TYPE Perspective
PUBLISHED 30 March 2023
DOI 10.3389/fsufs.2023.1159011

OPEN ACCESS

EDITED BY
Abdelazim Negm,
Zagazig University, Egypt

REVIEWED BY
Hassan Awaad,
Zagazig University, Egypt

*CORRESPONDENCE
Praharsh M. Patel
✉ praharshmpatel@gmail.com

SPECIALTY SECTION
This article was submitted to Water-Smart Food Production, a section of the journal Frontiers in Sustainable Food Systems

RECEIVED 05 February 2023
ACCEPTED 06 March 2023
PUBLISHED 30 March 2023

CITATION
Patel PM (2023) Agricultural transformations in the arid, drought-prone region of Kachchh: People-led, market-oriented growth under adverse climatic conditions.
Front. Sustain. Food Syst. 7:1159011.
doi: 10.3389/fsufs.2023.1159011

Agricultural transformations in the arid, drought-prone region of Kachchh: People-led, market-oriented growth under adverse climatic conditions

Praharsh M. Patel*

Agriculture Research Department, Prayaas, Bhuj (Kachchh), India

Water availability, soil suitability, and favorable climate are the primary requirements for stable agricultural production. However, due to erratic rainfall and scarcity of irrigation water, arid regions suffer from volatile conditions for agriculture. For example, Kachchh, the westernmost district of India in Gujarat, has an arid climate, with more than half of the area is either partially inundated by seawater or classified as desert. The remaining landmass experiences low (15 Year Annual Normal = 450 mm) and erratic (45 percent Coefficient of Variation) rainfall rendering agriculture in the region, not a promising occupation. But in recent years, access to irrigation through groundwater, the advent of micro-irrigation practices, and increasing market-oriented crops supported by regular rainfall have led to significant agricultural improvement for the region. As a result, there has been a significant shift toward less water-intensive and high-value horticulture crops. This paper ponders upon drivers of agricultural transformations in Kachchh combining the quantitative observation data and qualitative field insights. It also highlights hurdles to the smooth adoption of drought-resilient and market-oriented agriculture during the adverse climatic conditions.

KEYWORDS

adaptation strategies, agriculture, adverse climatic conditions, agriculture innovation, horticulture, arid region, Kachchh

1. Introduction

Agriculture is still the major contributor to the livelihood of more than half of the population in India and exhibits diverse set of challenges concerning people's livelihood, food security ad well as environmental concerns. Of all the climatically as well as culturally unique states of India, Gujarat has very diverse water shortage and soil suitability challenges but still holds a vibrant agrarian economy (Institute of Rural Management Anand/UNICEF, 2001). Within Gujarat, there are five distinct regions, (1) South Gujarat (South Gujarat and South Gujarat Hills), (2) Central Gujarat, (3) North Gujarat, (4) Saurashtra Peninsula (North Saurashtra and South Saurashtra), and (5) Kachchh. As shown in Figure 1 and Table 1, the climate and soils vary in these regions to a great extent.

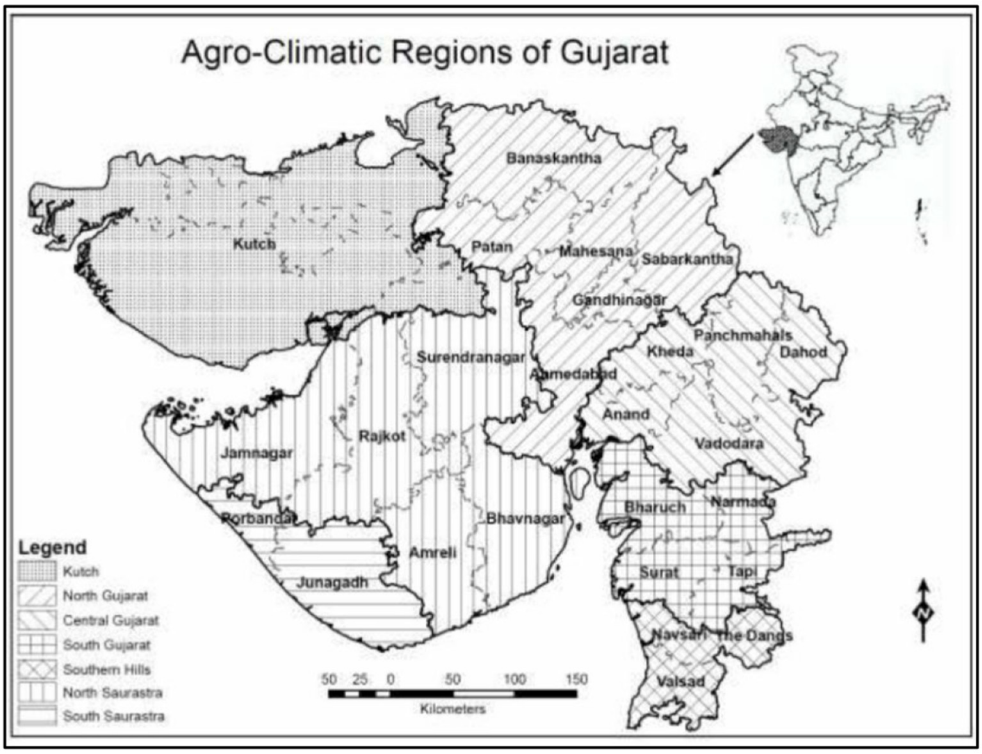

FIGURE 1
Agroclimatic regions of Gujarat and geographic location of Kachchh (Singh and Nair, 2012).

TABLE 1 Climate and soil types of the agro-climatic regions of Gujarat.

Sub region	Climate	Soil
Kachchh	Arid to semi-arid	Sandy, Saline
North Gujarat	Arid to semi-arid	Loamy, alluvium
Central Gujarat	Semi-arid	Medium black
South Gujarat	Semi-arid to dry sub-humid	Deep black, alluvium
Southern Hills	Semi-arid to dry sub-humid	Deep black, clayey alluvium
North Saurashtra	Dry sub-humid	Shallow, medium black
South Saurashtra	Dry sub-humid	Shallow, medium black, calcareous

1.1. A unique case of Kachchh

Out of the five regions of Gujarat, Kachchh is situated in the westernmost part that occupies a quarter of the total geographical area of the State. The region is topographically unique. It is surrounded by salt plains, a large area of salt marshes, and a sea isolating it from the rest of the state and the country. The region has been historically valued as a gateway to the middle-east through ports and still holds dynamic freight activities through four major ports; Kandla, Mandvi, Jakhau, and Mundra.

Although Kachchh has 45,652 sq km of the total landmass, most of the region is barren or desert land (53 percent), making only 20.7 percent of the total land in Kachchh available for agriculture after the exclusion of forest, wasteland, and grasslands. There is also a lack of irrigation (34 percent irrigated land as of 2010–11) and erratic rainfall patterns (45 percent coefficient of variation) that creates a perception of the region being dry and inhabitable.

Since catastrophic earthquake in 2001, Kachchh has had a transformative stint that captured global limelight for exemplar development in agriculture, manufacturing, handicraft, mining, tourism, and shipping. However, the extraordinary development of agriculture is the region is not often overshadowed by the other sectors. Historically, agriculture in Kachchh was limited for subsistence and household consumption and it was not a major occupation for the local communities due to the low productivity of land, low and erratic rainfall, and acute water shortage in most years (Bharwad and Mahajan, 2002). However, the scenario changed since 2001 earthquake when new development attracted investment in the region that propelled ripple effects into agrarian transformation providing necessary resources.

Initially, Kachchh was traditionally confined to a few rain-fed cereal and pulse crops for subsistence agriculture. It diversified to market-oriented cashcrop such as oilseeds and cotton in the early 21st century.

But, in the last decade, agriculture in Kachchh witnessed a major shift in cropping patterns, irrigation, and crop innovations. The objective of the paper is to understand this agrarian development in backdrop of pertaining drought conditions during 2014–2019. Especially, the boom in horticulture development. The region provided a unique perspective of the drivers for agricultural transformations, as the region, unlike other Indian states, has a

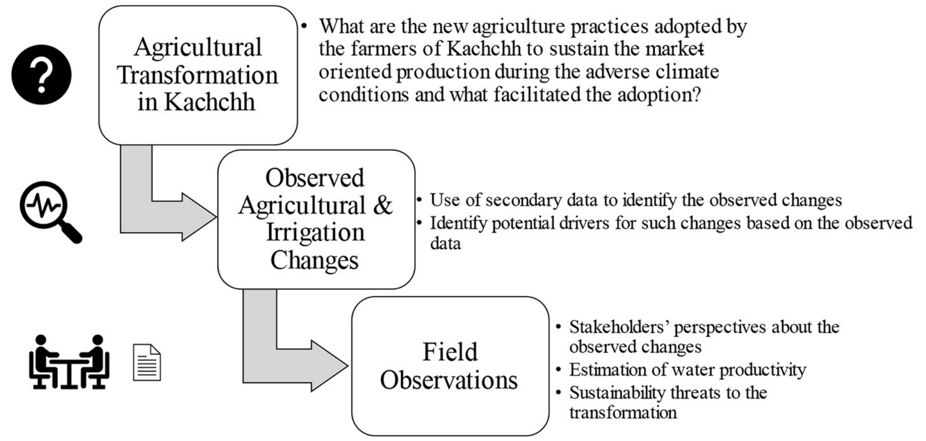

FIGURE 2
Conceptual flowchart of methodology.

higher proportion of large and medium farmers who can afford high-cost technology for improving yields. The paper brings together secondary data analysis and qualitative field insights to compile the case of the recent agrarian development in the region vis-à-vis rising challenges for sustaining this growth.

The rest of the paper is divided into three sections, Section 2 descibes the methodology. Section 3 represents data and analysis, and Section 4 discusses the key insights with the major takeaways.

2. Methodology

This paper is structured to utilize secondary data from agriculture and allied activities for quantitative data analysis along with the qualitative information gathered through filed visits by the author. Analysis is Section 3 is divided into two parts: (i) Section 3.1 focuses on developing understanding of the agriculture and irrigation development in the regions using observation data recorded by various government agencies/ministeries. (ii) Section 3.2 is compilation of qualitative understanding based on the insights from authors' field visits and unstructured stakeholder interviews.

In Section 3.1 The author analyzed the following secondary datasets to mainly identify changes and trends in agriculture practices, demography, and irrigation sources.

(a) *Landownership Pattern*: Distribution of land holdings, irrigation status, average crop yields of major crops) (Section 3.1.1).
(b) *Cropping Pattern*: Area under different types of crops, milk production, horticulture crop, farmer type (Section 3.1.2).
(c) *Irrigation and Groundwater:* Rainfall and Source of Irrigation, Micro-irrigation adoption, groundwater usage and estimated extraction (Section 3.1.3).

The secondary data analysis provides a macro analysis of potential driving factor for the agricultural transformation in recent years and increasing adoption of horticulture crops. However, to explore the micro-level changes and stakeholder's perspectives about agricultural and irrigation developments, The author conducted exploratory field visits of Kachchh region between December 2018 and August 2020. The field insights related to specific question, "Why Horticulture over Traditional Crops?" are

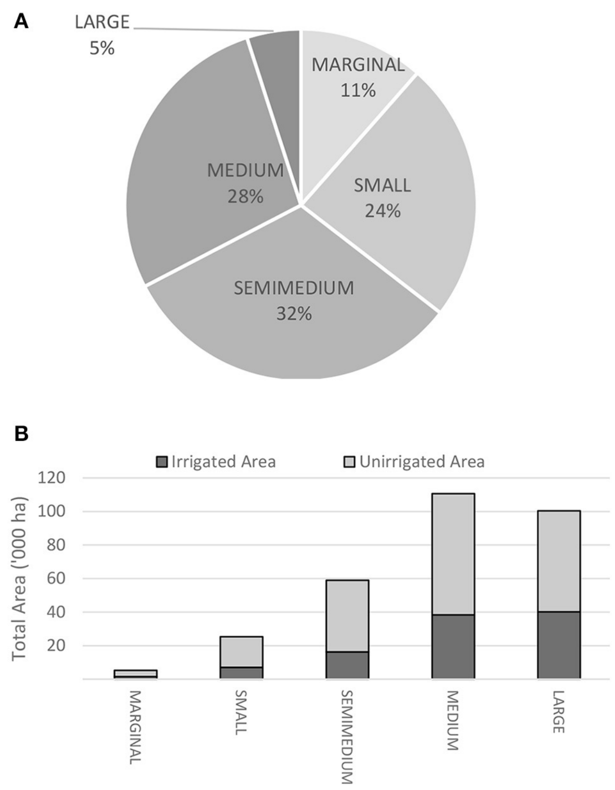

FIGURE 3
(A) Distribution of land holdings by the size group of holdings (Marginal <1 ha, Small: 1–2 hectares (ha), Semi-medium: 2–4 ha, Medium: 4–10 ha, Large >10 ha). **(B)** Area under different food grain production by size group of holdings and irrigation status.

TABLE 2 Average yield of major crops for Kachchh and the rest of Gujarat state from 2007–2012 (AID, 2019).

Crop Name	Season	Average yield (Kachchh)	Average yield (Rest of Gujarat)	Difference (percent)
Castor seed	Kharif	1.83	2.03	11%
Moong (Green Gram)	Kharif	0.43	0.48	12%
Cotton (lint)	Kharif	4.43	3.09	−30%
Groundnut	Kharif	1.60	1.36	−15%
Guar seed	Whole Year	0.49	0.57	16%
Bajra	Kharif	1.01	1.08	7%
Sesamum	Kharif	0.43	0.40	−7%
Wheat	Rabi	2.87	2.89	1%
Moth	Kharif	0.37	0.47	27%
Rapeseed and Mustard	Rabi	1.68	1.51	−10%

TABLE 3 Changing cropping pattern (Bharwad and Mahajan, 2002).

Crop	Area (Acre)		Change (percent)
	1958	1992-93	
Bajra	3,60,000	2,90,000	−20
Jowar	1,74,000	3,50,000	+100
Pulses	2,00,000	2,77,500	+38
Cotton	20,000	1,37,500	+587
Groundnut	7,000	2,15,000	+2970

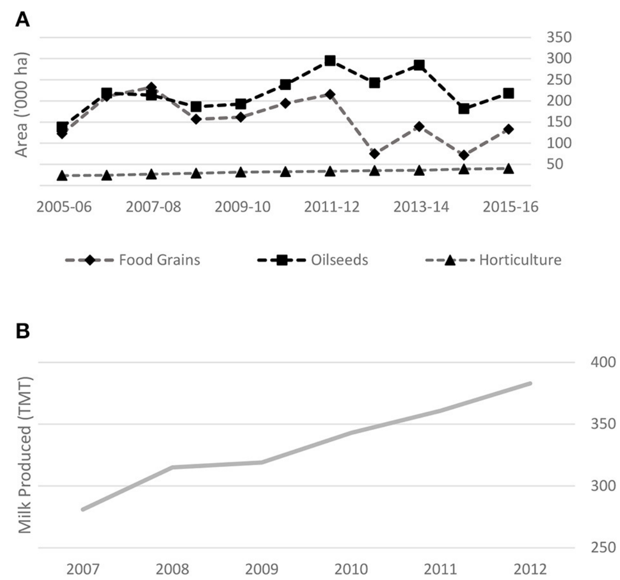

FIGURE 4
(A) Area under different types of crops (AID, 2019). **(B)** District milk production TMT (Thousand Metric Tones) (NDDB, 2013).

compiled in Section 3.2.1. The author further describes the role of water and labor resources in driving the shift in the observed high-value crop adoption. Furthermore, primary data collected during the farmers' interviews provides farmers' perceived estimation of total water usage, income, and water productiity from the major crops. Using this primary data, traditional farming (cereals and oilseeds irrigated by flood irrigation) is compared with progressive farming (Horticulture crops with water-conserving drip-irrigation technology) in Section 3.2.2 to understand the output value against the water used for irrigation. Section 3.2.3 and 3.2.4 also indicates the challenges with the agricultural transformation as conveyed by the farmers during the unstructured interviews. Conceptual flow chart in Figure 2 indicates the flow of arguments followed in rest of the paper.

3. Analysis and discussion

3.1. Agriculture in Kachchh region

3.1.1. Land ownership pattern

Unlike the general trend in India, where more than 85 percent of the holdings belong to Small and Marginal farmers, Kachchh has approximately 65 percent of holdings belonging to Medium, Semi-medium, and Large Farmers (Figure 3). The average landholding size of Kachchh is 3.51 ha compared to 1.15 ha at the national level (MoA, 2015). The relationship between land size and agricultural productivity is a long-debated issue. Fan and Connie (2005) opine that either land productivity has to increase or land to labor ratio has to improve to increase labor productivity and farmer's income. National media have highlighted stories and case studies about the innovative agriculture in Kachchh led by large-scale farmers. This phenomenon of having large farmers lead in progressive farming percolates to encouraging small farmers to shift to more promising, economically viable, and tested agriculture production.

Given the consensus that smaller farms have a lower land-labor ratio than large farms, Dyer (1997) consider that smaller farms enjoy higher land productivity in the short term. Still, over the long term, land productivity tends to drop when a technological change comes into the picture (Chand and Prasanna, 2011). The argument is that the long-term drop in land productivity results from over-intensive land cultivation to maintain labor productivity when more and more people need to survive on the same small

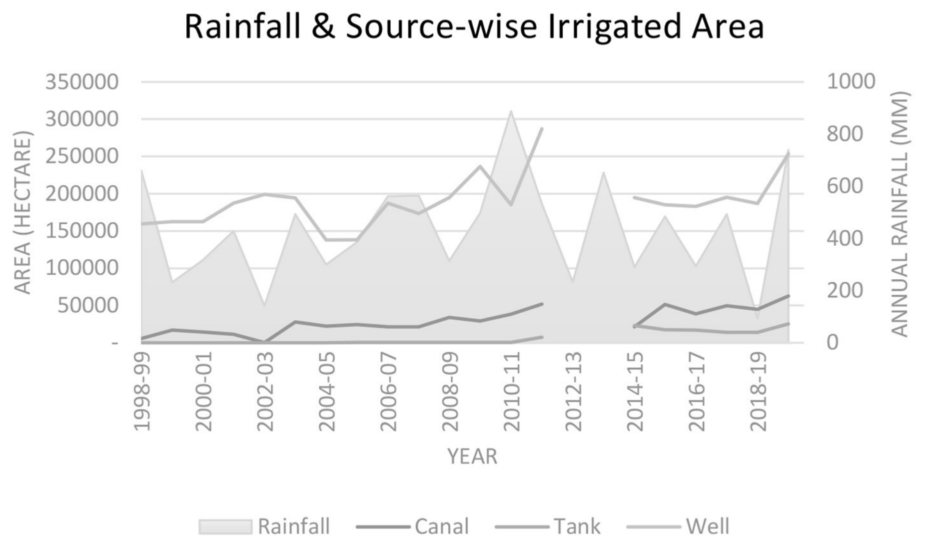

FIGURE 5
Irrigation by Source in the district of Kachchh (MoAFW-LUS, 2022) (Missing data for 2012–2015).

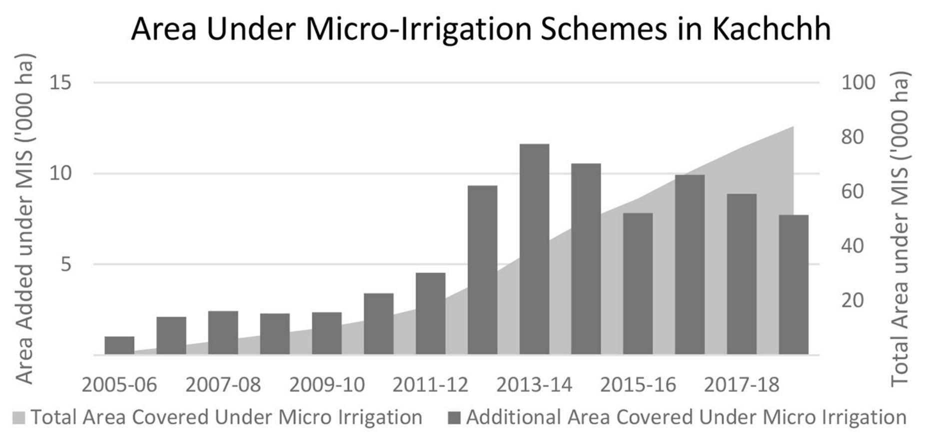

FIGURE 6
Area under micro-irrigation schemes implemented by GGRC (2019).

area of farmland. As the smaller farms are resource-poor to invest in preserving soil fertility, soil productivity eventually becomes exhausted, and land productivity drops. Data support this as although having a large land size and less suitable soil conditions, the average crop productivity for major crops is comparable for Kachchh with the rest of Gujarat, as given in Table 2.

3.1.2. Cropping pattern: An adaptive occurrence

Traditional agriculture was food-crop-oriented since it was meant for subsistence, but cash crop cultivation has increased rapidly in modern agriculture. The new adoption of high-value crops is frequently highlighted (Rahman, 2017). For example, the area under cotton has increased seven-fold and that under groundnut by 30 times from 1958 to 1993. However, the relative increase in food crops has been much lower, and the production of Bajra, the staple diet of local people, has fallen over time, as evident from Table 3. Additionally, recent agriculture census reports show a further decline in cereals production.

Figure 4 shows the change in area under different types of crops. The area under cash crops and fodder has been rising over the years. The change suggests an inclination toward crops with higher economic values. Here, fodder production can be used as a proxy for milk production. Increasing milk production also indicates an increase in value-based crop production. Another paradigm shift in agriculture is increasing horticulture farming. Apart from the increase in cash crop production, Kachchh has witnessed a sharp rise in very high-value horticulture crops in recent years. Given the utility available with relatively large farmers, the growth in horticulture crops, which require heavy initial investments in securing round-the-year irrigation and the care required for plants during the initial gestation period, can only be afforded by well-off farmers. It is important in the case of Kachchh to look at the land size given that field exploration suggests most innovative initiatives,

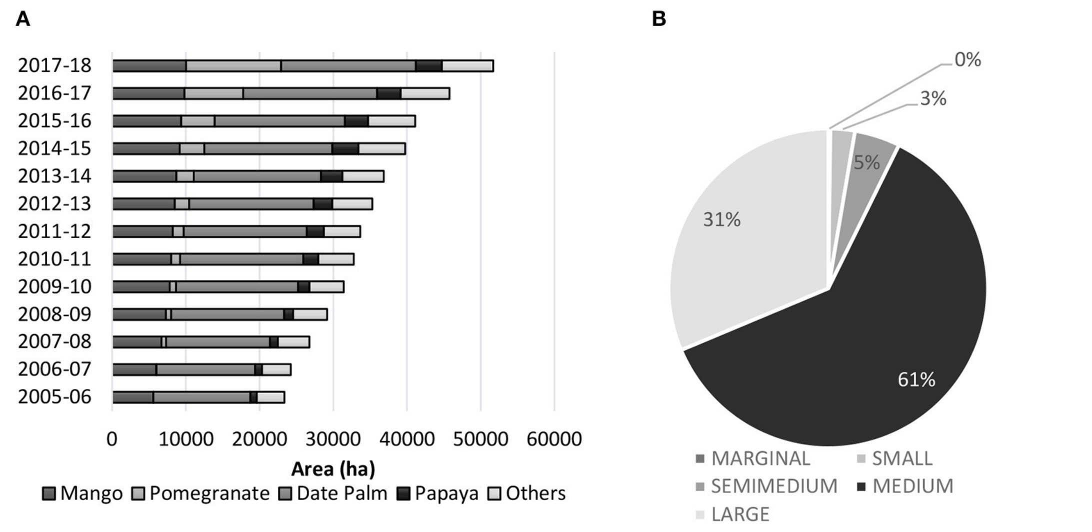

FIGURE 7
(A) Area under different Horticulture Crops (DoH, 2019). **(B)** Distribution of Horticulture crops by size group for the year 2010-11 (MoA, 2015).

TABLE 4 Expected crop production and value of output for major crops in the region.

Crop name	Gestation period (Months)	Gross income ('000 Rs/Acre)	Net income ('000 Rs/Acre)	No of irrigation	Water usage (m^3)	Gross income per m^3 (Rs/Acre/m^3)	Economic productivity of water (net income per m^3) (Rs/Acre/m^3)
Cotton	4–8	60–65	35–40	30–50	900–2000	17.5-44.4	30.0-72.2
Wheat	3	35–40	20–25	20–25	600–1000	20.0–41.7	35.0–66.6
Ground-nut	3–4	45–50	28–32	20–30	600–1,200	23.3–53.3	37.5–83.3
Rajko	2.5	20–24	12–15	15–20	450–800	15.0–33.3	25.0–53.3
Mustard	4	30–35	20–25	25–30	750–1,200	16.7–3.3	25.0–46.6
Castor	8	70–75	50–55	50–60	1,500–2,400	20.8–36.7	29.1–50.0
Mango**	30-36	300–450	200–250	120–150	600–900	222.2–416.7	333.3–750.0
Pome-granate**	15–18	250–450	200–300	120–150	600–900	222.2–500.0	277.8–750.0

(** Mango and Pomegranate are horticulture crops, and income from their production is for 12 months once they are fully grown and use Drip Irrigation). The data provided in this Table is compiled from the farmers' responses and it is not measured or estimated by the author. The data indicated farmers' perceived estimation of crop production, income, water use and economic water productivity.

such as horticulture crops, drip irrigation, sand filtration, etc., are adopted by farmers.

3.1.3. Contemporary development in irrigation and groundwater condition

Kachchh has a high inter-annual variability in annual rainfall (Figure 5). Such high variation causes uncertainty in agricultural production without alternative water sources. Isolated by salt plains and the sea from the mainland, major parts of Kachchh lack perennial water sources for irrigation. Lack of surface had been the major cause of stagnant agricultural growth in the region until the advent of groundwater irrigation.

With increasing access to the cheap boring and almost free farm power supply, Kachchh has been witnessing rapid growth in the area under irrigation. As of 2010–11, 37 percent area is under irrigation compared to 24 percent in 2000–01 (MoA, 2015). The improvement in irrigation is entirely due to groundwater, as surface water resources are scarce in the region. Farmers in Gujarat get 8 hrs of electricity for irrigation use. Thus, farmers pump out groundwater during these 8 h and store them in large surface water tanks before using it for irrigation. Since 2018, a few parcels of the region have started getting water from Narmada Canal. However, the reach of the canal is still limited (Figure 5).

It is more important to look at the development of water-efficient irrigation practices in the case of Kachchh. The

Government of Gujarat formed the *Gujarat Green Revolution Company* (GGRC) to promote and implement state micro-irrigation schemes. The government also provides subsidies (70 percent) to promote micro-irrigation technologies such as drip irrigation. Figure 6 shows the expansion of micro-irrigation in Kachchh. It is evident from comparing Figure 6 with Figure 7 that the increase in new Pomegranate cultivation and additional development in micro-irrigation are contemporaneous. Therefore, most new pomegranate cultivators had to adopt micro-irrigation practices for better water efficiency.

About 31,344 operational schemes for minor irrigation are distributed among ten blocks of Kachchh district, of which about 92% are groundwater based. Of these, 31 percent are dug wells, 22.5 percents are shallow tubewells, and 46.5 percent are deep tubewells (Sandeep, 2013; Patel and Saha, 2022).

Recent satellite data analyses by Thacker et al. (2022) and Goswami et al. (2023) have found good groundwater development potential in the isolated Katrol hill and Khadeer Island area of Kutch which have been sparecely populated due to lack of water resources. This can help further propagate the groundwater based agriculture development in these regions. However, Groundwater-based irrigation is sustainable if the annual extraction is less than renewable groundwater recharge. In the case of Kachchh, the recharge is much less due to the erratic rainfall and aquifer characteristics having low permeability for most of the region (Sandeep, 2013). This interaction of groundwater and agrarian development is further discussed by Patel and Saha (2022).

3.2. Field observations

This section synthesizes the major takeaways regarding improving irrigation through groundwater and increasing horticulture. The Supplementary material shows photographs from the field highlighting the horticulture crop cultivation in the arid region of Kachchh (Supplementary Presentation 1).

3.2.1. Why horticulture over traditional crops?

Horticulture data suggest rapid adoption of Pomegranate cultivation since 2010. It started with a few farmers experimenting with the crop, obtaining good economic returns. Quick adoption by other farmers can be broadly attributed to two reasons:

3.2.1.1. High economic value

Table 4 gives a comparative analysis of the output value per acre for major crops grown by farmers in the region. Agriculture production prices are susceptible to market dynamics; thus, the average expected market price of the crop in the regular season is considered. For a given year, using different possible combinations of crops, a traditional farmer can earn up to Rs 80,000 to Rs 90,000 per hectare (ha). On the other hand, farmers with pomegranates or mangoes in the same region can earn approximately Rs 300,000 to 400,000 per hectare, depending on the market prices and the yield (We are not considering date palms as they need specific soil conditions that may be unavailable for most of the central Kachchh. Also, as seen in Figure 7, mango and pomegranate are the crops that have significantly improved the economic productivity of water). The better economic productivity motivated many farmers to shift to horticulture phase-wise. Unlike other horticulture crops such as Mangoes and Date palms (3–4 Years), Pomegranates (15–18 Months) provide an advantage due to their shorter gestation period. The shorter gestation period made the transition less detrimental to farmers' income and encouraged others to take up the same.

3.2.1.2. Depleting groundwater

The region's agricultural growth depends entirely on groundwater resources to fulfill water requirements during non-monsoon months and erratic rainfall. Field studies highlight that all the places examined have witnessed groundwater depletion by ∼30 m in the last 10–15 years. With high depletion, the groundwater extracted has higher salt content. Most parts of Kachchh now face groundwater Total Diluted Salts (TDS) as high as 1,500 to 3,000 mg/l (see Figure 8) [As per World Health Organization (WHO) standards, TDS higher than 600 mg/l is considered poor, and higher than 1200 mg/l is unacceptable] (WHO). The overexploitation and unsustainable groundwater depletion challenge is further supported by recent scientific literature (Saha and Gor, 2020; Shah et al., 2022; Pandey et al., 2023). Under these conditions, many crops cannot sustain without fresh irrigation water. Pomegranates are gaining acceptance due to their TDS-tolerant properties. The plant can survive with irrigation water having TDS around 3000 mg/l. Also, the water requirement for the plants, when fulfilled using drip irrigation, helps reduce the total water requirement to a great extent.

3.2.2. Water demand estimation

For a *Kachchi* (a person from Kachchh region), water is scarcer than land resources. Thus, the economic productivity of water is the parameter of interest. Horticultural crops have a high economic volume per m^3 of water used (Malhotra and Das, 2016). Given the scarce water resources in Kachchh, it is also important to check whether horticulture crops substantially reduce water consumption compared to other traditional crops. Horticulture crops are mostly grown with drip irrigation technology that helps reduce irrigation water requirements compared to flood irrigation. Moreover, drip irrigation does not put a huge monetary burden on farmers, as the state government subsidizes it by almost 70 percent (GGRC, 2019).

Water requirements are estimated as follows:

$$\textit{Total water Required}: \mathbf{TWR} = \mathbf{N} * \mathbf{t} * \mathbf{Q}$$

N = Average Number of Irrigations Required
t = Time required to irrigate 1 Acre of Land (hr)
Q = water Discharged by the well in Unit Time (m^3/hr)

Based on the calculations, Table 4 shows the approximate value of production per cubic meter (m^3) of water used for traditional Flood Irrigated Crops as well as Horticulture crops irrigated using the drip irrigation method.

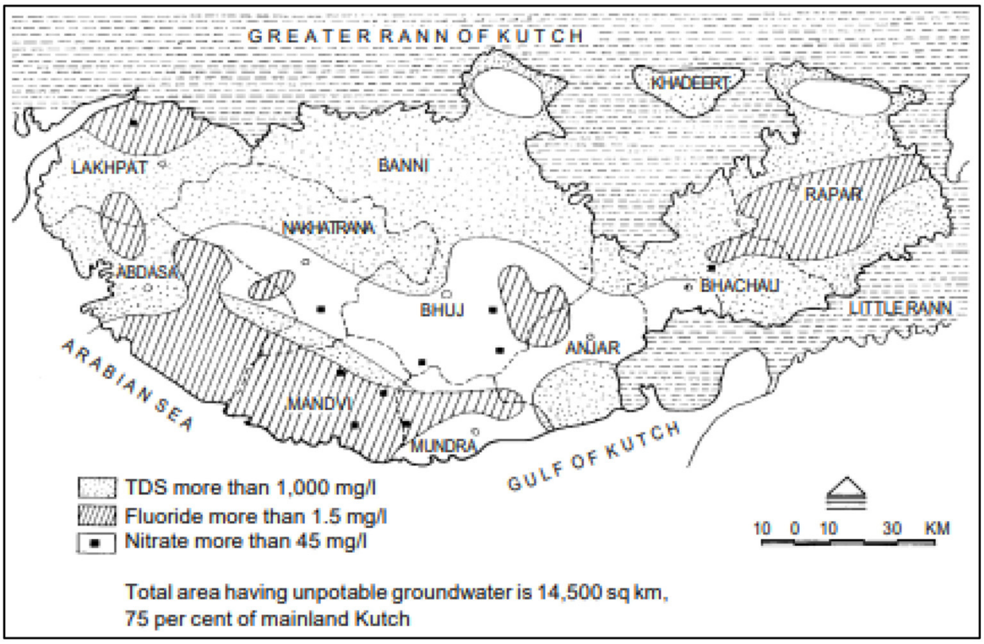

FIGURE 8
Ground water condition in mainland Kutch (Greater Rann of Kutch and Little Rann of Kutch are partially desert and partially salt planes that are inhospitable). Source: Patel (1996).

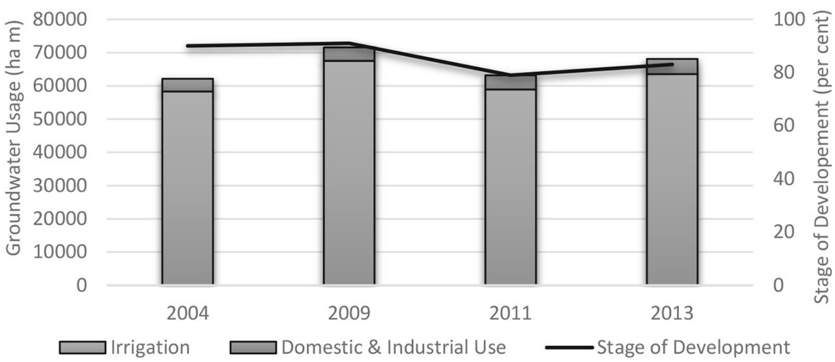

FIGURE 9
Total groundwater draft for irrigation, domestic and industrial uses, and the stage of development in hectare meters (ha m). A stage of development (percent) above 70 percent is considered unsafe (CGWB, 2006, 2011, 2014, 2017).

3.2.3. High labor cost

Based on the fieldwork, author observed that an average farm laborer earns Rs 300–350 for 8 h of work in Kachchh as compared to Rs. 150–200 in Central and Southern Gujarat. This is partly because of the following reasons. (1) High Industrial Labor Demand: As mentioned earlier, Kachchh has been a budding industrial hub for the manufacturing, shipping, and tourism industries. The advent of alternative sources of employment has reduced the labor supply for agriculture. (2) Relatively Skilled Labor Required: Farm laborers need better punitive skills than traditional farming for horticulture production. (3) Increased Landlord Income: Well-off landlords do not hesitate to spend more on labor for higher efficiency.

3.2.4. Market failure and falling productivity

Unlike cereals, pulses, and oilseeds, horticulture crops have a shorter shelf life and limited local demand in sparsely populated demand. Thus, larger adoption of horticulture beyond a threshold leads to market failure and falling estimated economic benefits. There is an increase in crop-water productivity (more crop per drop). Still, failing markets lead to falling economic water productivity (*more cash per drop*) and high wastage of food production (Patel, 2020a,b).

Also, the high labor and input cost burden the farmers to maintain the perineal orchards. Furthermore, the decreasing rainfall and high-water extraction (Figure 9) have caused unprecedented groundwater depletion in recent years. Also, Parmar et al. (2021) have also highlighted increasing land degradation in the Kachchh region. These factors jeopardize the sustainability of perineal horticulture crops requiring round-the-year irrigation availability and suitable soil conditions.

4. Conclusions and way forward

The analysis suggests that the horticulture crops grown using drip irrigation are raising economic water productivity for the crops grown in the region. The adoption of micro-irrigation is happening coherently with horticulture expansion to facilitate the agrarian transition. Besides the higher economic value realized, horticulture crops also help reduce the multiple sowing and cultivation cycles, reducing the efforts required to maintain the field. However, the land is not a limiting factor for crop production in this sparsely populated region. Thus, the farmers in the region would tend to exploit as much water as possible to increase their profits. Therefore, while water use is becoming very efficient in physical and economic terms, the sustainability of water use remains a concern due to the expansion of groundwater-based irrigation.

Agriculture in Kachchh under erratic rainfall and scarce water resources helps us understand how farmers can be more climate-resilient with progressive technology and suitable cropping patterns that improve their water productivity. However, sustainable groundwater management practices are the need of the hour in regions that lack perineal surface water resources and face scanty rainfall.

Author's note

The content of this manuscript has been presented in part at the 3rd World Irrigation Forum, 1–7 September 2019, Bali, Indonesia.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

PP contributed to the conception and design of the study, organized the database, performed the statistical analysis, wrote the first draft of the manuscript, contributed to the manuscript revision, read, and approved the submitted version.

Funding

IWMI-Tata Water Policy Program, Anand, Gujarat, provided funding for fieldwork, travel, and publication charges.

Acknowledgments

The author acknowledges IWMI-Tata Water Policy Program (ITP) and International Water Management Institute (IWMI) support. The paper benefits from the insights of old farmer Chhagan Mavji Patel (aged 99). Ramji Keshrani and Yogesh Jadeja helped with fieldwork and survey of farmers. Tushar Haathi, Tushaar Shah, M. Dinesh Kumar, Shilp Verma, and Mohan Patel helped with framing the initial versions of the manuscript and reviewing initial drafts. Finally, the author thanks the organizers of the 3rd World Irrigation Forum 2019 for allowing the paper to be presented and sharing it for feedback.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1159011/full#supplementary-material

References

AID (2019). Crop Production Statistics Information System. Retrieved from Area and Production Statistics, Ministry of Agriculture and Farmers Welfare: Available online at: https://aps.dac.gov.in/APY/Index.htm (accessed April 15, 2019).

Bharwad, C., and Mahajan, V. (2002). Drinking water crisis in Kachchh: a natural phenomenon? *Econ. Polit. Weekly* 3, 4859–4866.

CGWB (2006). *Dynamic Ground Water Resources of India*. New Delhi: Central Ground Water Board (CGWB).

CGWB (2011). *Dynamic Ground Water Resources of India*. New Delhi: Central Groundwater Board, Ministry of Water Resources, Govt. of India.

CGWB (2014). *Dynamic Ground Water Resources of India*. New Delhi: Central Groundwater Board, Ministry of Water Resources, Govt. of India.

CGWB (2017). *Dynamic Ground Water Resources of India*. New Delhi: Central Groundwater Board, Ministry of Water Resources, Govt. of India.

Chand, R., and Prasanna, P. (2011). Farm size and productivity: understanding the strengths of smallholders. *Econ. Polit. Weekly* 3, 5–11. Available online at: https://www.jstor.org/stable/i23017920

DoH (2019). Horticulture Census. Retrieved from Department of Horticulture, Agriculture, Farmer's Welfare and Cooperation Department, Government of Gujarat. Available online at: https://doh.gujarat.gov.in/horticulture-census.htm (accessed April 15, 2019).

Dyer, G. (1997). *Class, State and Agricultural Productivity in Egypt: A Study of the Inverse Relationship between Farm Size and Land Productivity.* London: Frank Cass Publishers.

Fan, S., and Connie, C.-K. (2005). Is small beautiful? Farm size, productivity, and poverty in asian agriculture. *Agricult. Econ.* 32(Supplements-1), 135–46. doi: 10.1111/j.0169-5150.2004.00019.x

GGRC (2019). Gujarat Green Revolution Company Limited. Available online at: District- Taluka- Village wise Report: http://portal.ggrc.co.in/ (accessed January 05, 2019).

Goswami, A., Gor, N., Borah, A. J., Chauhan, G., Saha, D., Kothyari, G. C., et al. (2023). Groundwater potential zone demarcation in the Khadir Island of Kachchh, Western India. *Groundwater Sustain. Develop*. 20, 100876. doi: 10.1016/j.gsd.2022.100876

Institute of Rural Management Anand/UNICEF. (2001). *White Paper on Water in Gujarat, Report Submitted to the Department of Narmada, Water Resources and Water Supply, Government of Gujarat, Gandhinagar, April 2001*.

Malhotra, S. K., and Das, M. (2016). *Augmenting Water Use Efficiency in Horticulture. World Aqua Congress*. New Delhi, (pp.45-60).

MoA (2015). Ninth *Agricultural Census of India 2010–11*. New Delhi: Ministry of Agriculture and Farmers Welfare (MoA).

MoAFW-LUS (2022). *Land Use Statistics Data*. New Delhi: Ministry of Agriculture and Farmers Welfare (MoA), Accessed through Land Use Statistics Information System. Available online at: https://aps.dac.gov.in/LUS/Index.htm (accessed December 1, 2022).

NDDB (2013). *Milk Production Statistics*. Anand: National Dairy Development Board.

Pandey, A., Padhya, V., Ganguly, A., Chakra, S., and Deshpande, R. D. (2023). Surface water groundwater interaction in water-stressed semi-arid western India: insights from environmental isotopes. *J. Arid Environ.* 208, 104879. doi: 10.1016/j.jaridenv.2022.104879

Parmar, M., Bhawsar, Z., Kotecha, M., Shukla, A., and Rajawat, A. S. (2021). Assessment of land degradation vulnerability using geospatial technique: a case study of Kachchh District of Gujarat, India. *J. Indian Soc. Remote Sens.* 49, 1661–1675. doi: 10.1007/s12524-021-01349-y

Patel, P. M. (2020a). Horticulture pile-up, yet farmers stare at losses in Kachchh, India Water Portal. Available online at: https://www.indiawaterportal.org/articles/horticulture-pile-yet-farmers-stare-losses-kachchh (accessed May 10, 2020).

Patel, P. M. (2020b). Fruit of their labour, India Development Review. Available online at: https://idronline.org/ground-up-stories/fruit-of-their-labour/ (accessed May 13, 2020).

Patel, P. M., and Saha, D. (2022). "Groundwater: a juggernaut of socio-economic development and stability in the arid region of Kachchh," in, *Groundwater for Sustainable Livelihoods and Equitable Growth*, eds Viviana Re, Rodrigo Lilla Manzione, Tamiru A. Abiye, Aditi Mukherji, and Alan MacDonald (1st ed.). CRC Press. doi: 10.1201/9781003024101-13

Patel, P. P. (1996). *'Kutch Ni Jal Samasya: Swaroop. Kaaran Ane Nivaran'*. Kutch Taari Asmita, Kutch Mitra, Bhuj, Gujarat, India.

Rahman, A. P. (2017). *Arid Land Yields a Bounty of Succulent Fruits. The Hindu Business Lines*. Bhuj: The Hindu Business Line.

Saha, D., and Gor, N. (2020). A prolific aquifer system is in peril in arid Kachchh region of India. *Groundwater Sustain. Develop.* 11, 100394. doi: 10.1016/j.gsd.2020.100394

Sandeep, V. (2013). *Groundwater Brochure Kachchh District.* Government of India Ministry of Water Resources Central Ground Water Board West Central Region, Ahmedabad, India. Available online at: http://cgwb.gov.in/district_profile/gujarat/kachchh.pdf

Shah, Y., Bhimani, S., Thacker, H., Borah, A. J., Jadeja, Y., Thakkar, M., et al. (2022). Spatial variations and trend analysis of groundwater salinity along coastal aquifers of Mundra-Kachchh over a decade—Using thematic maps and GIS mapping. *Appl. Water Sci.* 12, 1–19. doi: 10.1007/s13201-022-01760-x

Singh, P. K., and Nair, A. (2012). *Environmental Sustainability of Cropping Patterns in Gujarat*. (Working Paper 235). Anand: Institute of Rural Management Anand.

Thacker, H., Shah, Y., Borah, A. J., Jadeja, Y., Thakkar, M., Bhimani, S., et al. (2022). Assessment of groundwater potential zones across Katrol Hill Fault, Kachchh, Western India: a remote sensing and GIS approach. *Open J. Geol.* 12, 111–135. doi: 10.4236/ojg.2022.122006