be profitable through MI on irrigated vegetables and horticulture but poor on low-value cereal crops unless some form of subsidy or contract/market linkage is available, which might also explain some regional differences. (extensionjournal. com)

4. Adoption barriers

Synthesised evidence (financial, technical, institutional, social)
High upfront capital cost & access to credit
Smallholders lack liquidity; subsidy procedures can be cumbersome; commercial bank lending often requires collateral. Studies show financial constraints are among the top reported barriers.

4.1. Size and fragmentation of landholdings

MI systems are more economical at larger contiguous areas; tiny, scattered plots reduce economies of scale and make installation and maintenance harder. (Observed in Maharashtra case studies and national policy briefs.)

4.2 Water source reliability and pump capacity

Karjat's heavy reliance on dugwells (large counts) implies variable yields and limited pump capacity MI works best where reliable pressurised water is available. If the pumping capacity is low, the required pressure/uniformity is not achieved. Documented as a practical constraint in the local water balance report. (soppecom.org)

4.3 Operation & maintenance knowledge gaps

The MI systems need to be checked and filters cleaned regularly, emitter flushing required, as well as other repairs from time to time. There are inadequate extension services and trained technicians at the taluka level. Studies recommend local technician training. Experimental evidence (RCTs) suggests that improved irrigation efficiency (drip) per se does not reduce groundwater extraction, but may result in farmers intensifying cropping or increasing irrigated area, which can lead to risks of aquifer sustainability unless conjunctive measures (metering, groundwater governance) are enforced. Subsidy schemes tend to be provided for big or more well-connected farmers, leading to discrimination, while tardiness and bureaucracy reduce their uptake. Indeed, a few studies have found that poorly designed subsidies can harm the climate.

5. Results & Discussions

5.1 Estimate the likely cost-effectiveness (simple payback and benefit: cost) of installing micro-irrigation on typical smallholdings (1–3 ha) in Karjat using secondary cost and yield data.

An indicative assessment of the potential cost-effectiveness of MI adoption on representative Karjat smallholdings (1–3 ha) can be made through the use of available secondary data relating to capital costs, subsidies, yield benefits and crop prices. A front-end analysis of studies and government data suggests that drip & sprinkler systems, along with the subsidies under PMKSY, could cut farmer investment cost by as much as 50% per hectare while delivering up to double-digit yield gains, especially in high-value or water-intensive crops like Sugarcane, Banana, vegetables, etc. Economic modelling using literature and market-based data indicates that on average, the simple payback period is in the range of 2 years during its life cycle, thus MI appears to be a financially attractive as well resource resource-efficient technology for the region. The above point is justified based on below points.

5.1.1 Data, assumptions, and why they're reasonable

We apply official PDMC/PMKSY subsidy norms (55% for small & marginal farmers, 45% for other farmers) and indicative/unit-cost ranges triangulated from government guidelines and sector sources; ₹0.85–1.50 lakh/ha is used as a realistic installed-cost band for drip and ~₹0 sectors; farmer outlay = cost – subsidy dosing or per-unit help.

5.1.2 Press Information Bureau pmksy.gov.in

We express benefits as monetized (i) yield increases estimated for Maharashtra (e.g. sugarcane +36–46%; banana +16–73%; onion +4–26% from MHT seed/onion studies in Western Maharashtra), and(ii) level of energy/water savings credible enough that they can be traded for cash (a conservative approach – ag power is commonly flat-tariff). For valuing output, we consider the Govt-notified sugarcane FRP (₹340/qtl for 2024–25; ₹355/qtl for 2025–26) and wholesale onion price bands reported recently in Maharashtra (≈₹950 – ₹3,600/qtl over 2024–25 Current avg ~₹2,000/qtl).

Base line yields are estimated primarily based on modern Maharashtra statistics (sugarcane ≈91 t/ha) at the bottom in mixture with published variety estimates of onion productiveness for western Maharashtra/Nashik (≈17–23 t/ha) incomes a be aware on excessive intra-season yield volatility; in which district-unique statistics is skinny, proxies making use of state/district-cluster averages are used instead. For the Karjat context, where semi-arid climate and groundwater reliance of well irrigation makes the yield-stabilisation advantage of micro-irrigation particularly important, we present between-band scenario ranges (low/base/high) to reflect weather and market variation year-on-year.

5.1.3) Drip on sugarcane (1 ha; extend linearly to 2–3 ha)

Costs & subsidy: Rs. 1.10 lakh/ha can be considered as an average installed cost for one standard set of sugarcane; with PDMC, farmers would pay around Rs 49,500 (farmer share @ 55% for small/marginal) or Rs 60,500 (farmer share @45% in all other cases) Tigray evidence +42% (DRIP: Thirsty) ⇒ 21 t/ha incremental sugar Yield benefit: Maharashtra evidence reports +36–46% yield with drip; conservatively take +30% for base case on a 91 t/ha baseline ⇒ +27 t/ha incremental cane. Revenue lift: Rs 27/t at FRP. At ₹3,400/t (₹340/qtl, 2024–25) extra revenue ≈₹91,800/ha/yr; at ₹3,550/t (₹355/qtl, 2025–26) ≈₹95,850/ha-/yr; O&M ~2-3% of capital is minor compared to gains so the net benefit will still be around `88–93k +. Farmer share ₹49,500–₹60,500 (simple payback ≈0.5–0.7 years); full system cost ₹1.10 lakh (≈1.1–1.3 years) with good payback for perennial cane. Benefit: Cost (B: C): Based on the net annual benefit ≈₹90k and annualized cost proxy as "full capex" (conservative; one-year horizon) gives a B: C ≈0.8 if you exclude multiyear life, but using standard practice-benefits over ≥5–7year life for both methods of measurement alluded in the previous paragraph, B: C comfortably crosses 3-4 and even with one-year snapshot on farmer outlay, B:C remains between 1.5 and 1.9. The author is an external advisor, NITI Aayog.

5.1.4) Drip on onion (1 ha; transferable to vegetables/banana with crop-specific rates)

Cost & subsidy: ₹1.10 lakh/ha mid-cost; farmer share with PDMC ≈₹49,500 (small/marginal) or ₹60,500 (other).

Gain: Onion alone (including seed/onion systems) following drip in studies in western Maharashtra by roughly 4–26%; water saving widely documented; before: Onion bulb baseline 20 t/ha – seed/onions, mltn outlet &glabh;mtps. antagonists/weed controls. Other inputs and +15% yield gain ⇒ +3 t/ha. Maharashtra onion data is a minefield of price banding; recent bands: ₹950–₹3,600/qtl… ₹2,000/qtl (₹20,000/t) hardly overstates it at present.

Revenue lift: +3t×₹20,000/t = ₹60,000/ha/yr (mid-case); low-case(₹10,000/t)≈₹30.000; high-case(₹36,000/t)≈₹108.0 00;[drip may also cut fertigation/water costs, but we exclude to stay conservative].

Payback & B:C: Mid-case payback ≈1.0-1.2 years on farmer share; low-case ~ 1.7-2.0 years; high-case ~ 0.5 year; one-year B:C on farmer share ranges approximately 0.5 -2.2 (low → high), with multi-year system life pushing true B: C well above 2 in typical seasons

5.1.5) Sprinkler on field crops (sorghum, pulses, onion on wider spacing)—1 ha case

Micro /mini sprinklers evidence unit cost ₹0.65 –0.95 lakh/ ha (depending on spacing/area); PDMC subsidy shares remain the same; hence, farmer outlay is ₹29- 52k (SC and ST) or ₹36- 52k for all others. Yield & water effects tend to be smaller than drip; literature commonly reports on-farm 5–15% yield gains with ~20–40% water saving, depending on design; in our value-only-yield (cash), we treat water savings as risk-buffering. Illustrative onion/wide-row vegetable case (baseline 18 t/ha; +10% gain ⇒ +1.8 t): here \(at ₹20,000/t\) this is ≈₹36,000/ha/yr additional revenue; payback <0.7–1.4 years depending on the exact kit cost and subsidy category. Payback will be slower (often ~2–3 seasons) for cereals/pulses with lower value per tonne, unless combined with fertigation or intercropping that raises gross returns per ha. Some of its water-saving turns to real rupee savings in energy, where electricity is either metered or diesel pumping employed, potentially improving paybacks further, but acknowledges that this will vary by farm and may not be widely realised under flat-tariff power.

5.1.6) Sensitivity, scaling to 2–3 ha, and bottom line for Karjat

Scaling: At 2–3 ha, per-hectare hardware costs usually fall slightly (longer mains, but economies on filters/controls), so farmer outlay/ha drops a bit; benefits scale roughly with area if water is adequate (a key constraint in semi-arid Karjat). (pmksy.gov.in)

Market sensitivity: Onions are price-volatile; in low-price months (₹900–₹1,200/qtl) paybacks lengthen; in high-price phases (₹3,000–₹3,600/qtl) they compress dramatically; sugarcane is more stable due to FRP, so drip on cane is the most robust investment.

5.1.6.1 Food & Public Distribution

Representative results (per ha): (A) Sugarcane drip—farmer payback ≈0.5–0.7 yrs; one-year B: C on farmer outlay ≈1.5–1.9; multi-year B: C ≫2–3; (B) Onion drip—payback ≈0.5–2.0 yrs depending on price; (C) Sprinkler—payback ≈0.7–3.0 yrs depending on crop/value.

5.1.6.2 Press Information Bureau

Caveats: Field performance depends on design quality, filtration, maintenance, and reliable water source; Jevons-type rebound (using saved water to expand area) can raise pumping time rather than save water, so aquifer-sensitive governance is needed.

5.2 Identify and categorise the main adoption barriers (financial, technical, institutional, social) as described in policy reports and academic literature.

Policy reports and academic literature have documented financial, technical, institutional and social barriers leading to low adoption of micro-irrigation (MI) in Karjat tahasil. Smallholders cannot afford the high upfront costs of installing these systems, especially after PMKSY subsidies, and face financial stress; with poor access to credit and delays in subsidy release further acting as a deterrent. These technical problems include system inefficiency as a result of poor design, poorly filtered and delivered water to plants and insufficient maintenance by skilled staff. The institutional challenges are multi-dimensional in that they arise from iterative barriers which include complicated application processes, not all actors acting in unison and a lack of extension resources. Another barrier to adoption includes social factors — the risk-averse nature of people, who usually rely on traditional methods, and other people have bad experiences using peer-to-peer technology. The challenge in that is tremendous and overcoming these barriers would involve a suite of integrated financial, technical, as well as community-based interventions contextualised to Karjat. The point mentioned above is illustrated through the points below.

5.2.1) Financial barriers

The cost of Up-front MI is high in Karjat for smallholders, granted, PDMC (PMKSY) does contribute towards this but the quantum of support at the time of purchase is still significant. (PM Kisan Samman Nidhi, pdmc. da. Source: Maharashtra DBT Portal (dbt.maharashtra.gov.in) Source2:

Maharashtra DBT Portal (dbt.maharashtra.gov.in) The subsidy sharing pattern outlined in the government of Maharashtra's own DBT portal mentions common shares — 45 per cent if you are not a small or marginal farmer and only around 55 per cent of that share for others such as small/marginal farmers, suggesting a hefty farmer contribution which cash-strap [ed households could shy away from. As in NABARD Ahmednagar PLP notes, while credit is critical for adoption of technology, the very processes of documentation/collateral/procedural delays serve as a bottleneck to slow down conversion. MI economic analyses from Maharashtra show that the frictions (timelines/clearance related) in availing subsidies lead to working-capital gaps between installation and reimbursement. (India Water Portal). With Karjat experiencing severe drought and groundwater stress, farm cash flows are erratic at best, as usual, the farmer's immediate needs take precedence over long-term investments spanning several seasons (even when MICL might be profitable on paper). (soppecom. org)

5.2.2) Technical barriers

In the field design, filter and after-sales service is not improper cause emitter plugging most many times, being a profound ditch in water Table and very bio-degradable sewage slowly, it may take longer to become but ultimately results in Hereby on slow lower PPM and eye holing, which proves viol proof. Poorly accounted for head losses, improperly calibrated well-based irrigation techniques in such cases of Ramnadi and Karjat may lead to disinformation regarding the water distribution, possibly occurring through undulating terrains. Ahmednagar couplet-based CGWB solution has made SIAM operation time-bound as CGWB proposes an aquifer-wise approach based on nonuniform availability + quality of groundwater. (Central Ground Water Board) Lack of adequate trained local technical manpower, and gaps in the capacity building of farmers has resulted in minor faults to lie unattended at such critical periods leading to low perception benefits. Will MI continue being slowly rolled out without proper extension and integration with established crop rotations and fertigation practices, incurring incomplete yield gains and alienating the neighbours? (switchon. org. in)

5.2.3) Institutional barriers

Procedural complexity and delays in PDMC/DBT processing reduce farmer confidence and can force bridge financing at extra cost during installation. Fragmented coordination among departments, suppliers, and extension agents leads to inconsistent guidance on model selection, layout, and post-installation support. NABARD PLPs for Ahmednagar repeatedly underline the need for stronger credit linkages and last-mile facilitation to translate potential into financed adoption**.** District water-resource diagnostics (SOPPECOM) call for governance measures alongside hardware, implying MI uptake should be coupled with local institutions that manage wells and aquifers. **(soppecom.org)** Without responsive grievance redressal and timely subsidy release, early adopters' bad experiences circulate socially and depress subsequent demand. (**India Water Portal)**

5.2.4) Social barriers

Familiar flood methods are preferred especially by risk-averse farmers in drought-prone Karjat–Jamkhed, so new-age practices have been much harder to shift, demanding a journey of practical evidence and trust-building through credible demonstrations. (naammh. Behavioural Insights Team listens (Source: Behavioural Insights Team) Peer effects are potent: bad word-of-mouth spreads rapidly about badly-installed systems, and the weight of a brochure pales in comparison. (switchon. org. lack of awareness & training — even women farmers deciding on irrigation involvement is limited by the lack of knowledge they have, so less confidence in being able to fix things from day-to-day and make sustained use. (NABARD). With broadscale perception of groundwater stress comes the expectation of future prioritisation tanker water and emergency coping over investment in on-farm efficiency hardware, leading to slower adoption cycles. (naammh. SOPPECOM (soppecom.org) Sustained social mobilisation tied to local water-balance evidence can counter scepticism by demonstrating crop and aquifer outcomes from MI plus governance. (soppecom. org)

Conclusion

This study reveals that there is a substantial scope of upliftment in terms of water-use efficiency, leading to higher crop productivity as well as better economic prospects for the farming community in the semi-arid, drought-prone context of Karjat taluka under micro-irrigation (MI). PMKSY subsidies demonstrate that these drip and sprinkler systems can achieve paybacks (often less than 2 years for high-value crops such as sugarcane, banana or vegetables) and benefit–cost ratios over the system lifespan is typically more than 2 [5]. The yield-stabilising effects of MI assume further relevance in a place like Karjat, where fossilised groundwater from natural wells is the mainstay for agriculture, but its availability year after year is rather variable (and unpredictable). While quite a few interlinked barriers continue to hold back adoption. At a financial level, the high costs of investment, lack of access to credit and delays with subsidy payments have all acted as immediate impediments for smaller farmers in adopting CA. Performance is technically crippled by the poor design of the system, issues with maintenance of the facility and supply limitations. Procedural complexity and weak coordination institutionally, and insufficient extension support at the provincial level are some of the factors that have inhibited uptake. Social: Risk-aversion, low awareness and bad word-of-mouth complaints conspire to further retard diffusion. These results imply the need for financial incentives alone not to be enough for MI adoption in Karjat and emphasise that strong technical training, reliable after-sales services, efficient subsidy disbursement or community-level awareness programs are necessary. The MI expansion should therefore be combined with governance over the local groundwater resources to avoid rebound effects and ensure the long-term sustainability of the aquifers. Working towards these holistically can lead to unlocking MI's dual promise of higher farm incomes and water security in Karjat.

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