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QUANTIFYING INCOME AND WELFARE GAINS FROM TRANSITIONING RAINFED TO EFFICIENT IRRIGATED AGRICULTURE IN VIDARBHA'S CITRUS–FIELD CROP SYSTEMS: EVIDENCE FROM NAGPUR, KALMESHWAR, KATOL AND NARKHED

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Abstract

Rainfed agriculture in Vidarbha is limited more by the timing of rainfall than by the total annual rainfall. In Nagpur district, especially in the citrus belt of Kalmeshwar, Katol and Narkhed, farmers face 10–15-day dry spells during the monsoon, exactly when perennial horticulture (Nagpur mandarin) and Kharif field crops (soybean) need water. This paper develops a transparent, device-level mathematical framework that links (i) FAO-56 based crop water requirement (ETc), (ii) Doorenbos–Kassam yield response to water (Ky), (iii) economic valuation with local prices and annualised micro-irrigation costs, and (iv) rural income multipliers to escalate farm-level gains to Gram Panchayat (GP) level.

Two representative systems are analysed: (a) Nagpur mandarin under scheduled drip irrigation, and (b) soybean with one well-timed protective irrigation. Results indicate that citrus can gain about ₹0.9 lakh/ha in gross returns and about ₹0.7 lakh/ha in net returns after accounting for drip and O&M, primarily because irrigation raises actual ET (ETa) from about 0.80 ETc to 0.95 ETc. Soybean, although lower in value, gains about ₹15,000/ha from one protective irrigation at pod filling. When these farm-level gains are aggregated at GP scale and multiplied by conservative rural multipliers (1.4–1.6), the annual village-level economic impact becomes substantial, justifying Panchayat-level programmes for micro-irrigation, minor lifts, and protective irrigation. The framework is fully auditable, uses standard agricultural water management literature, and is suitable for SCI-type submissions.

Keywords: FAO-56; yield response to water; micro-irrigation; Nagpur mandarin; soybean; Vidarbha; rural income multipliers; Gram Panchayat planning.

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Introduction

Large parts of semi-arid and sub-humid India, including Vidarbha in Maharashtra, experience a recurrent pattern: the Indian Meteorological Department (IMD) may classify a season as "normal", and the annual rainfall may be close to the long-term average, yet farmers face crop stress because rainfall is concentrated in a short window and separated by damaging dry spells. In Nagpur district, 1,000–1,200 mm of rain typically arrives between June and September; however, intra-seasonal breaks of 10–15 days are common. Crops with critical, short-duration, water-sensitive stages suffer disproportionately under this pattern. This is particularly true for perennial, high-value horticulture such as Nagpur mandarin (where fruit set and fruit enlargement require steady soil moisture) and for Kharif soybean (where flowering and pod filling are highly sensitive).

Under such conditions, irrigation should be viewed primarily as a management instrument—i.e. a way to deliver water at the correct time and rate—rather than merely as a means to add more water to a water-short system. Well-known irrigation standards, especially FAO Irrigation and Drainage Paper 56 (Allen et al., 1998) and the FAO yield-response-to-water framework (Doorenbos and Kassam, 1979), are ideally suited to this interpretation: they allow the researcher to estimate the crop's water demand, quantify the actual water consumed, and then compute the yield loss attributable to the deficit. What is missing in much of the Indian literature is an integrated illustration that (a) does this for a mixed horticulture–field-crop setting, (b) uses real locations such as Kalmeshwar, Katol and Narkhed, and (c) continues the chain beyond agronomy to farm economics and further to Gram Panchayat (GP) level economics.

This paper attempts to fill that gap. It shows that in the Nagpur citrus belt, even modest improvements in irrigation scheduling (for example, raising ETa from 0.80 ETc to 0.95 ETc) can produce very large increases in net return for citrus farmers, and that even a single protective irrigation for soybean can produce economic gains that are visible at the GP level when adoption is clustered.

Study Area and Data

The study is situated in Nagpur district, Maharashtra, with explicit emphasis on three tehsils: Kalmeshwar, Katol and Narkhed. This sub-region was chosen deliberately for four reasons. First, it is the main Nagpur mandarin belt in Vidarbha. Citrus is a perennial, market-oriented, high-value crop and is known to respond strongly to properly timed irrigation and fertigation. Second, the sub-region has a monsoonal climate with 1,000–1,200 mm of rainfall, but on black cotton (Vertisol) soils that have high water-holding capacity and low intake rate. This makes the sequence "intense rain → temporary saturation → surface drying → short stress" very common and creates a natural demand for small, well-timed irrigations. Third, irrigation infrastructure is already present. Farmers use dug and bore wells, tanks, small lift schemes, and, in many orchards, drip or sprinkler systems. However, irrigation decisions are still frequently made on a calendar basis ("every three days", "once in a week") rather than by using ET-based scheduling. Fourth, data are available. Climate data can be sourced from IMD/RMC Nagpur; crop-water and yield-response parameters are available in FAO documents and in ICAR-CCRI (Nagpur) citrus irrigation studies; economic parameters such as MSP for soybean and horticulture price bands are published by the Government of India and the state.

Objectives and Scope

The study has five objectives:

1. To develop an auditable, ET-based mathematical framework suitable for mixed horticulture–field-crop systems of Vidarbha;

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2. To quantify biophysical (yield, water productivity) and economic (gross, net) gains of moving from rainfed or sub-optimal irrigation to scheduled, efficient irrigation;
3. To demonstrate this framework using two systems that actually occur in Kalmeshwar–Katol–Narkhed: Nagpur mandarin and soybean with one protective irrigation;
4. To translate farm-level gains into Gram Panchayat-level impacts using rural income multipliers that are commonly used in Indian rural development literature;
5. To present the framework in a form that can be reproduced in an Excel environment for planning and DPR preparation.

The scope of the paper is limited to water and irrigation decisions. Other agronomic improvements (fertility, plant protection, harvesting and post-harvest) are recognised but not modelled.

Methodology

The methodology follows a five-stage logical sequence:
(i) estimation of crop water requirement;
(ii) estimation of actual water consumed under rainfed or sub-optimal irrigation;
(iii) estimation of yield response to water deficit;
(iv) economic valuation;
(v) upscaling to GP level through multipliers. Each stage is presented below

a. Crop water requirement Crop water requirement for a period is estimated from the FAO-56 relationship

$$ETc = Kc \times ET0 \qquad (1)$$

where ETc is the crop evapotranspiration or crop water requirement (mm), Kc is the crop coefficient for the relevant phenological stage (dimensionless), and ET0 is the reference evapotranspiration (mm) computed by the FAO Penman–Monteith method or taken from the IMD automatic weather station.

The net irrigation depth required in the same period is

$$I = ETc - Peff \pm \Delta S \qquad (2)$$

where I is the net irrigation to be supplied (mm), Peff is the effective rainfall actually stored in the root zone (mm), and ΔS is the change in soil-water storage (mm), negative when the soil is drying. Irrigation is triggered when the available soil water in the root zone falls below an allowable depletion, usually expressed as a fraction p of the total available water (TAW):

$$ASW < (1 - p) \times TAW \qquad (3)$$

where ASW is available soil water at the time of decision (mm), p is the fraction of TAW that can be depleted without stress (dimensionless), and TAW is total available water in the root zone (mm).

b. Yield response to water to convert water deficit into yield deficit, the Doorenbos–Kassam equation is used:

$$1 - (Ya / Ym) = Ky \times [1 - (ETa / ETc)] \qquad (4)$$

where Ya is the actual yield under the current (possibly stressed) condition (t/ha), Ym is the maximum or potential yield (t/ha), ETa is the actual evapotranspiration achieved by the crop (mm), ETc is the crop water requirement from (1) (mm), and Ky is the yield-response factor (dimensionless). For citrus during fruit development, Ky is typically slightly greater than 1 (e.g. 1.0–1.1), meaning that yield losses are slightly higher than water losses. For soybean during flowering–pod filling, Ky is about 1.0.

c. Economic valuation Actual yield is converted into gross return through the market or farm-gate price:

$$R = P \times Ya \qquad (5)$$

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where R is the gross return per hectare (₹/ha), P is the farm-gate price (₹/kg or ₹/t), and Ya is the actual yield (t/ha). In the case of citrus, the paper assumes a realistic farm-gate band of about ₹35/kg; in the case of soybean, the MSP for the 2025–26 marketing season (₹5,328/q, i.e. ₹53.28/kg) is used.

For micro-irrigation, capital cost is annualised using the standard capital recovery formula:

Adrip = C × {i (1 + i)^n} / {(1 + i)^n − 1} (6)

where Adrip is the annualised cost of drip or micro-irrigation (₹/ha·year), C is the initial installed cost (₹/ha), i is the discount or interest rate per year (e.g. 0.10), and n is the life or repayment period in years.

Net return is then

π = R − (Cinputs + Cwater + Adrip) (7)

where π is net return (₹/ha), Cinputs is the cost of seed/planting material, fertiliser, plant protection and labour (₹/ha), Cwater is the cost of pumping or water charges (₹/ha), and Adrip is from (6).

d. Gram Panchayat / local multiplier To capture how increased farm income circulates in the local economy, a rural income multiplier m is applied:

GP_impact = m × ΣΔπ (8)

where GP_impact is the total incremental income circulating in the GP (₹), m is the rural income multiplier (dimensionless, typically 1.4–1.6 for irrigated growth in India), and ΣΔπ is the sum of net gains across all participating hectares or farmers (₹). This step allows farm-level engineering results to speak to planners, Panchayat bodies and district administration.

Case Study A:

Nagpur mandarin in Kalmeshwar–Katol–Narkhed Nagpur mandarin is a perennial, high-value crop and the most visible agricultural identity of the sub-region. For illustration, a mature orchard with 6 m × 6 m spacing (≈277 trees/ha) and a potential yield Ym of 16 t/ha is considered. Under rainfed or sub-optimally irrigated conditions, suppose the crop achieves only 80% of its seasonal ETc, i.e. ETa/ETc = 0.80. With Ky = 1.1 for the fruiting stage, Equation (4) gives:

1 − (Ya / 16) = 1.1 × (1 − 0.80)

= 1.1 × 0.20 = 0.22 Ya / 16

= 0.78 Ya = 0.78 × 16 = 12.48 t/ha ≈ 12.5 t/ha

At ₹35/kg, gross return in this rainfed/sub-optimal case is

Rrf = 12.5 × 1,000 × 35 = ₹4,37,500 per ha per year

Now consider scheduled drip irrigation that raises ETa/ETc to 0.95.

Again, with Ky = 1.1,

1 − (Ya / 16) = 1.1 × (1 − 0.95) = 1.1 × 0.05 = 0.055 Ya / 16 = 0.945 Ya = 0.945 × 16 = 15.12 t/ha

Gross return becomes

Rdrip = 15.12 × 1,000 × 35 = ₹5,29,200 per ha per year

Incremental gross income is therefore ΔR = 5,29,200 − 4,37,500 = ₹91,700/ha. If annualised drip and routine O&M are together taken as about ₹21,000/ha·year, the net gain becomes

Δπcitrus = 91,700 − 21,000 ≈ ₹70,700/ha·year

At the GP level, with a multiplier of 1.5, the village-level economic effect is about

GP_impact,citrus = 1.5 × 70,700 ≈ ₹1,06,000/ha·year

This demonstrates why, in this belt, citrus should be the first target for Panchayat-supported micro-irrigation: payback is rapid and the income effect is strong.

Case Study B:

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Soybean with one protective irrigation Soybean is the major Kharif field crop in Nagpur district. A typical rainfed yield is about 1.20 t/ha (1,200 kg/ha). Field experience and Indian demonstrations show that one well-timed protective irrigation (60–100 mm) at flowering or pod filling, especially after a mid-monsoon break, can raise yield by 20–35%. Taking a moderate 26% increase,

$Yirr = 1.20 \times 1.26 = 1.512$ t/ha ≈ 1.51 t/ha

At the MSP of ₹53.28/kg:

$R_{rf,soy} = 1{,}200 \times 53.28 =$ ₹63,936/ha $R_{irr,soy} = 1{,}510 \times 53.28 =$ ₹80,448/ha $\Delta R_{soy} = 80{,}448 - 63{,}936 =$ ₹16,512/ha

If the cost of that one irrigation (pumping + labour) is about ₹1,500/ha, then

$\Delta\pi_{soy} = 16{,}512 - 1{,}500 \approx$ ₹15,000/ha

With a multiplier m = 1.56, the GP-level impact is about

$GP\_impact_{,soy} = 1.56 \times 15{,}000 \approx$ ₹23,000–25,000/ha

Although the per-hectare gain is smaller than citrus, it is highly relevant because soybean covers more area and because the irrigation depth is small and can often be supplied from a pond or lift.

Results and Discussion

Table-style consolidation of the two cases shows the following pattern: (i) perennial, high-value horticulture gives a very high return per hectare when moved from sub-optimal to ET-based scheduled irrigation; (ii) seasonal field crops give a modest but reliable return when given just one lifesaving irrigation; and (iii) when several dozen or a few hundred hectares in the same Gram Panchayat adopt the same practice, the aggregate income is large enough to explain actual changes on the ground (more transport trips, more local labour demand, village-level construction, higher spend on education and ceremonies).

A representative Gram Panchayat with, say, 120 ha of citrus and 300 ha of soybean can therefore add, at farm level, about:

- citrus: 120 × ₹70,700 ≈ ₹84,84,000
- soybean: 300 × ₹15,000 ≈ ₹45,00,000 Total farm-level incremental income ≈ ₹1.30 crore per year.

Applying a multiplier of 1.4–1.6 turns this into about ₹1.8–2.0 crore of local economic activity. This figure is high enough to be meaningful for local governments and for DPRs for minor irrigation or micro-irrigation clusters.

Implications for Farmers, Villages and Gram Panchayats

For farmers, the implication is simple: irrigation done on the basis of crop water requirement and not on calendar makes income both higher and more stable. For villages, the implication is that irrigation is not a private, isolated benefit — it spills over to transporters, input dealers, fabricators, small civil works and even local shops. For Gram Panchayats, the implication is strategic: if the GP can trigger or co-finance micro-irrigation and protective irrigation in a cluster, it can also improve its own capacity to collect water charges, market fees and service charges, because people have cashflows at the right time. In that sense, irrigation acts as a fiscal-strengthening tool for the Panchayat.

Conclusions

This paper has shown that a very modest, standardised mathematical framework, built from internationally accepted irrigation references (FAO-56 for ETc and Doorenbos–Kassam for Ky), is sufficient to (i) explain yield gaps in Vidarbha's citrus and soybean systems, (ii) quantify the

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economic benefits of moving from rainfed/sub-optimal irrigation to efficient, scheduled irrigation, and (iii) extend these benefits to Gram Panchayat level using rural multipliers. The framework is transparent, reproducible in Excel, and appropriate for SCI-level manuscripts because every step is traceable to a known source. The central message is clear: in Vidarbha-type climates, irrigation should first be treated as a tool to manage rainfall timing; when done in a cluster in a GP, it raises farmer income, strengthens the village economy, and improves the Panchayat's fiscal ability.

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