International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Optimizing Irrigation in Sugarcane Farming: A Study of Farmer Practices and Challenges in Kolhapur Division

Dr. Ashok Lokhande

Assistant Professor, Krishna Foundation Jaywant Institute of Management, Wathar, Karad

Abstract
Efficient irrigation management is essential for sustainable sugarcane cultivation, yet farmers in the Kolhapur division face challenges such as water scarcity, infrastructure limitations, and a lack of precise irrigation knowledge. This study systematically analyzes prevalent irrigation practices, sources of irrigation guidance, decision-making factors, and challenges faced by farmers. The results indicate significant regional variations in irrigation frequency and adoption of advanced methods like drip irrigation, with Kolhapur showing the highest adoption. ANOVA analysis reveals that while irrigation frequency differs significantly among farmer groups, sources of irrigation guidance remain consistent. Key challenges include water unavailability, infrastructure constraints, and difficulties in implementing automation tools. To address these issues, this study proposes two future strategies: (1) an Expert Opinion-Based Database for Irrigation Management to document best practices and provide data-driven insights and (2) a Knowledge-Based Expert System for Sugarcane Irrigation Management, integrating predictive modeling and real-time recommendations. These interventions aim to enhance irrigation efficiency, optimize water use, and improve decision-making for sustainable sugarcane farming.

Keywords: Sugarcane irrigation, irrigation management, water resource challenges, expert system, decision support system, precision agriculture, sustainable farming, ANOVA analysis, irrigation efficiency.

1. INTRODUCTION

Sugarcane (Saccharumofficinarum) is a highly water-intensive crop that significantly contributes to the agricultural economy of Maharashtra, particularly in the Kolhapur Division. Efficient irrigation management is crucial for enhancing crop yield, optimizing water-use efficiency, and ensuring long-term sustainability in sugarcane cultivation (Singh et al., 2021). However, farmers in the region face multiple challenges, including limited water availability, high operational costs, outdated irrigation infrastructure, and inadequate access to modern irrigation techniques (Patil & Jadhav, 2020). Traditional flood irrigation remains dominant despite its inefficiency, while modern methods such as drip and sprinkler irrigation are gradually being adopted (Kumar et al., 2019).

Effective irrigation management in sugarcane farming encompasses various strategies, including scheduling, water conservation techniques, and soil moisture monitoring. Research indicates that micro-irrigation methods can significantly enhance water-use efficiency and improve crop productivity (Shah et al., 2022). However, the widespread adoption of these technologies is hindered by financial constraints, lack of technical knowledge, and unpredictable water availability (Deshmukh et al., 2023). This study aims to investigate the prevailing irrigation practices among sugarcane farmers in Kolhapur Division and explore the barriers to the adoption of efficient irrigation methods. The findings will provide insights into policy interventions to improve irrigation sustainability and water management in the region.

2. Literature Review

Multiple studies have analyzed irrigation management in sugarcane farming, focusing on conventional and modern techniques, as well as the challenges in implementation. Gupta et al. (2018) emphasized that efficient irrigation significantly improves sugarcane yield and minimizes water wastage. Similarly, Sharma et al. (2019) found that drip irrigation improves water-use efficiency by up to 50% compared to traditional flood irrigation. Mishra and Patel (2020) assessed the economic feasibility of micro-irrigation and identified high initial costs as a major deterrent for small farmers.

Verma et al. (2021) highlighted the impact of climate variability on irrigation scheduling, advocating for adaptive water management strategies. Prasad et al. (2022) suggested integrating remote sensing and GIS technology for optimized irrigation planning. Meanwhile, Rajput and Mehta (2023) emphasized the role of government subsidies and technical training in promoting the adoption of efficient irrigation methods. Other studies (Choudhary et al., 2020; Iyer& Reddy, 2019; Naik et al., 2018) examined socio-economic and technological challenges associated with irrigation adoption, stressing the necessity of targeted policy interventions.

Research by Kale et al. (2023), Pawar and Joshi (2021), and Bhosale et al. (2020) underscored the importance of farmer education and awareness programs in promoting efficient irrigation practices. Singh et al. (2022) analyzed the influence of soil type and land topography on irrigation effectiveness, while Yadav et al. (2021) assessed how cooperative sugar mills contribute to irrigation support for farmers.

Recent studies by Thomas et al. (2022) demonstrated that the use of soil moisture sensors significantly enhances irrigation efficiency, reducing water wastage. Bose and Ranjan (2023) examined the implications of climate change on water resources in sugarcane farming, advocating for climate-resilient irrigation methods. Fernandes et al. (2022) and Patel et al. (2023) examined the integration of solar-powered pumps in sugarcane irrigation, reducing dependency on conventional energy sources.

Kumar et al. (2023) explored the role of precision irrigation systems in optimizing water use and boosting productivity. Their findings align with those of Pandey and Srivastava (2021), who found that advanced irrigation scheduling helps farmers manage erratic rainfall patterns. Bhatia et al. (2020) analyzed economic aspects of irrigation, suggesting that cooperative farming models improve access to irrigation infrastructure.

Goswami et al. (2021) highlighted the importance of agricultural extension services in educating farmers about irrigation innovations. Jadhav and Patil (2023) studied the impact of government policies on irrigation improvements. Studies by Mishra et al. (2022) and Sharma &Dubey (2023) emphasized the role of knowledge-sharing platforms and farmer cooperatives in promoting modern irrigation adoption.

Additional research by Prakash et al. (2022) focused on soil-specific irrigation strategies, reinforcing the need for localized water management. Rajan et al. (2021) proposed AI-based decision support systems for optimizing irrigation. Tiwari et al. (2023) and Sinha et al. (2022) found that data analytics integration in irrigation scheduling leads to significant water conservation.

Jain et al. (2023) explored the use of automated irrigation systems for sugarcane farming, emphasizing energy efficiency. Saxena et al. (2022) studied the influence of government incentives on irrigation technology adoption. Chopra et al. (2021) assessed the socio-economic impact of improved irrigation infrastructure. Kaur et al. (2020) analyzed farmer perceptions regarding precision irrigation technologies.

In summary, extensive research highlights various irrigation management strategies and their benefits in sugarcane farming. Key challenges include financial constraints, lack of technical expertise, and inadequate policy support. The studies emphasize the need for an integrated approach combining advanced technology, farmer training, and government initiatives to enhance irrigation practices in Kolhapur Division.

3. Data and Methodology

Research Questions

1. What are the prevalent irrigation management practices among sugarcane farmers in Kolhapur Division?
2. What challenges do farmers face in implementing effective irrigation management techniques?

Research Objectives

1. To analyze the current irrigation practices adopted by sugarcane farmers in Kolhapur Division.
2. To identify challenges in implementing efficient irrigation techniques.

Hypotheses

HO: There is no significant difference between the current practices adopted by sugarcane grower farmers for Irrigation management.

H1: There is significant difference between the current practices adopted by sugarcane grower farmers for Irrigation management.

H0: There is no significant difference between Irrigation management problems faced by farmers in different districts.

H1: There is significant difference between Irrigation management problems faced by farmers in different districts.

Pilot Study

Researcher carried out an initial pilot survey for pre-testing the questionnaires. The purpose of the pilot study was to test the quality of items in the questionnaires and to confirm the feasibility of the questionnaires. In the present study Cronbach‟s alpha test was applied to find the reliability of questionnaires.

Questionnaire

The sugarcane soil problems were studied with well structured questionnaire. A comprehensive questionnaire was prepared in Marathi to collect data from farmers keeping in view the main objective and hypothesis of study. The questionnaire incorporated different scaling techniques as demanded by the study.

Sample Design:

In order to understand the problems associated with factors Irrigation Management, it was necessary to conduct personal interviews of sugarcane growers and experts in this field. Since the population of

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farmers in three districts is infinite (population is greater than 1,00,000), following equation is used to finalize the sample size of farmers.

SS = [Z^2p (1 − p)]/ C^2

Where, SS = Sample Size Z = Z-value represent the probability that a sample will fall within a certain distribution. (e.g., 1.96 for a 95 percent confidence level) P = Percentage of population picking a choice, expressed as decimal (0.5) C = Confidence interval, expressed as decimal (e.g., .05 = +/- 5 percentage points) 3.8416 x 0.5 x 0.5 SS = 0.0025 SS = 384.16 i.e. approximately 400 respondents will be selected. For selection of number of farmers from each taluka random sampling will be used. (33 Talukas of 3 districts) which is calculated in proportion of sugarcane cultivation area.

In the study farmers are at the centre place. They are respondents who provide information regarding their understanding, opinion, experiences and perception towards sugarcane irrigation management problems.70 farmers were selected for pilot study. And 405 were selected for final study. The details are shown in Table No 1

Table No 1: Sample Size Percentage of Farmers Selected from Kolhapur Division

No.	District	Taluka	Area (ha)	Count	%	
1	Kolhapur	Hatkanangale	21400	23	6.03	180
2		Shirol	23800	27	6.71	
3		Panhala	11280	13	3.18	
4		Shahuwadi	5130	6	1.44	
5		Radhanagari	9791	11	2.76	
6		Gaganbavada	4360	5	1.22	
7		Karveer	22709	25	6.4	
8		Kagal	21634	24	6.1	
9		Gadhinglaj	12021	14	3.39	
10		Bhudargad	5690	6	1.6	
11		Ajara	5900	7	1.66	
12		Chandgad	14971	17	4.22	
13	Sangli	Miraj	15906	18	4.48	
14		Walava	39605	44	11.17	120
15		Shirala	7107	8	2	
16		Tasgaon	6910	8	1.94	
17		Palus	9874	11	2.78	
18		Kadegaon	11120	13	3.13	
19		Vita	3980	5	1.12	
20		Atpadi	2180	3	0.61	
21		Kavathemahankal	4810	6	1.35	
22		Jat	2274	3	0.64	
23	Satara	Satara	9631	11	2.71	105
24		Koregaon	22854	25	6.44	
25		Khatav	2566	3	0.72	
26		Karad	29818	33	8.4	

27		Patan	5941	7	1.6	
28		Wai	6957	8	1.96	
29		Jawali	933	1	0.26	
30		Mahabaleswar	0	0	0	
31		Khandala	3597	4	1.01	
32		Phaltan	9112	10	2.56	
33		Man	695	1	1.19	

Source: Kolhapur division Sugarcane cultivated land (2022-23) report of Regional Joint Director (Sugar), Kolhapur Division, Kolhapur

Table No 2: Sample Size

Kolhapur	180
Sangali	120
Satara	105

D. Reliability Statistics Table No 2 shows case processing summery. Reliability of questionnaires was tested and found to be satisfactory by using Cronbach’s alpha test as shown.

Table No 3: Reliability Statistics Pilot

Table:3 Reliability Statistics of scale opinion about challenges face in implementing effective Irrigation management practices n=70

Cronbach's Alpha	N of Items
0.64	11

Table No 4: Test of Reliability of final scales

Test of Reliability of final scales has been checked using Cronbach‟s Alpha. The alfa of all the 11 factor scales has been presented as below. n=405

Cronbach's Alpha	N of Items
0.701	11

Source: Pilot data compiled by researcher through SPSS

As compared to Cronbach‟s Alpha of this scale at pilot study, the reliability has been increased which is significant.

4. Results and Discussion

This section deals with systematic and logical presentation of the findings of the investigations followed by their logical interpretation. Data received from respondents of the prevalent soil management practices and problems faced by the farmers for Irrigation management in sugarcane cultivation under Kolhapur division area were compiled, tabulated and statistically treated analyzed in the line with the objectives. Selected socio-economic characteristics of the farmers

Table No 5: Irrigation Frequency

	Satara		Sangli		Kolhapur	
	Frequency	Percent	Frequency	Percent	Frequency	Percent

Twice a day	0	0	0	0	0	0
Once a day	1	1.0	0	0	1	.6
Once in two days	1	1.0	0	0	1	.6
Once in 15 days	25	23.8	17	14.2	1	.6
Once in 1 month	17	16.2	39	32.5	39	21.7
Once in 8 days in germination phase and once in 15 days onwards	48	45.7	50	41.7	46	25.6
Depending upon water availability	8	7.6	8	6.7	62	34.4
Depending on water irrigation parameters	5	4.8	6	5.0	12	6.7

The data highlights significant variations in irrigation practices across Satara, Sangli, and Kolhapur, influenced by factors such as water availability, agronomic conditions, and farmer preferences.The majority of farmers in all three regions prefer irrigating once in 8 days during the germination phase and once in 15 days thereafter (Satara: 45.7%, Sangli: 41.7%, Kolhapur: 25.6%). This suggests that farmers recognize the importance of phased irrigation based on crop growth stages.In Kolhapur, 34.4% of farmers adjust their irrigation schedules based on water availability, significantly higher than in Sangli (6.7%) and Satara (7.6%). This indicates that Kolhapur farmers rely more on fluctuating water resources. Once a month irrigation is relatively more common in Sangli (32.5%) and Kolhapur (21.7%) compared to Satara (16.2%), possibly due to better retention capacity or constraints in water resources.

Table No 6: Furrow irrigation

	Satara		Sangli		Kolhapur	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Yes	67	63.8	81	67.5	127	70.6
No	38	36.2	39	32.5	53	29.4

The highest percentage of farmers using furrow irrigation methods is in Kolhapur (70.6%), followed by Sangli (67.5%), and Satara (63.8%).

Table No 7: Drip irrigation

	Satara		Sangli		Kolhapur	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Yes	33	31.4	48	40.0	87	48.3
No	72	68.6	72	60.0	93	51.7

Kolhapur leads in the adoption of advanced irrigation methods, but a significant proportion of farmers across all three districts still rely on traditional irrigation. To increase adoption, interventions such as subsidies, training programs, and awareness campaigns are necessary to encourage farmers to transition to more efficient irrigation practices.

Table No 8: Sources primarily rely on for irrigation guidance

	Satara		Sangli		Kolhapur	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Agricultural extension services	11	10.5	16	13.3	17	9.4
Fellow farmers	50	47.6	42	35.0	82	45.6
agricultural input suppliers	9	8.6	10	8.3	16	8.9
online resources	9	8.6	15	12.5	11	6.1
Government advisories	19	18.1	23	19.2	44	24.4
other	7	6.7	14	11.7	10	5.6

Fellow farmers remain the most trusted source of irrigation guidance, while government advisories and online resources are underutilized. There is an opportunity to enhance the role of extension services and digital platforms in disseminating irrigation knowledge for improved decision-making among farmers.

Table No 9: Factors influence decision-making process regarding Irrigation management practices

	Factors	**Overall Mean**	**SD**	**CV**	**Rank**
1	Past experience	3.55	1.34	1.81	3
2	Weather condition	3.76	1.22	1.50	1
3	Soil type	3.69	1.25	1.56	2
4	Water Availability	3.40	1.29	1.67	4
5	Variety of sugarcane	3.19	1.39	1.95	6
6	Growth phase	3.20	1.35	1.83	5
7	Fertilizer type	2.37	1.22	1.51	9
8	Method of planting	3.03	1.31	1.72	7
9	cost considerations	2.99	1.35	1.84	8
10	Does not depend upon above parameters	2.04	1.01	1.02	10
Total	405				

The study reveals that weather conditions, soil type, past experience, and water availability are the primary drivers of irrigation decision-making. Farmers prioritize environmental and agronomic factors over cost-related considerations, emphasizing the need for climate-adaptive irrigation strategies to ensure sustainable water use.

Hypothesis-I

HO: There is no significant difference between the current practices adopted by sugarcane grower farmers for irrigation management.

H1: There is significant difference between the current practices adopted by sugarcane grower farmers for irrigation management.

Table No 10: ANOVA result of Current practices adopted by sugarcane grower farmers for irrigation management

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Past experience	Between Groups	336.775	179	1.881	1.065	.325
	Within Groups	397.333	225	1.766		
	Total	734.109	404			
Weather condition	Between Groups	225.578	179	1.260	.743	.981
	Within Groups	381.667	225	1.696		
	Total	607.244	404			
Soil type	Between Groups	314.800	179	1.759	1.244	.060
	Within Groups	318.000	225	1.413		
	Total	632.800	404			
Water Availability	Between Groups	280.831	179	1.569	.896	.780
	Within Groups	394.167	225	1.752		
	Total	674.998	404			
Variety of sugarcane	Between Groups	313.778	179	1.753	.826	.909
	Within Groups	477.333	225	2.121		
	Total	791.111	404			
Growth phase	Between Groups	346.823	179	1.938	1.103	.242
	Within Groups	395.167	225	1.756		
	Total	741.990	404			
Fertilizer type	Between Groups	254.516	179	1.422	.900	.770
	Within Groups	355.667	225	1.581		
	Total	610.183	404			
Method of planting	Between Groups	299.201	179	1.672	.951	.636

	Within Groups	395.500	225	1.758		
	Total	694.701	404			
cost considerations	Between Groups	291.127	179	1.626	.805	.936
	Within Groups	454.833	225	2.021		
	Total	745.960	404			
Does not depend upon above parameters	Between Groups	151.365	179	.846	.720	.989
	Within Groups	262.000	223	1.175		
	Total	413.365	402			

The ANOVA analysis reveals that Past experience, Weather condition, Soil type, Water Availability, Variety of sugarcane, Growth phase , Fertilizer type , Method of planting and cost considerationsdo not show significant variation (**$p > 0.05$**), meaning these practices are perceived similarly across different farmer groups. Null hypotheses is accepted as There is no significant difference between the current practices adopted by sugarcane grower farmers for Irrigation management. The findings confirm that sugarcane farmers generally follow similar irrigation management practices, irrespective of regional or individual differences. While climatic and agronomic factors play a critical role in decision-making, economic and technological aspects show no significant impact. This highlights the need for widespread awareness, financial incentives, and technological interventions to enhance irrigation efficiency across all farmer groups.

Table No 11: ANOVA result of Irrigation Frequency and sources rely on for irrigation guidance

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Irrigation Frequency	Between Groups	275.509	179	1.539	1.265	.047
	Within Groups	273.667	225	1.216		
	Total	549.175	404			
sources rely on for irrigation guidance	Between Groups	476.601	179	2.663	1.135	.184
	Within Groups	527.833	225	2.346		
	Total	1004.435	404			

The F-value (1.265) with a p-value of 0.047 indicates that there is a statistically significant difference in irrigation frequency between different farmer groups at a 5% significance level.
Since $p < 0.05$, the null hypothesis (that there is no difference in irrigation frequency across groups) is rejected.This suggests that farmers in different regions or with varying access to resources follow different irrigation schedules, likely due to differences in water availability, soil type, crop stage, and

infrastructure.
The F-value (1.135) with a p-value of 0.184 suggests that there is no significant difference in the sources farmers rely on for irrigation guidance.Since $p > 0.05$, the null hypothesis is accepted, meaning that farmers across different groups generally depend on similar sources for irrigation information.The uniform reliance on fellow farmers, government advisories, agricultural extension services, and online resources suggests that these sources play a crucial role in shaping irrigation practices.Future efforts should focus on customized irrigation scheduling support and strengthening extension services and digital advisory platforms for better decision-making in irrigation management.

Table No 12: Challenges face in implementing effective irrigation management practices

	Challenges	**Overall Mean**	**SD**	**CV**	**Rank**
1	Cannot get exact water requirement for sugarcane	3.61	1.19	1.42	3
2	Cannot get sufficient water for irrigation	3.49	1.25	1.57	6
3	Cannot get water as and when required because of common irrigation schemes	3.47	1.29	1.68	7
4	Cannot implement new automation tools because of common irrigation schemes	3.80	1.28	1.65	1
5	No proper irrigation management	3.25	1.33	1.76	9
6	Cannot get electricity regularly for irrigation	3.33	1.38	1.92	8
7	water availability	3.18	1.35	1.83	10
8	irregular rainfall	3.68	1.39	1.93	2
9	technical knowledge	2.99	1.32	1.75	11
10	financial constraints	3.58	1.34	1.80	4
11	infrastructure limitations	3.57	1.36	1.85	5

The study reveals that the major challenges in irrigation management for sugarcane farmers include restrictions due to common irrigation schemes, irregular rainfall, difficulty in determining water requirements, financial constraints, and infrastructure limitations. The inability to implement automation tools and water scarcity further hinder efficient irrigation.

Hypothesis-II
H0-There is no significant difference between Irrigation management problem faced by farmers in different districts.
H1- There is significant difference between Irrigation management problem faced by farmers in different districts.

Table No 13: ANOVA result of Challenges face in implementing effective Irrigation management practices

ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.

Cannot get exact water requirement for sugarcane	Between Groups	235.078	179	1.313	.867	.841
	Within Groups	340.833	226	1.515		
	Total	575.911	405			
Cannot get sufficient water for irrigation	Between Groups	384.220	179	2.146	1.909	.000
	Within Groups	253.000	226	1.124		
	Total	637.220	405			
Cannot get water as and when required because of common irrigation schemes	Between Groups	321.757	179	1.798	1.132	.188
	Within Groups	357.167	226	1.587		
	Total	678.923	405			
Cannot implement new automation tools because of common irrigation schemes	Between Groups	228.133	179	1.274	.651	.999
	Within Groups	440.667	225	1.959		
	Total	668.800	405			
No proper irrigation management	Between Groups	421.138	179	2.353	1.803	.000
	Within Groups	293.667	226	1.305		
	Total	714.805	405			
Cannot get electricity regularly for irrigation	Between Groups	297.478	179	1.662	.780	.959
	Within Groups	479.500	226	2.131		
	Total	776.978	405			
water availability	Between Groups	277.342	179	1.549	.754	.976
	Within Groups	462.500	226	2.056		
	Total	739.842	406			
irregular rainfall	Between Groups	361.379	179	2.019	1.076	.301
	Within Groups	422.167	226	1.876		
	Total	783.546	406			
technical knowledge	Between Groups	289.294	179	1.616	.864	.846

	Within Groups	420.667	226	1.870		
	Total	709.960	405			
financial constraints	Between Groups	327.967	179	1.832	1.028	.419
	Within Groups	400.833	226	1.781		
	Total	728.800	405			
infrastructure limitations	Between Groups	377.479	179	2.109	1.279	.040
	Within Groups	371.000	226	1.649		
	Total	748.479	405			

The ANOVA analysis reveals thatCannot get sufficient water for irrigation, No proper irrigation management and infrastructure limitationsshowstatistically significant differences ($p < 0.05$)**,** leading to H_0 rejection**.**

In contrast, Cannot get exact water requirement for sugarcane, Cannot get water as and when required because of common irrigation schemes, Cannot implement new automation tools because of common irrigation schemes, Cannot get electricity regularly for irrigation water availability, irregular rainfall, technical knowledge, financial constraints do not show significant variation **(**$p > 0.05$**),** meaning these challenges are perceived similarly across different farmer groups.

5. Emerging Constraints and Future Policies

The analysis of irrigation management practices among sugarcane farmers in Kolhapur Division highlights key areas requiring intervention.

1. Expert Opinion-Based Database for Irrigation Management

- Develop a database by collecting insights from experienced farmers, agronomists, and irrigation experts.
- Include region-specific best practices, water management strategies, and adaptive irrigation techniques.
- Utilize data analytics to identify patterns in irrigation efficiency and challenges.
- Provide real-time recommendations based on historical data and environmental conditions.

2. Development of a Knowledge-Based Expert System for Sugarcane Irrigation Management

- Design an decision support system integrating weather data, soil conditions, and water availability.
- Implement predictive modeling for irrigation scheduling based on crop growth stages.
- Offer personalized irrigation recommendations via mobile apps or online platforms.
- Enhance accessibility through multilingual support and integration with government advisory services.

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