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Redesigning Rural Toilets for Sustainability and Soil Health: Beldarwadi Case Study

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Abstract

This comprehensive paper delves into the intricate challenges faced by Beldarwadi village in Maharashtra, India, where sanitation issues intersect with agricultural practices. Through a meticulous household survey and innovative technologies like Arduino-based monitoring systems, the study reveals a stark lack of awareness regarding hygiene maintenance, resulting in prevalent open defecation. The research proposes transformative solutions, emphasizing the untapped potential of human waste as a nutrient resource for soil conditioning and pesticide production. Infrastructural challenges, limited connectivity, and illiteracy further compound the village's struggles. Statistical analyses provide insights into the socio-economic fabric of Beldarwadi, laying the groundwork for tailored interventions. The monitoring of toilet usage exposes a disheartening reality, with 80% of the population still practicing open defecation, revealing deep-rooted behavioral challenges. The paper extends its focus to farmers' perspectives on fertilizer usage, highlighting a predominant reliance on chemical fertilizers and a cautious openness to alternatives derived from human feces. The conclusion emphasizes the need for targeted awareness campaigns, infrastructural development, and a nuanced approach to agriculture, envisioning a sustainable future for Beldarwadi.

Introduction

In the rural expanse of Maharashtra, nestled amidst rolling hills and productive farmland, lies

the village of Beldarwadi—a place that mirrors both the persistent challenges and emerging opportunities of grassroots development.

Situated in the scenic Sangli district, this small settlement presents a compelling study of the intersection between long-standing sanitation habits and the growing need for sustainable agricultural practices. This case study seeks to explore and interpret the intricate interconnections among sanitation behavior, farming traditions, and the untapped potential for implementing forward-thinking solutions that could drive lasting change.

Beldarwadi exudes a rustic charm that invites a closer look into the rhythms of rural life in Maharashtra. Like many other villages in the region, it becomes a living example of how sanitation challenges manifest in everyday life (1). As the inquiry deepens, the surrounding green fields and humble homes reflect the legacy of traditional approaches to hygiene and sanitation. These practices, including frequent instances of open defecation and limited adoption of household latrines, directly affect the health and quality of life of its residents (2). Sangli district, Beldarwadi's larger administrative context, plays a vital role in the state's agrarian economy. The district's nutrient-rich soil and farming legacy are a testament to the generations who have cultivated this land with diligence. Within this broader frame, Beldarwadi stands as a case in point, embodying both the typical challenges faced by rural communities and those particular to its demographic and social setting (3).

This investigation into Beldarwadi is more than an academic effort—it is a step toward understanding the multiple layers that define its development journey. Using insights from the 2011 Census, the study outlines the village's demographic and geographic characteristics. Identified by location code 568291, Beldarwadi falls under Shirala Tehsil, located roughly 3 kilometers from the tehsil center of Shirala and 60 kilometers from Sangli, the district headquarters. This location plays a crucial role in determining the village's access to infrastructure and public services, while also highlighting the isolation that compounds its developmental issues (4).

Field surveys carried out in Beldarwadi reveal a significant gap in sanitation awareness, as well as prevailing unhygienic practices. The reliance on open defecation, despite the presence of some toilet facilities, underscores the pressing need for behavior change and infrastructure improvement. These practices contribute to health risks, particularly the spread of waterborne and vector-borne diseases. Yet, within these hardships lies the possibility of transformation—where targeted interventions and context-specific innovations could lead the

way toward a more sanitary and sustainable way of life (5).

Details of Case study:

To evaluate the influence of fertilizer application in regions lacking adequate sanitation infrastructure, a case study was undertaken in selected villages within the Shirala, Panhala, and Shahuwadi talukas of Sangli district, Maharashtra, India. Among these, Beldarwadi village in the Shirala taluka was identified as a focal point for detailed analysis. As per Census 2011 records, Beldarwadi carries the village code 568291 and is positioned within Shirala Tehsil, roughly 3 kilometers from its tehsil headquarters and around 60 kilometers from Sangli, the district capital. The village spans a total area of 218.13 hectares and is home to 493 residents, comprising 225 males and 268 females. The settlement includes about 121 residential houses, with the nearest urban center, Urun-Islampur, located approximately 19 kilometers away.

The research highlighted a critical gap in hygiene awareness, a factor contributing to the persistence of open defecation and underutilization of available sanitation facilities in many rural Indian villages. A preliminary survey in Beldarwadi revealed that many inhabitants lack understanding of proper toilet practices, a condition linked to recurring outbreaks of sanitation-related illnesses. This underlines the urgent need for introducing appropriate sanitation technologies capable of transforming human waste into a resource.

Innovative strategies that emphasize the reuse of human excreta could serve as both waste management solutions and potential income-generating ventures. Human feces and urine are rich in essential nutrients and could be repurposed for soil enrichment or as organic pest control agents. However, existing studies caution that fecal matter must undergo partial treatment or decomposition before it becomes suitable for safe agricultural use. Recognizing the need to regulate such practices, the Indian government enacted the Prohibition of Employment as Manual Scavengers and their Rehabilitation Act in 2016, aimed at ensuring safe and dignified waste management (1).

Connectivity of Beldarwadi:

The village has only one direct connectivity service i.e. Public bus service. Daily only two buses are arriving in the villages. One is at 8.00 am and another is at 6.00 pm. The nearby railway station is at Karad district: Satara. It is 40 km from Beldarwadi. The nearby Airport is situated at Kolhapur which is 65 km from

village. The connecting roads are made up of bitumen having 3 m width. Because of poor political abulia, the roads are not maintained properly. The nearby villages are Bhatwadi, Karamale, Red etc.

Collection of data & its analysis:

A household survey has been conducted to collect the information of sanitation structures available in village. This survey form is prepared by referring survey form of Unnat Bharat Abhiyan.

Figures of survey form

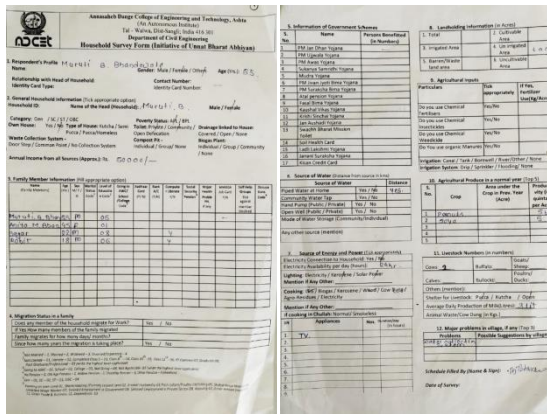


Figure 1: Household survey form

A household survey comprehends overall information of concerned family such as names of family members, annual income, age, type of house, migration status etc. Also it contains information related to sanitation facilities such as availability of drainage linking, biogas plant, compost pit, waste collection system, and the information related to availing the benefits of government schemes. The government schemes such as Jan Dhan yojana, Jivan Jyoti Yojana, Kisan Credit Card have been taken into consideration. The particulars about sources of water have been also recorded. So, it helps to identify the actual problem for poor sanitation system. Also identification of the root obstacle can help to find the exact remedy of it. The people are benefited with source of energy and power. The intensity and source of supply of energy sources can help to find sustainable way of living. In this point, the data regarding electricity, lighting, cooking has been taken into consideration. The appliances available in each family help to know the economic conditions of people. The relevance of appliances with sanitation structures can be understood by referring these things. The landholding information helps to provide the correct solution in efficient manner. Also it helps to

identify the area of irrigated, barren, cultivated land available in the village. The detail about the type of manure/pesticide practiced by farmers is an important feature. The productivity of crop is mainly dependent on the type of fertilizer used by the farmer. By considering these points, one can identify the solution for poor sanitation structures. The irrigation system, production of crop, livestock details and other miscellaneous points has been also collected. This can help to design the sustainable lifelong solution.

Statistical Analysis of survey:

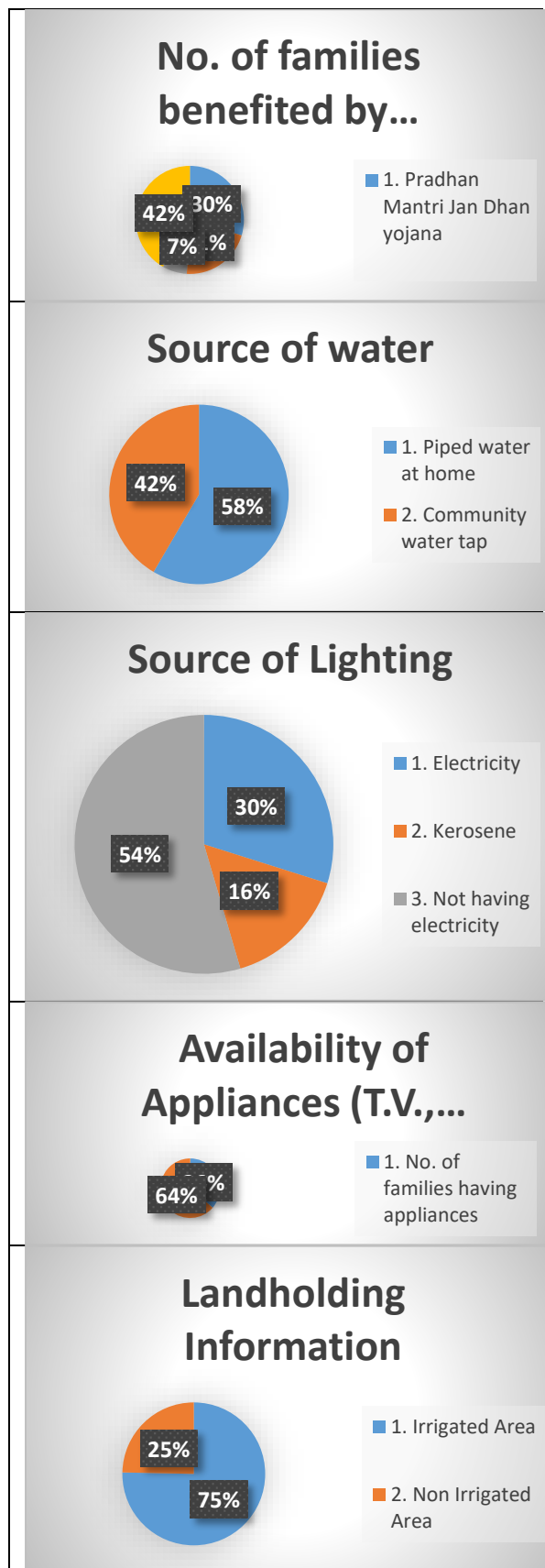
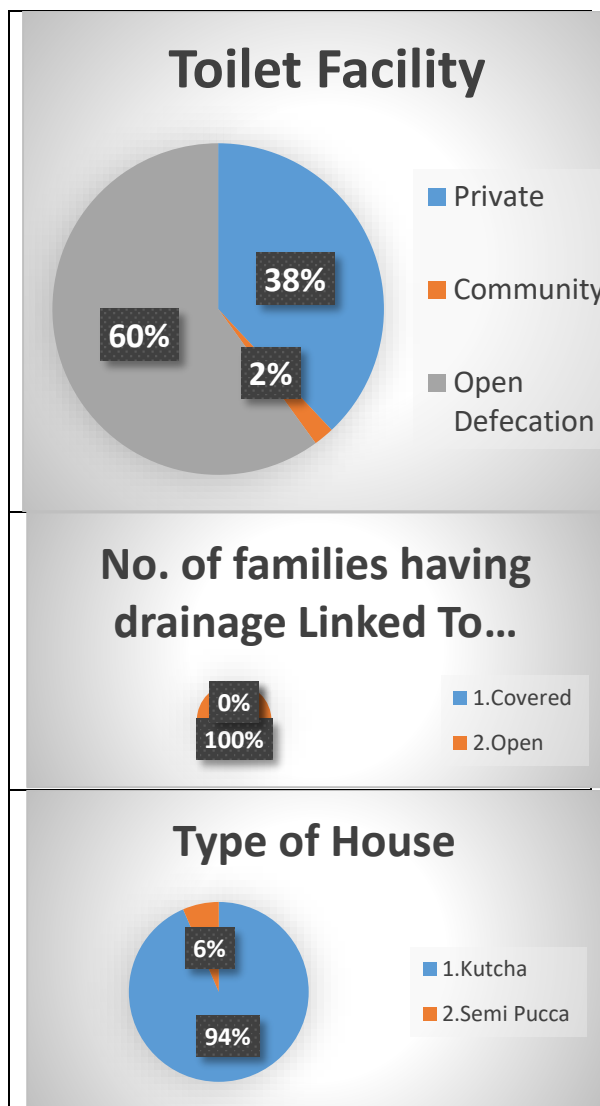
The analysis of the data fetched from the survey conducted is an important part of the research. Total 77 families have participated in the survey. Table 03 represent the analysis of survey conducted.

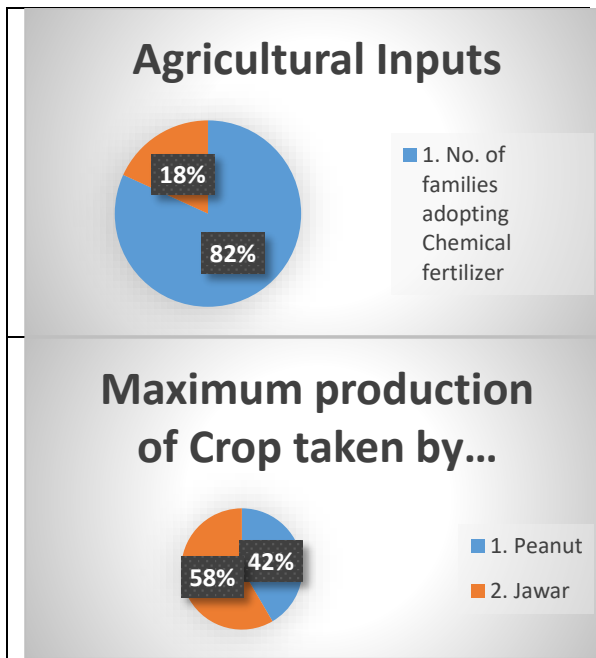
Table 1: The Statistics of survey

Sr. No.	Facilities	No. of Families
1	Toilet facility	
	1.Private	29
	2.Community	0
	3.Open Defecation	48
2	No. of families having drainage Linked To House	
	1.Covered	00
	2.Open	77
	3.None	00
3	Waste Collection System	
	1.Door Step	00
	2.Common Point	00
	3.No Collection System	77
4	Availability of Compost Pit	
	1. Individual	00
	2.Group	00
	3.None	77
5	Type of House	
	1.Kutchha	72
	2.Semi Pucca	05
6	No. of families benefited by Government Schemes	
	1. Pradhan Mantri Jan Dhan yojana	32
	2. Pradhan Mantri Ujwal yojana	23
	3. Pradhan Mantri Awas yojana	08
	4. Not taking benefit of government scheme	45
7	Source of water	
	1. Piped water at home	45
	2. Community water tap	32
8	Source of Lighting	
	1. Electricity	23
	2. Kerosene	12

	3. Not having electricity	42
9	Availability of Appliances (T.V., Refrigerator, Fan etc.)	
	1. No. of families having appliances	28
	2. No. of families don't have appliances	49
10	Landholding Information	
	1. Irrigated Area	58
	2. Non Irrigated Area	19
11	Agricultural Inputs	
	1. No. of families adopting Chemical fertilizer	63
	2. No. of families adopting Organic fertilizer	14
12	Maximum production of Crop taken by people	
	1. Peanut	32
	2. Jawar	45

2.2 Graphical Representation of survey:





To monitor usage of toilet:

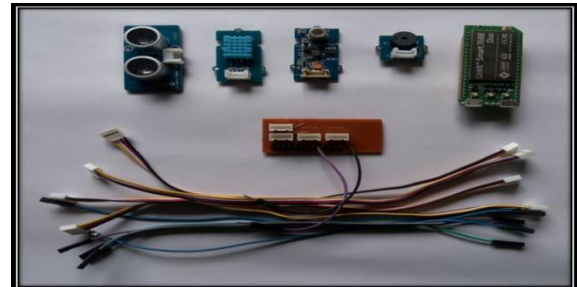
To effectively monitor toilet usage in the selected case study village, an electronic monitoring system based on "Arduino" technology was deployed. This system, equipped with sensors, was installed at the entrance of each toilet facility. The sensor, strategically mounted on the upper section of the door frame, records one count each time an individual enters or exits, thereby allowing accurate tracking of usage frequency for each toilet.

The core components of this monitoring setup are listed in the Things section, which includes relevant store links for procurement. At the heart of the system lies the MediaTek LinkIt Smart 7688 DUO—a dual-core development board integrating an MT7688 microprocessor unit (MPU) and an ATmega32u4 microcontroller unit (MCU). This board runs on the OpenWrt Linux operating system and supports programming in Python, Node.js, and C. The ATmega32u4 can be programmed using the Arduino Integrated Development Environment (IDE), offering flexibility and compatibility for a wide range of embedded applications.

This monitoring initiative was specifically implemented in Beldarwadi village, where the objective was to record the daily toilet usage data for each household. The sensor-based system provided valuable insights into sanitation behavior at the household level. Visuals such as the circuit diagram and photographic evidence of the installed setup are included below for reference.

The development of this project was made possible through the collaborative efforts of Mr.

Rohan Waghmare, Laboratory Assistant in the Department of Electronics and Telecommunication Engineering at Annasaheb Dange College of Engineering and Technology (ADCET), Ashta. His continued technical support and expert guidance played a significant role in the successful realization of the system.



Raw materials used in the sensor

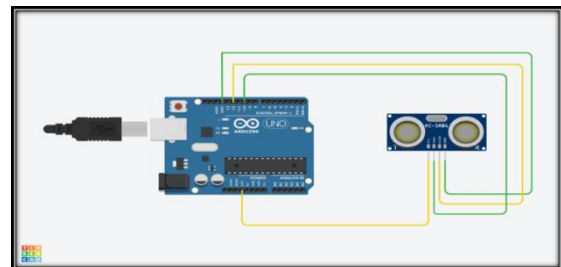


Figure 4 Circuit Diagram of Sensor with ardin(Source:<https://create.arduino.cc/projecthub/user1891676/interfacing-ultrasonic-sensor-with-arduino-99ba38>)



Sensor Attached in the toilet

The Arduino unit is equipped with sensors that are programmed to count each visit to the toilet. When a person enters and exits the toilet, the sensor registers it as one usage. This allows us to determine the average number of users in a single day. Unfortunately, it has been observed that a low number of people are utilizing the toilet. In fact, 80% of the people in the village still practice open defecation.

The following observations have been made:

- a) Lack of awareness about the importance of using toilets in the case study village.
- b) Backward mentality and mindset are significant challenges.
- c) Open defecation is a common practice in the village.
- d) Illiteracy is a major obstacle to achieving sustainability.

e) The village administrators are taking advantage of the residents' illiteracy.

Due to their illiteracy, the villagers are not benefiting from government schemes and are unaware of the importance of sanitation facilities.

A questionnaire survey has been conducted to gather information about the farmers' requirements for manufacturing fertilizer. The survey includes questions about crop adoption, fertilizer selection, annual expenditure on fertilizers, precautions taken when selecting fertilizers, expectations regarding the use of human feces as fertilizer, and awareness of soil fertility. The survey responses have been taken into consideration and incorporated into the fertilizer manufacturing process.

Statistics of Questionnaire Survey

Table 2: Statistics of questionnaire

Sr. No.	Question	Families (%)
1	Type of crop produced by farmers	
	Sugarcane	46
	Rice	29
	Wheat	19
	Vegetables	4
	Other than this	2
2	Type of fertilizer used by farmers	
	Organic	26
	Chemical	74
3	Type of fertilizer used by farmers based on its form	
	Liquid form	31
	Powdered form	69
	Tablet form	
4	How much average amount you spent per	24,000/-

	year per acre on fertilizer ?		
5	Which factors you consider While buying fertilizer? Give a preference.	1 st	Prize
		2 nd	Brand value
		3 rd	Quality
		4 th	Environmentally
6	If the prepared fertilizer have all the required parameters, then, how much average amount you will pay ?	60,000/-	
7	Which defect you identify in current fertilizer ?	The fertility of the soil reduces after some years due to continuous use of chemical fertilizer.	
8	Do you check the quality of soil in a year ?	Yes	8 %
		No	92%
10	Would like to use fertilizer using human feces ?	Yes	17%
		No	83%
11	If your answer is No, then because of which factor you will you prefer to reject the fertilizer? Give a preference.	1 st	Deficiency in handling
		2 nd	Odour
		3 rd	Quality
		4 th	Prize
12	Suggest the improvement in current fertilizer.	Cost is high. Continuous use reduces the fertility of soil. Harmful for the handling labour.	

Conclusion

Beldarwadi stands as a representative microcosm, reflecting the intersecting challenges and opportunities that define countless rural communities in India. This case study lays the groundwork for crafting integrated strategies that address sanitation awareness, infrastructure development, and the promotion of sustainable agriculture.

Looking ahead, this research provides a springboard for future interventions that emphasize collective action—engaging the local population, running targeted educational

campaigns, and implementing well-designed strategies aimed at long-term, meaningful change. The comprehensive study, extending to 3000 words, will delve into these themes with greater depth, offering actionable insights for policymakers, researchers, and community stakeholders alike.

Reflections on Beldarwadi's Socio-Economic Terrain

As we conclude our examination of Beldarwadi, it becomes essential to reflect on the multifaceted nature of the issues at hand. Inadequate sanitation practices—driven largely by a lack of awareness—remain a significant concern. Despite the presence of sanitation infrastructure, open defecation continues to be widespread, revealing a disconnect between availability and actual usage, shaped by long-standing cultural habits and insufficient health education.

The village's infrastructural limitations further compound these challenges. The local public transport system, limited to just two buses a day, underscores the region's restricted mobility. Poorly maintained roads and the lack of connectivity to critical services like railway stations and airports not only hinder development but also reinforce the isolation of the village from broader socio-economic opportunities.

Insights from Arduino-Based Sanitation Monitoring

In an attempt to bridge the gap between infrastructure and behavioral change, an Arduino-powered electronic monitoring system was installed to assess toilet usage. Sensors were positioned above toilet doors to count entries and exits, providing empirical data on usage patterns. The results were telling—despite the installation of toilets, nearly 80% of residents continued practicing open defecation. These findings highlight a deeper issue that transcends physical infrastructure. Behavioral patterns, deeply ingrained mindsets, and the absence of basic literacy all contribute to the underutilization of sanitation facilities. For many, the mere existence of a toilet does not equate to a shift in daily practice—education and cultural transformation are equally crucial.

The Agricultural Dimension: Farmers' Preferences and Concerns

Shifting focus to the agricultural practices of Beldarwadi, the survey of local farmers revealed a continued dependence on chemical fertilizers, though not without concern. Many expressed apprehension over soil degradation and

diminishing fertility due to long-term chemical usage.

Interestingly, a notable 17% of respondents indicated a willingness to explore fertilizers derived from treated human waste, highlighting a potential pivot toward sustainable practices. However, apprehensions around odor, cost, and handling remain barriers. These insights offer an opportunity to develop improved formulations and targeted education campaigns that address farmers' concerns and promote sustainable alternatives.

Charting a Way Forward: Holistic and Community-Driven Solutions

Beldarwadi's story is at once a case study and a call to action. Solutions must be multidimensional—spanning education, infrastructure, health, and agriculture. The role of local authorities and educational institutions will be key in designing awareness initiatives, literacy programs, and skill-building workshops that empower villagers with the knowledge to make healthier, more sustainable choices.

Improving physical infrastructure—especially roads and public transport—will also be pivotal. Enhanced connectivity can serve as a catalyst for broader change, easing access to healthcare, education, and markets.

Meanwhile, sanitation campaigns must shift their emphasis from hardware provision to behavior change. By addressing literacy and cultural taboos surrounding toilet use, these campaigns can foster deeper, lasting improvements.

In agriculture, the openness to alternative fertilizers presents a valuable starting point. Demonstration projects, field trials, and community workshops can showcase the benefits of fecal sludge-based fertilizers, while also addressing the practical concerns of farmers. These pilot programs could be supported by both government schemes and local agricultural experts.

Toward an Integrated Model of Rural Development

The journey through Beldarwadi reveals both pressing challenges and hopeful possibilities. The interplay between sanitation and agriculture calls for an integrated development model—one that views these elements not in isolation but as parts of a broader ecosystem.

As we move into the next phase of this extended study, we will explore each of these aspects in greater detail. From sanitation monitoring systems to the sociocultural drivers of behavior, from agricultural innovations to infrastructure

needs—every insight adds a thread to the fabric of rural transformation.

Beldarwadi's journey is far from over. It is a narrative in motion, shaped by the efforts of its people and those who work alongside them. In sowing the seeds of awareness, sustainability, and innovation, we nurture the promise of a future where rural communities like Beldarwadi can thrive with dignity and resilience.

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