Monitoring and Evaluation of JalTara Pits

Assessing field and watershed scale impacts in semi-arid Maharashtra.

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About WELL Labs

Water, Environment, Land and Livelihoods (WELL) Labs co-creates research and innovation for social impact in the areas of land and water sustainability. We collaborate with partner organisations to design and curate systemic, science-based solutions to enable a high quality of human life and nurture the environment. WELL Labs is based in Bengaluru, India, and is part of the Institute for Financial Management and Research (IFMR) Society.

About the Technical Consulting programme

The Technical Consulting team at WELL Labs focuses on systematising Monitoring, Evaluation and Learning (MEL) for the water sector. The current thematic focus of the MEL programme is to assess three community-based groundwater management approaches in Maharashtra, Karnataka and Andhra Pradesh. It aims to develop an MEL Toolbox so that civil society organisations can continuously monitor and assess impacts themselves. The initiative is also developing simple, accurate indicators on the state of water security that could play a critical role in solving India's water crisis.

About the Environmental Defense Fund

A global nonprofit, Environmental Defense Fund (www.edf.org) collaborates with governments, NGOs, research and academic institutions, corporates and others to support and advance India's vision of shared, sustainable prosperity. We combine scientific and economic foundations, a broad network of partnerships and a pragmatic approach in support of India's ambitions. Our areas of interest include demonstrating the viability of sustainable livelihoods in agriculture, livestock and fisheries, establishing the shareholder value potential through responsible business, informing of the potential of market-based mechanisms, and catalysing the climate technology ecosystem in India. Connect with us on X @EnvDefenseFund, on LinkedIn, and visit our website EDF.org/India.

About Save Groundwater Foundation

The Save Groundwater Foundation is a non-profit organisation on a mission to recharge global aquifers. Their focus has been on the JalTara 'one-recharge-pit-per-acre' methodology, which aims to significantly improve water tables, crop yields, and farmer incomes. SGF's JalTara vision is guided by the larger goal of solving the global water crisis through a low-cost, nation-scale approach for rapid and massive groundwater recharge addressing both droughts and floods.

Acronyms

EDF	Environmental Defense Fund
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
MAR	Managed Aquifer Recharge
mbgl	Metres below ground level
mm	Millimetres
MWF model	Multiple Wetting Front model
PVC	Polyvinyl Chloride
SCS-CN	Soil Conservation Service Curve Number
SGF	Save Groundwater Foundation
VMC	Volumetric Moisture Content
WELL Labs	Water Environment Land and Livelihoods Labs

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A well being dug in Jalna district. Credit: Saumya Srivastava

EXECUTIVE SUMMARY

Marathwada in the western state of Maharashtra is one of India's most drought-prone regions, primarily due to the relatively low annual average rainfall of only 776 mm (Pawar et al. 2022). Farmers here are among millions across the country who struggle with access to water. Their problems are amplified by extreme heatwaves and erratic rainfall, rendered more intense and frequent because of climate change.

This region also faces specific problems stemming from the type of soil and aquifer that underpins the region. Clayey black soil carpets the ground; it has low hydraulic conductivity, which means that water does not percolate through it resulting in significant challenges such as waterlogging during the monsoon and severe water scarcity during the summer because water does not drip down to the aquifer below, recharging it.

Both problems lead to crop loss. Moreover, the layers of basaltic aquifers underground are characterised by low storage capacity, which means that water depletes quickly. The nature of the soil and the aquifer are central to understanding how we solve the dilemma faced by farmers in the region, who are primarily rainfed in this infamously low rainfall region.

The JalTara approach aims to address both challenges.

In response to these challenges, the Save Groundwater Foundation initiated the JalTara project, which involves the construction of infiltration pits designed to reduce waterlogging and enhance groundwater recharge. These pits are like holes that puncture the thick soil, thereby allowing surface runoff to bypass the less permeable black soil layer into the more permeable weathered rock layer beneath. JalTara also aims to provide an affordable and scalable solution to groundwater recharge.

In Maharashtra, the project aims to extend water availability by 1-2 months every year, which is critical for the region because it would increase dry season irrigation supply and allow farmers to cultivate and harvest more, thereby adding to their income.

This approach shows promise but it needs to be systematically evaluated.

It is based on this context that we shaped the objective of this study – evaluate the effectiveness of JalTara pits in reducing waterlogging and improving groundwater recharge. Our methodology included a combination of field infiltration tests and a comprehensive farmer survey to understand the efficacy of the pits and farmer perceptions.

While the goal of the larger study is to understand whether JalTara pits address both waterlogging and groundwater recharge, this report only covers work done in terms of addressing the first objective. In this report, we detail our methodology, how we approached our fieldwork and document the results we have got so far and what next steps it points toward.

JalTara pits could potentially enhance groundwater recharge

We conducted infiltration tests at different sites to assess whether JalTara pits could facilitate groundwater recharge. We found that the pits have potential to significantly increase rates of infiltration compared to the surrounding farmland. However, its effectiveness varied based on how well the pit had been maintained.

The second core part of the work we have done so far involved farmer surveys. They described benefits in terms of waterlogging reduction and crop loss prevention as a result of the JalTara pits. The survey also highlighted the critical role of proper pit placement, maintenance, and farmer involvement in the overall success of the intervention.

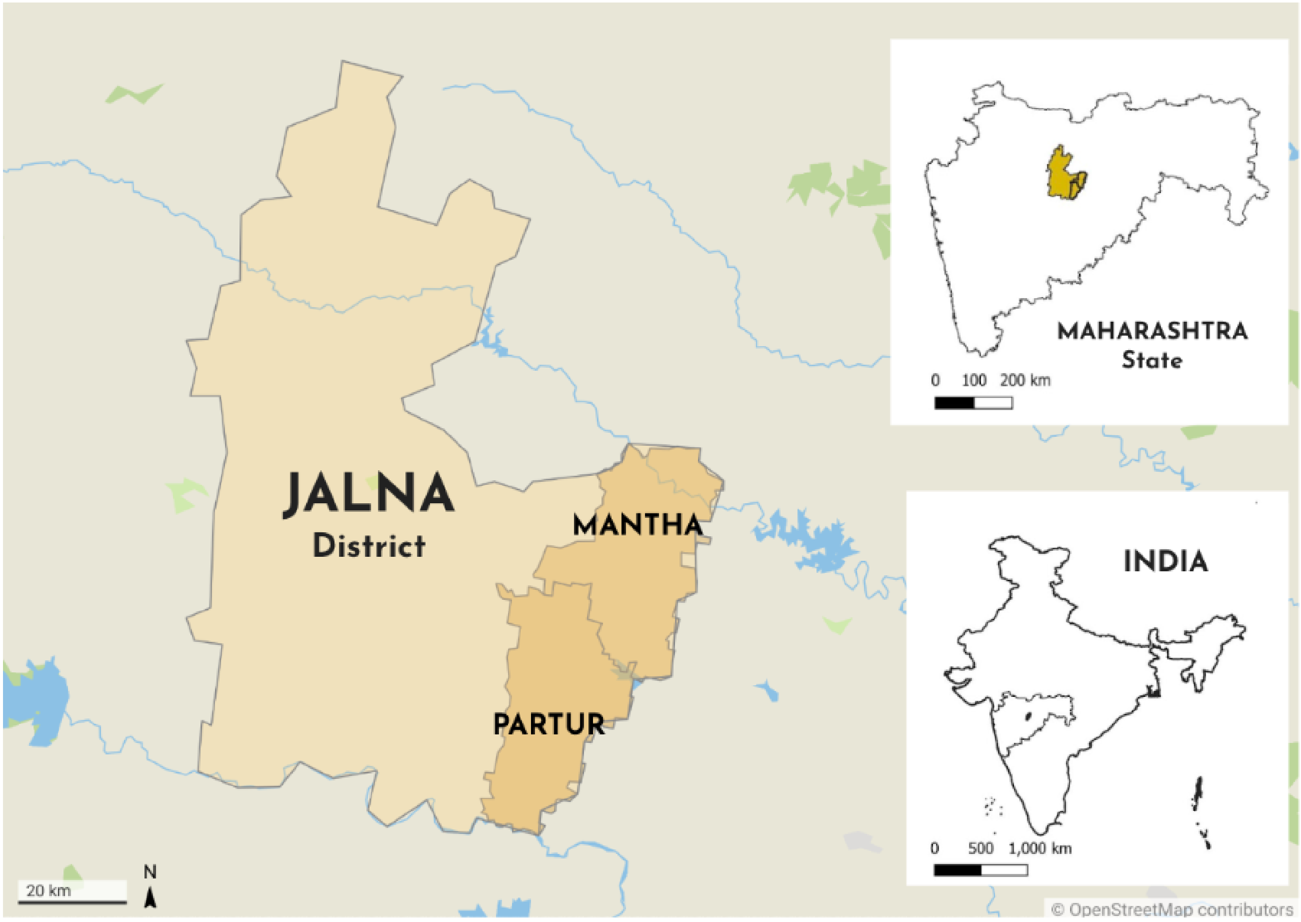


Figure 1*: The study was conducted in the Mantha and Partur talukas (an administrative subdivision) of Jalna district, which lies in the Marathwada region in interior Maharashtra state.*

We identified two main challenges with the design and implementation of JalTara

For one, these pits are prone to siltation, which reduces their infiltration capacity. After a rainfall spell, the ensuing runoff carries with it soil from the surrounding fields and depositing it on top the JalTara. This necessitates regular maintenance, which has not been consistently performed by all farmers.

Second, there is a need for increased farmer education and training regarding the benefits of the pits and the importance of maintenance to ensure their long-term functionality.

Design tweaks and better capacity building could result in more effective pits.

There are two hypotheses that this research project has tested so far. Based on our findings, we have narrowed down on a few recommendations that both farmers and field staff of Save Groundwater Foundation could attempt to better realise this method's potential.

- **Develop standardised guidelines for JalTara pit construction and maintenance** to maximise their effectiveness. We have explained how changes such as adding a bund around the pit to reduce inflow of silt and a mulch layer to act as another filter, could address one of the main problems we found with JalTara implementation – siltation.
- **Implement training sessions for farmers** to improve understanding and execution of pit maintenance. Farmer surveys revealed that majority farmers either did not know how or that regular maintenance needs to be carried out for JalTaras to remain effective beyond one or two rainfall events.
- **Continue to monitor the pits' effectiveness and gather empirical data** to refine and adapt project strategies based on observed outcomes. We are conducting research over the 2024 monsoon season as well to supplement our findings so far and further clarify how the JalTara system works and could be improved upon before scaling them to other parts of India facing similar hydrogeological challenges.

India is one of the most water-stressed countries in the world.

India is also heavily dependent on groundwater, a fast-depleting resource. The crisis is not due to a lack of funding – governments, philanthropies, and grassroots organisations are spending billions of dollars every year to improve water security. They do this mainly through conservation measures like check dams, farm ponds and trenches. However, these solutions often fail to get the desired impact due to problems like sub-optimal site selection, siltation and the lack of focus on water demand management.

There is a growing need to find evidence-based solutions to direct climate adaptation funding. WELL Labs has partnered with the Environmental Defense Fund to assess promising groundwater interventions in some of the most water-stressed parts of India – the JalTara method being implemented by the Save Groundwater Foundation in Jalna district in Maharashtra is one of these solutions.

CONTEXT

Jalna's black soil is prone to waterlogging. Credit: Lakshmikantha N.R.

REGIONAL CONTEXT

Maharashtra is one India's largest states, lying towards the west of the country's coastline. In terms of state Gross Domestic Product (GDP), Maharashtra remains the wealthiest with the service economy in urban centres like Mumbai accounting for a large portion of this wealth (Directorate of Economics and Statistics, 2022). Farther inland where large swathes of farmland make up the landscape, there are significant challenges related to both excess rainfall and droughts. Increasing climatic variability fuelled by the climate crisis is exacerbating existing vulnerabilities that result from a wide range of practices such as deforestation and inefficient water management.

Like other parts of the subcontinent, Maharashtra experiences the annual southwest monsoon season from June to September. The intense rainfall combined with Maharashtra's poorly draining black soil often leads to waterlogging during this period, which can destroy crops, severely affecting the livelihoods of farmers . Historically, black soils in India were not cultivated during the monsoon due to this problem of excess water. To curb this, contour trenches were widely recommended as a water and land management strategy that can capture excess runoff (ICRISAT, 1981; Panigrahi et al., 2021). Trenches are also capable of arresting topsoil erosion to which black soils are highly vulnerable. Gully and rill erosion is commonly sighted as a result of the disaggregated nature of the soil.

On the other hand, water remains scarce during the summer from March to May. Compounding these dry conditions is the excessive withdrawal of groundwater for agriculture and industrial uses, which lowers the water table and exacerbates drought conditions. Water scarcity affects daily life and leads to severe drinking water shortages. An indirect impact is that drought conditions can lead to migration, as people move in search of better employment opportunities.

Both waterlogging and droughts lead to crop failure, reducing agricultural productivity and causing economic distress for farmers. Studies have found that the yield of soybean, a widely grown crop in the Marathwada region, has reduced by 50-60% as a result of these hydrological stressors (NAAS, 2017). Often, this is the result of poor management of water resources, including inefficient irrigation practices, inadequate recharge and lack of drainage (Ward et al., 2020).

The dichotomy of too much and too little water is widespread in the larger region of Marathwada.

In the study region of Jalna district, the challenge of water resources is two fold. First, the annual rainfall here is limited to 750.4 mm (CGWB, 2018) and in case of any deficit, farmers are left highly vulnerable. Second, hard rock aquifers underlying the region have limited storage capacity (CGWB, 2018). Therefore, there is a high dependency on recharge through rainfall every year.

The challenge of water availability is further exacerbated by increased extraction for water-intensive crops like sugarcane and demand for growing sectors such as steel manufacturing, liquor production and sugar processing industries (Mulye, 2019; Vohra, 2022). Crops like soybean, cotton and sugarcane have witnessed a reasonable increase in the area under cultivation for the Marathwada region (Deshpande, 2021).

Water is primarily sourced from open wells that start to decline from the month of January until the beginning of the monsoon in June. There are also tubewells (which involves a long pipe bored into the aquifer to pump out groundwater), but these have largely been unsuccessful due to poor yields from deep groundwater systems with low storage capacity that runs out of water quickly. This forced people to turn to water tankers instead. Tankers plying water for drinking and irrigation purposes are a common sight in Marathwada (Nitnaware, 2024; Barkved et al., 2014).

The violence wreaked by drought is sharply visible in the Marathwada region, which records high numbers of farmer suicides and has thus drawn nationwide attention. The most recent report by the state's relief and rehabilitation department says that 1,088 farmers ended their lives in eight districts of Marathwada region in 2023 alone, a statistic that could be understated (Deshpande, 2024).

There is a wide range of problems that fuel agrarian distress in the region. But the scope of this report is limited to the interplay (or lack thereof) between the impermeable black soil and the low-storage basaltic aquifers upon which cultivation is carried out.

To counter the twin problems of waterlogging and scarcity, the Save Groundwater Foundation, a non-profit dedicated to recharging aquifers, implemented JalTara.

The project involves digging infiltration pits to allow rainwater runoff to drain from the fields. The pit acts as a conduit, bypassing the low permeable black soil layer and directing water to the weathered rocks underlying the soil. Not only does this target the waterlogging problem, these pits are also hypothesised to recharge aquifers such that the availability of water is extended by 1-2 months (beyond February).

Recharge pits, as an approach for rainfall runoff management, have appeared in literature on water management (Ganguly & Ganguly, 2021; Saha, Sikka & Goklani, 2022). But it is apparent that implementation is rare in India's rural context as other forms of artificial recharge methods dominate such as check dams, recharge shafts and percolation tanks. Recharge pits for stormwater management are often discussed in the urban context as a sustainable drainage system (Narasimhan et al., 2023). Therefore, the project forms a novel case study to understand the effectiveness of the intervention.

It is essential to conduct monitoring and evaluation of the JalTara approach to consider scaling such infiltration pits to other parts of India plagued by low recharge.

This assessment will allow us to draw empirical learnings from the field that are currently missing from the literature in the rural context. At the same time with around 60,000 pits adopted in the two *talukas* we focused on in Jalna, there are potential watershed-level impacts that also need to be evaluated and quantified. Other than monitoring and evaluation, there is an added component of *learning* to this project where findings will be assessed to provide feedback to improve this measure. In the case of JalTara, both design and implementation are determinants of the efficacy of these pits.

JALTARA PITS

The Save Groundwater Foundation introduced JalTara pits in 2021 to allow water to infiltrate through the subsurface layers by bypassing the black soil stratum. The top layer of black soil in the region has been found to vary in depth from one foot to six feet. By constructing pits that were six feet deep, the water could reach the *murum* stratum (layer of fragmented rock; weathered basalt, in this context) and recharge aquifers. The top of the pit was generally rectangular in shape with dimensions of typically 4 ft (length) x 4 ft (wide) with some variations.

Pit filling is central to the design of JalTara – it is not an empty pit. The pit is reportedly filled for two reasons. First, so that the pit boundary does not fall into itself. Second, a filled-up pit can be used for agriculture without any loss of land. The filling is ideally composed of larger boulders in the bottom followed by smaller boulders over it, and *murum* on the top, as shown in Figure 2.

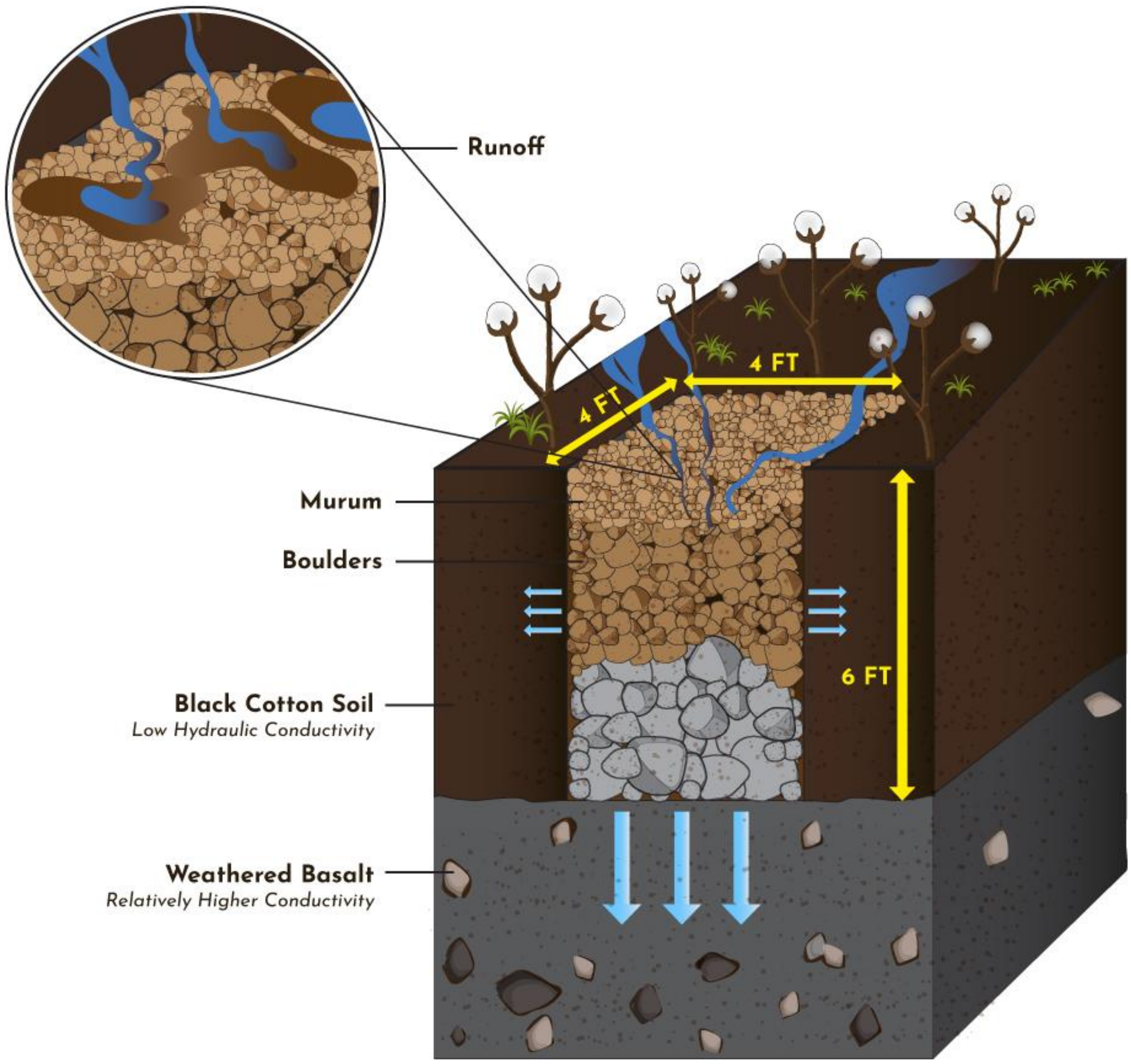


***Figure 2**: Schematic representation of a JalTara pit, with runoff from the landscape flowing to the pit and infiltrating into the murum layer. Illustration by Sarayu Neelakantan.*

Farmers primarily source boulders from outside the farm (but within the village). In a few cases, if a well was constructed recently, there are usually enough boulders from the excavated ground to use for 3-4 pits in the farm. Pit construction takes place in the lean agriculture period or pre-monsoon between April and May. At this time, agricultural land is barren and is being prepared for the upcoming *kharif* season.

During our fieldwork in Jalna, we found that there seemed to be a lot of variation in the way the pits are actually filled. In a few cases, due to lack of enough boulders, much of the pit is filled mostly by *murum*, which is much finer (see the top layer in Figure 2). Often, farmers till over the JalTara pit with the soil from other parts of the farm overlying the JalTara itself to make it almost indistinguishable from surrounding land.

Figure 3: Boulders excavated from a well, to be used to fill a JalTara pit. Credit: Vivek Grewal

These pits are planned and placed in a way that they capture rainfall runoff from an area of one acre. They are placed at the lowest elevation in the farm to be able to drain the cultivated area and collect maximum water. Generally, farms have been found to have more than one pit, mostly located at the edges of the field along the bunds or embankments. Sometimes farmers are also likely to place a pit closer to the well. This process of site selection is guided by farmers who know the contours of their farm and have years of experience with channelling and redirecting water in their fields. Therefore, farmer participation is key to the process of implementing JalTara.

Since 2021, about 39,000 pits have been constructed so far in Jalna district in Mantha and Partur talukas. In 2024, 17,000 were added, covering 11 villages in the same blocks.

STUDY AREA

The current study focuses on the Mantha and Partur *talukas* of Jalna district, part of the Marathwada region in Maharashtra state, where there has been extensive implementation of JalTara recharge pits. These pits have been constructed every year in the dry season since 2020. But most of the pits were constructed in 2022 and 2023.

In the Marathwada region, water scarcity is a critical issue due to the relatively low annual rainfall, and high agricultural water demand. In the heart of Marathwada lies Jalna district, where most wells typically dry up around January-February each year. These wells remain dry through the summer and are recharged by the monsoons around July. This seasonal depletion of wells by February is a clear indicator of the region's water scarcity challenges.

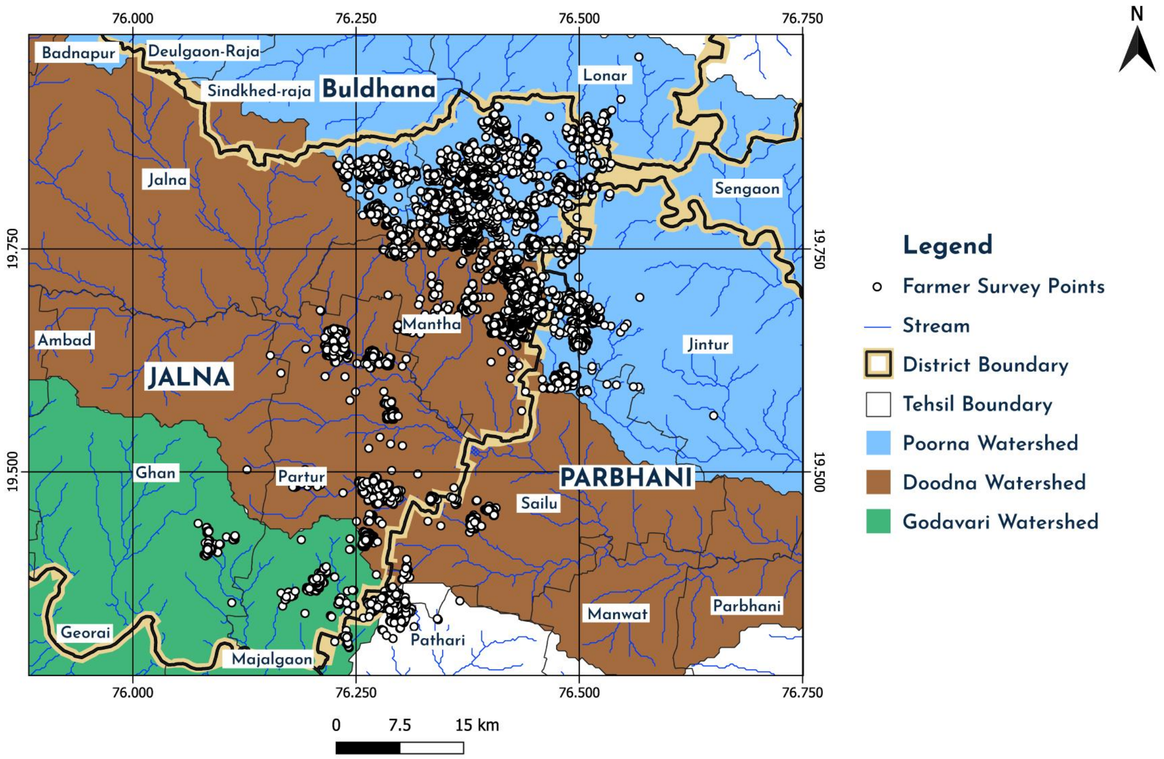


***Figure 4**: Distribution of JalTara pits (from 2022 and 2023) across taluka and district boundaries.*

Rainfall

This region receives 83% of its annual rainfall during the southwest monsoon period from June to September. In terms of daily intensity, rainfall distribution data between 2013 to 2022 is depicted in Figure 5. According to the Indian Meteorological Department: ~65% of days in a year recorded no rainfall in Jalna district, fewer than 7% days in the year reported rainfall above 10 mm.

The volume of runoff after a spell of rain is governed by two factors – infiltration rates and the intensity of rainfall. This means that runoff is generated when rainfall intensity is more than the rate at which water infiltrates through the soil. There are also other factors such as the condition of the soil at the time of rainfall – whether it is saturated or unsaturated – as well as the gradient of the slope. Therefore, the functioning of JalTara pits is determined by rainfall intense enough to generate runoff, which then filters through the pits.

Soil

The black cotton soil of the region has low hydraulic conductivity and retains water for a long time after a rainfall event. Hydraulic conductivity was found to significantly vary and range between 12.6 mm/h to 0.2 mm/h in India (Chinchmalatpure & Vibhute, 2017).

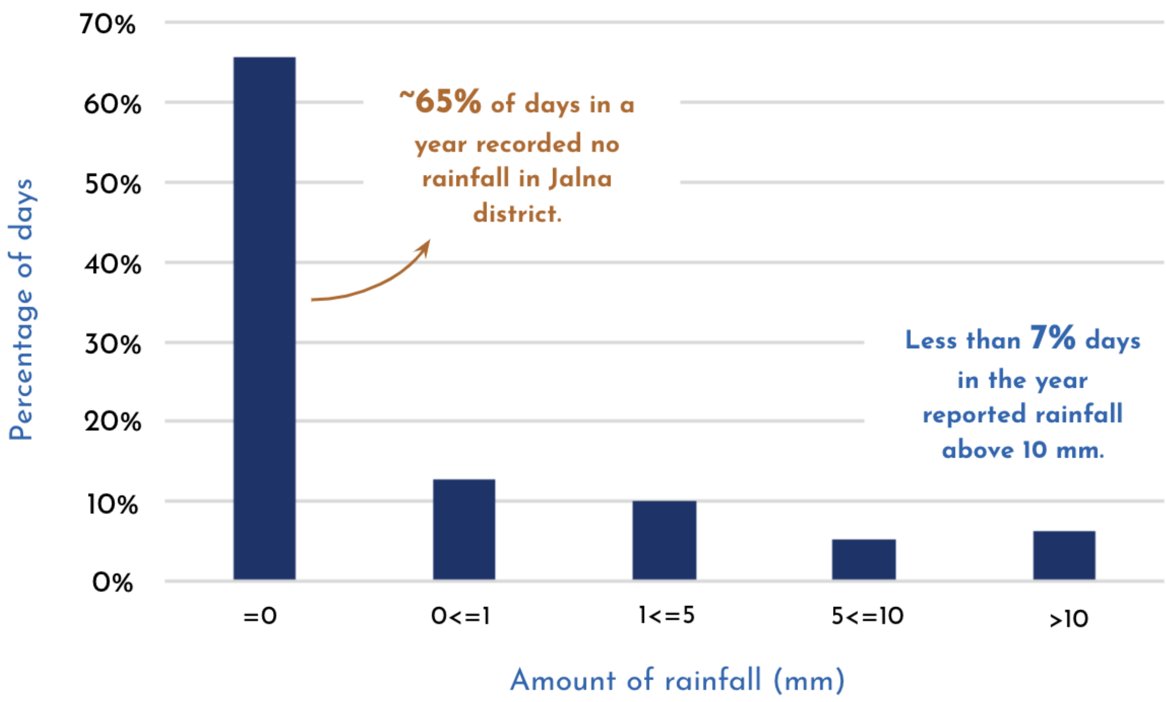


Figure 5: *Daily rainfall (mm) distribution in the last decade in Jalna district (Source: IMD)*

The clay particles, being smaller than 2 microns (or micrometres (μm)), result in small pores and have a high molecular affinity for water, preventing it from easily percolating downward. This results in a much lower water infiltration rate compared to sandy soils. The thickness of this low-conductivity soil can vary from 1 to over 10 feet.

Beneath the soil lies a relatively higher conductivity layer of weathered basaltic rock, locally known as *murum*. Bypassing the low conductivity soil layer could significantly increase the rate of groundwater recharge.

The black soils also rapidly shrink and swell, in the absence and presence of water. Cracks as deep as two metres in cultivated soils can be observed during the dry season, whereas high water retention is evident during the monsoon (Hodnett and Bell, 1981). This property of rapid shrinking and swelling imparts them with the property of pedoturbation or churning. The material from the surface falls into the cracks and gets trapped when cracks fill up with water (Chinchmalatpure, 2019). The process allows natural homogenization of the soil profile.

Black soil behaves this way because it is primarily composed of silt (0.002 – 0.075 millimetres (mm)) and clay (< 0.002 mm) – both made of the smallest particle sizes. The soil's capacity to retain water results in a flourishing cotton crop and improved yields, as moisture is crucial for an input-intensive and investment-heavy crop like cotton. However, water logging in the fields during monsoon affects crop growth due to poor exchange of air in the root zone leading to rot and loss of crops.

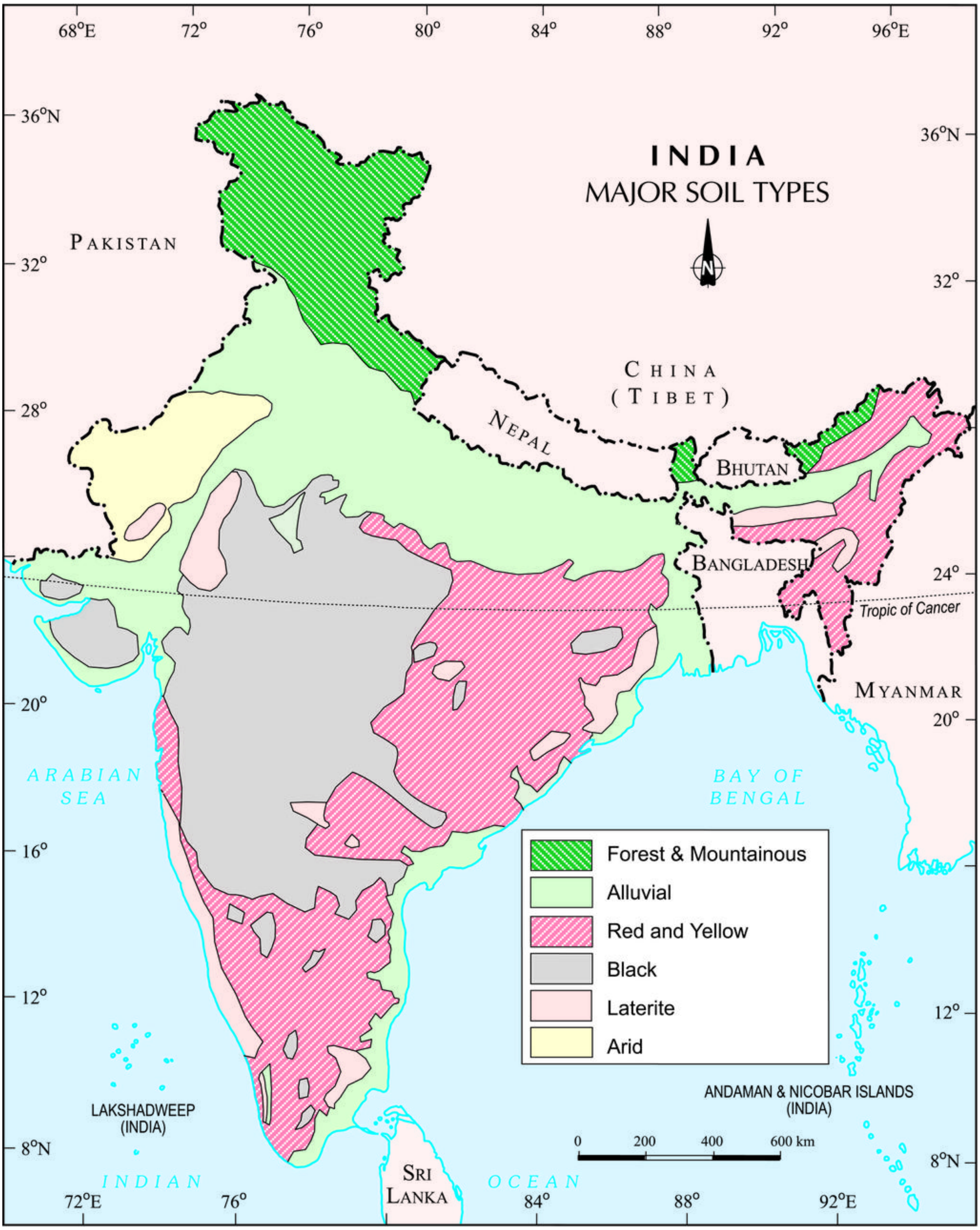


***Figure 6**: The main soil types of India (This map is taken from the government's National Council of Educational Research and Training [(NCERT) textbook])*

According to the Food and Agriculture Organisation's soil database (Sanchez et al., 2003), the main soil category in the blocks we studied is Chromic Vertisols (Vc43-3a and Vc43-3ab), which is clay rich (~55% of the soil's composition) and shrinks and swells with changes in moisture content. These soils exhibit high infiltration rate at the beginning of the infiltration tests, but we observed sharp decreases after soil saturation. These soil compositions impact water retention and infiltration rates, further influencing water availability in the region.

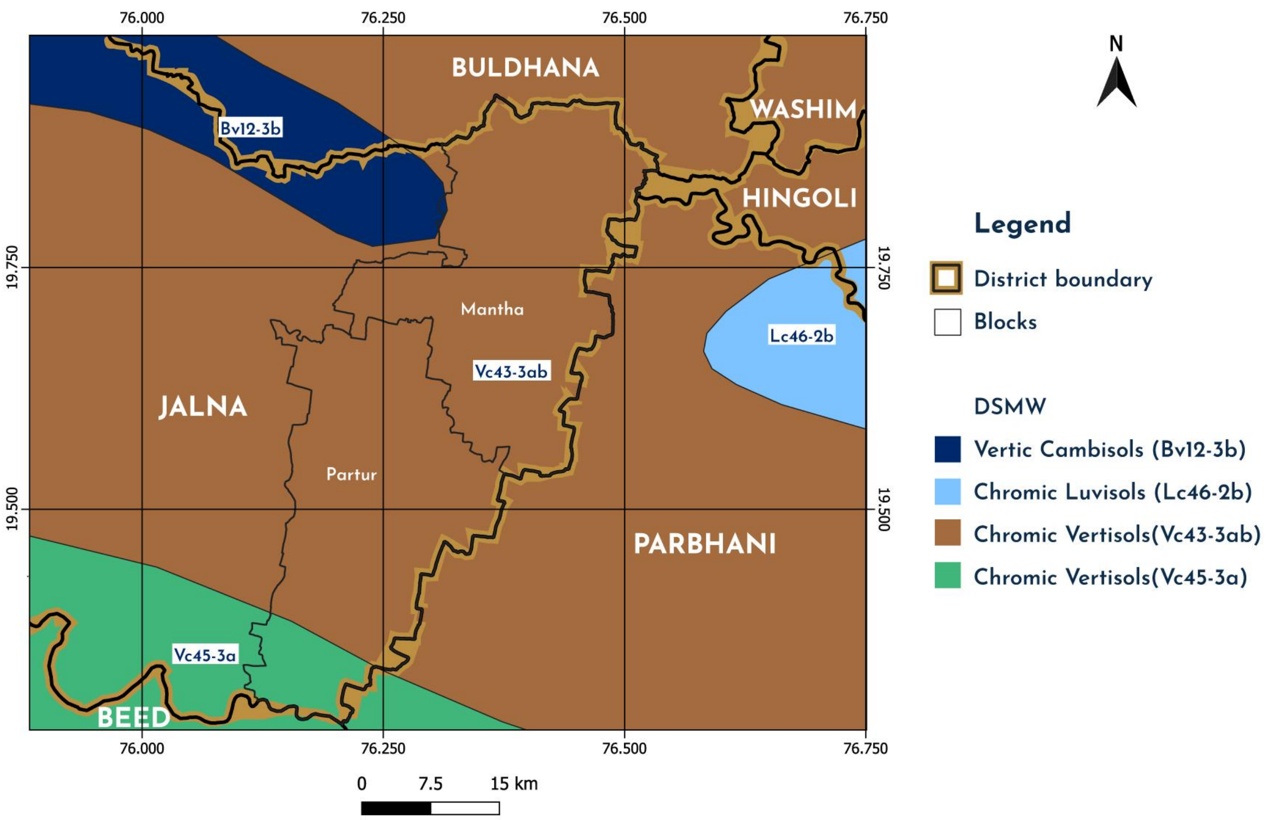


***Figure 7**: The soil type in the study area, as sourced from the FAO's Digital Soil Map of the World. Accessed on June 13, 2024 from FAO's Map Catalog.*

Hydrogeology

Subsurface layers in this region consist of alternating massive basalts and vesicular basalts as depicted in Figure 8. Vesicular basalts, as the name indicates, are characterised by vesicles that both store and act as channels for water conductivity. They are also erodible in nature whereas massive basalts are consolidated rocks. The layered nature of basaltic aquifers means that low-lying areas near rivers often have perennial water, while uphill areas only have seasonal groundwater.

After the monsoon, groundwater from uphill areas moves towards the valley, gradually emptying upstream aquifers. This allows farmers near rivers to grow water-intensive crops like sugarcane, while those uphill must grow low water requirement crops like sorghum and pulses. The varying water availability forces farmers to adapt their cropping patterns based on their location within the watershed.

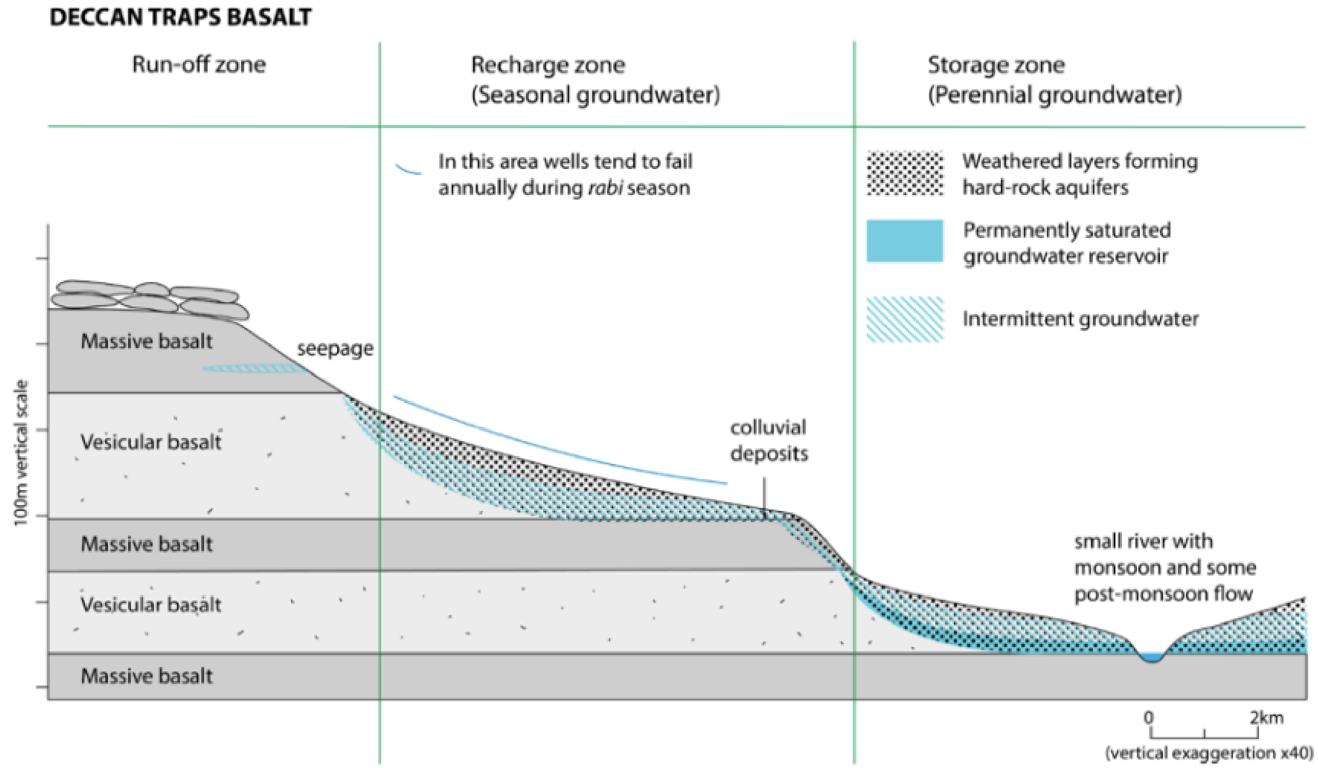


Figure 8: *Typical hydrogeological cross-section of a Deccan Trap basalt micro-watershed (Original source: Foster et al. (2007), this image is from Barkved et al. (2014).*

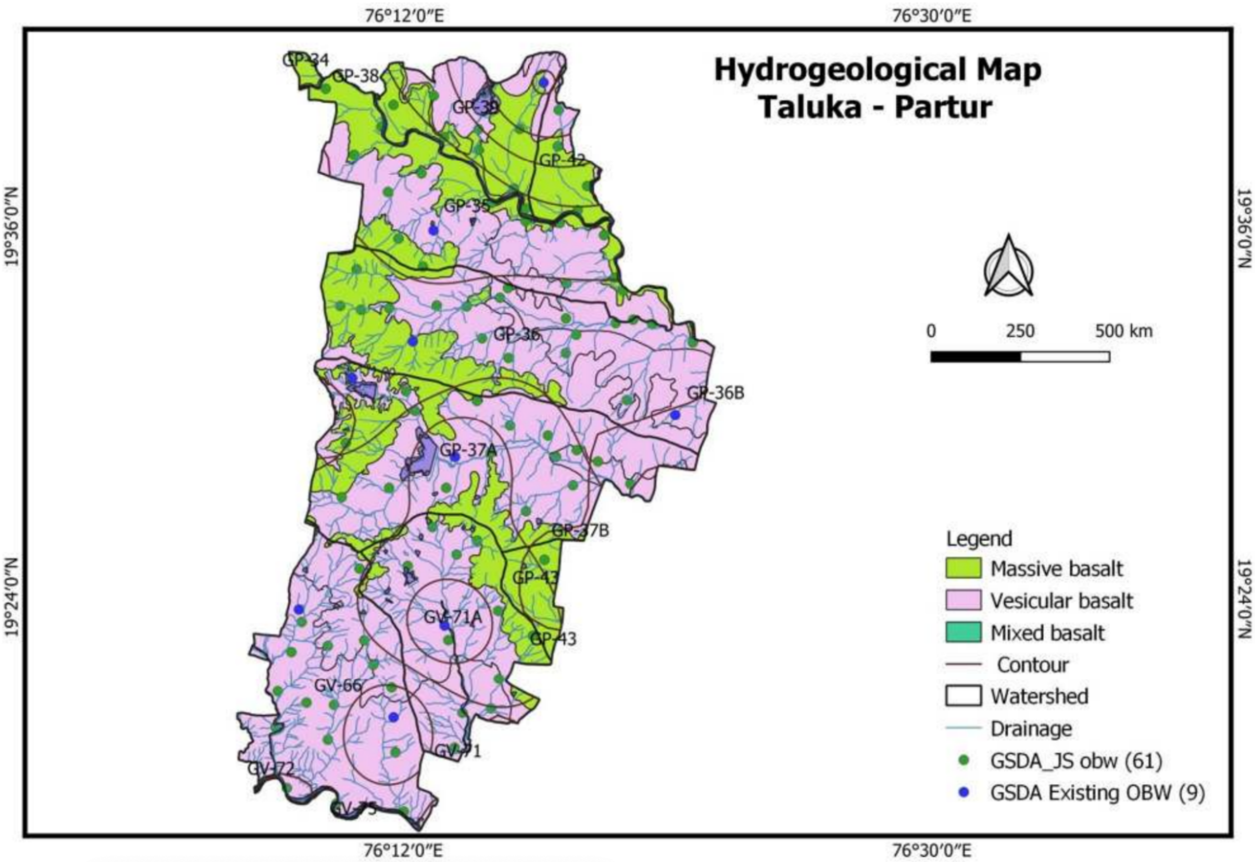


Figure 9: *Top view of alternating vesicular and massive basalts in Partur taluka (Source: Groundwater Surveys and Development Agency, 2020)*

Land Use

The land use in the study area is predominantly agricultural cropland, followed by forest and barren/uncultivable land. The JalTara pits are concentrated on agricultural land.

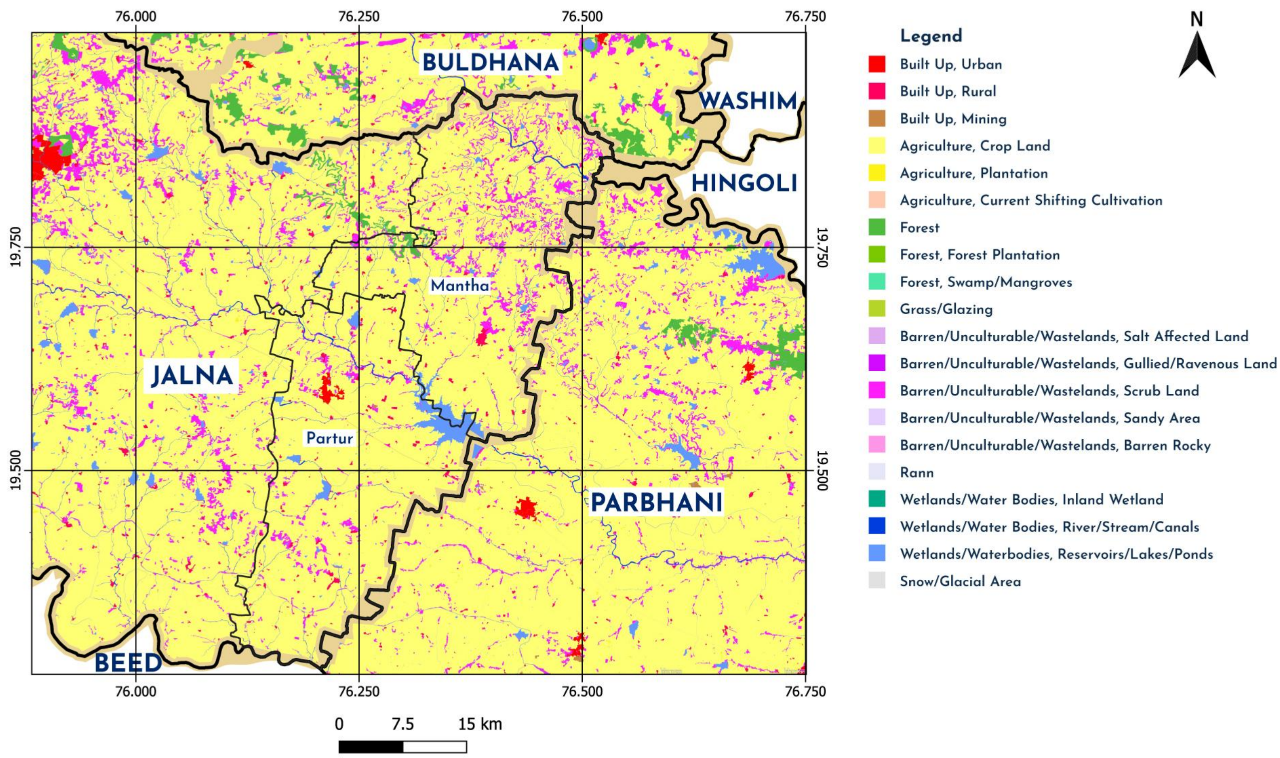


***Figure 10**: Land Use Land Cover (1:10K) map by Bhuvan, a web-based tool by the Indian Space Research Organisation that details geospatial information and services.*

Crop Choices

Table 1: Farming patterns in Jalna district (Source: CGWB, 2018)

Cropping Season	Kharif (Monsoon: June to October)	Rabi (Winter: November to March)
Area Sown	81,216 hectares (ha) or 99.7% of the total cultivable land	38, 645 ha (47.4% of the total cultivable area).
Major Crops Grown	Jowar, Cotton, Tur, Soybean, Safflower, Green Gram, Sugarcane	Jowar, Cotton, Wheat, Gram, Maize, Bajra, Sugarcane

Figure 11: *Top: sorghum; bottom left: cotton; bottom right: wheat (Pictures by Ishita Jalan, Lakshmikantha N.R.)*

Elevation

JalTara pits have been implemented across an elevation range of 410 metres (m) to 630 m above mean sea level, spread across the Poorna (upper watershed), Doodna (middle watershed), and Godavari (lower watershed) watersheds. The Poorna and Doodna rivers join the Godavari river downstream. Largely, the slope of the land is towards the eastern and southeastern direction.

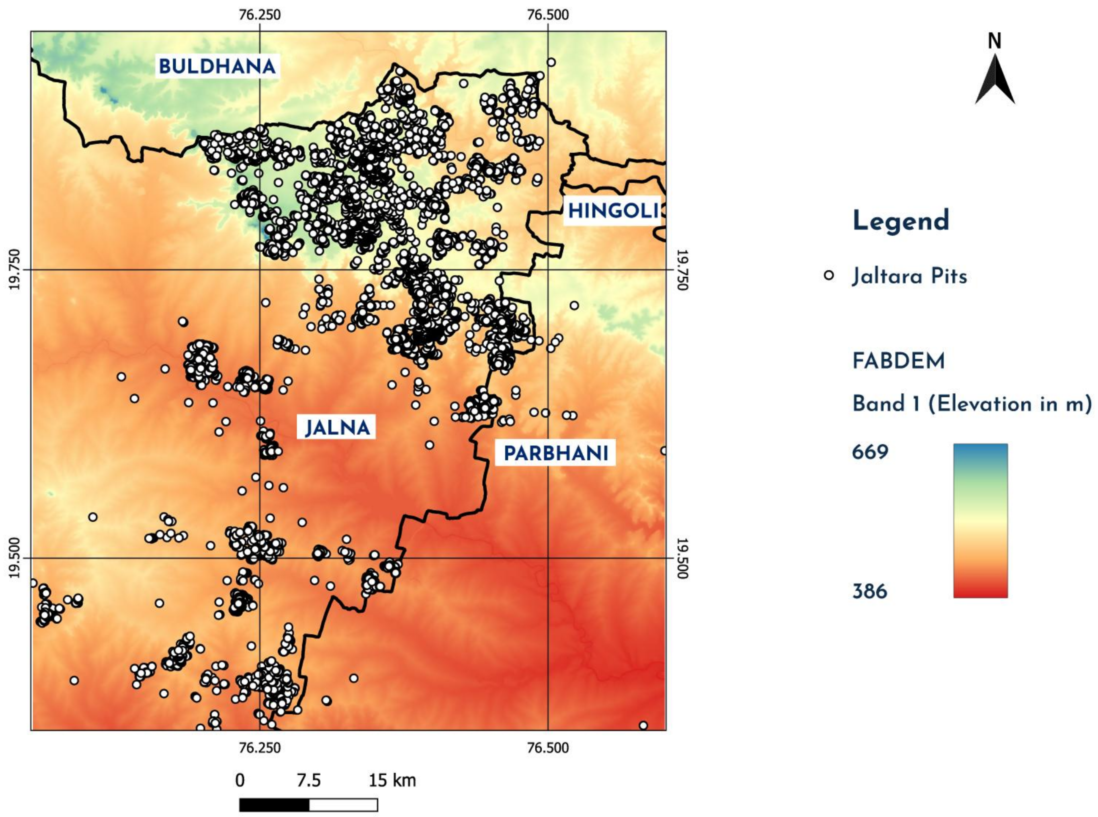


***Figure 12**: Elevation map of Jalna district.*

METHODOLOGY

Equipment to test water infiltration rates. Credit: Lakshmikantha N.R.

STUDY OBJECTIVES

The goal of the larger study is to understand both whether Jaltara pits address waterlogging but also whether they contribute significantly to groundwater recharge. This interim report primarily covers work done on the first objective and highlights work-to-date on the second objective.

We visited the field on December 13, 2023, to recce the area and conduct a preliminary assessment of the solution. We scheduled meetings with the local field team of the Save Groundwater Foundation and their local partners associated with the Art of Living Foundation. They provided us with context about the area and how the JalTara model was conceptualised to solve water logging and groundwater scarcity.

We directly interacted with approximately **10 farmers** in the two blocks during the recce visit. The farmers were quite positive about the impact of JalTara and provided anecdotal information of how it reduces water logging. We even observed waterlogging on some of the fields we visited – a result of rainfall that the place received over a week ago, illustrating a part of the problem. The field visits gave us confidence that more detailed experiments were worth undertaking. We documented our early observations in a blog (Grewal & Lakshmikantha, 2024).

Based on the recce visit we developed the following objectives for the research:

OBJECTIVE 1 | Do JalTara pits reduce water logging and thus crop losses?

This was formulated based on claims that JalTara pits ***reduce water logging of fields significantly by redirecting runoff*** *into the ground; and that* ***farmers perceive the benefits and are motivated to construct*** *and maintain the pits.*

OBJECTIVE 2 | Do JalTara pits contribute significantly to groundwater recharge?

This was formulated based on claims that JalTara pits are able to ***drain water fast enough so that they contribute to recharge****, and consequently, they* ***improve regional recharge rates****, so water tables are higher post monsoon.*

HYPOTHESES

The claims that are being made by Save Groundwater Foundation were both at the field and watershed scales. Therefore, we proposed a set of hypotheses and corresponding tests to investigate both (Table 2 below). Hypotheses 1 and 3 involve measuring field parameters and modelling to quantify the impact of JalTara at a field scale. Hypothesis 2 focuses on farmer-centric perceptions and is addressed through a farmer survey that captures information from both sets of farmers – those who adopted pits and those who did not. Note that Hypotheses 1–3 support understanding both research objectives, because the more water that infiltrates into the pit, the more water logging will be reduced and groundwater recharge will be enhanced. Hypothesis 4 focuses on measuring the impact of JalTara pits at a watershed scale.

Table 2: Tests were formulated to address each hypothesis we identified (This report covers work completed for Hypotheses 1 and 2).

Hypothesis	Primary approach
1: JalTara pits have a significantly higher infiltration rate (10-100X) per unit area than the surrounding fields.	**Field infiltration experiments**: Since the JalTara method mainly focuses on bypassing water from dense topsoil that allows little infiltration to the subsurface *murum* that allows infiltration, we needed to test that the infiltration rate in the pits was significantly higher than on the field.
2: Water ponding in fields has reduced where JalTara has been implemented.	**Farmer survey**: Farmers with JalTara on their fields were interviewed. A control group – farmers who did not adopt pits – were also spoken to and their responses compared to understand the benefits of the intervention.
3: At least 25% of excess runoff within that acre can percolate down via the pits.	**Simulation modelling**: A Multiple Wetting Front (MWF) model will be used for hydrological partitioning at plot scale.
4: Water levels improved at a watershed level as a result of JalTara.	**Paired watershed approach**: The large-scale impact of JalTara pits on groundwater levels can be assessed using the paired watersheds analysis approach. In this method, well water levels are compared from each watershed where one would have pits and the other would not.

Hypothesis 1: Field Experiments

The first hypothesis centres around the ability of JalTara to allow water to percolate down by diverting it from dense topsoil to porous *murum* layer. The change in infiltration rate due to JalTara is one of the important hydraulic properties that needs to be measured. Because the land surface area of pits is much smaller than the total land surface area of the farm, the surface of pits must exhibit considerably higher infiltration rates than the cropped area in order to have a meaningful effect on total infiltration.

Infiltration rates can be measured using various methods, with single and double ring infiltrometers being the most common. **We chose the double ring infiltrometer as it reduces errors caused by horizontal water flow, more prevalent in single ring tests.**

Our setup included two cylinders: an inner ring with a height of 45 cm and a diameter of 30 cm, and an outer ring with a height of 45 cm and diameter of 60 cm (Fatehnia et al., 2016). The water between the inner and outer ring promotes vertical flow, minimising horizontal movement from the inner ring. We used the constant head method, maintaining a consistent water level and measuring the amount of water needed to sustain this level.

Test design

To assess the effects of JalTara recharge pits, we designed four tests:

Test 1: On-farm infiltration test – This test measures the infiltration rate on the farm land where the pit is located. It serves as a baseline to compare with the pit infiltration rates.

Test 2: Top-of-pit infiltration test – Conducted on the pit surface, this test assesses the infiltration rate where water first enters the pit.

Test 3: Desilted pit test – During our initial site visit, we observed significant siltation in the pits, making them nearly indistinguishable from the surrounding farmland. To get accurate measurements, we removed the topsoil to expose potential boulders and performed a pit filling test (Cahill et al., 2011). This involved digging a 1-foot diameter pit on top of the silted JalTara pit, adding water and recording the head decline and water volume added over time.

Test 4: Bottom-of-pit infiltration test – Since the bottom layer of the pit plays a crucial role in enhancing percolation, we measured its infiltration rate. For newly constructed pits that had not yet been filled with boulders, we conducted this test directly at the bottom of the pit. This allowed us to compare the infiltration rate at the bottom with those of the other layers. The test was performed in the same plots as the first two tests to provide a comprehensive understanding of the variation in infiltration rates across different layers.

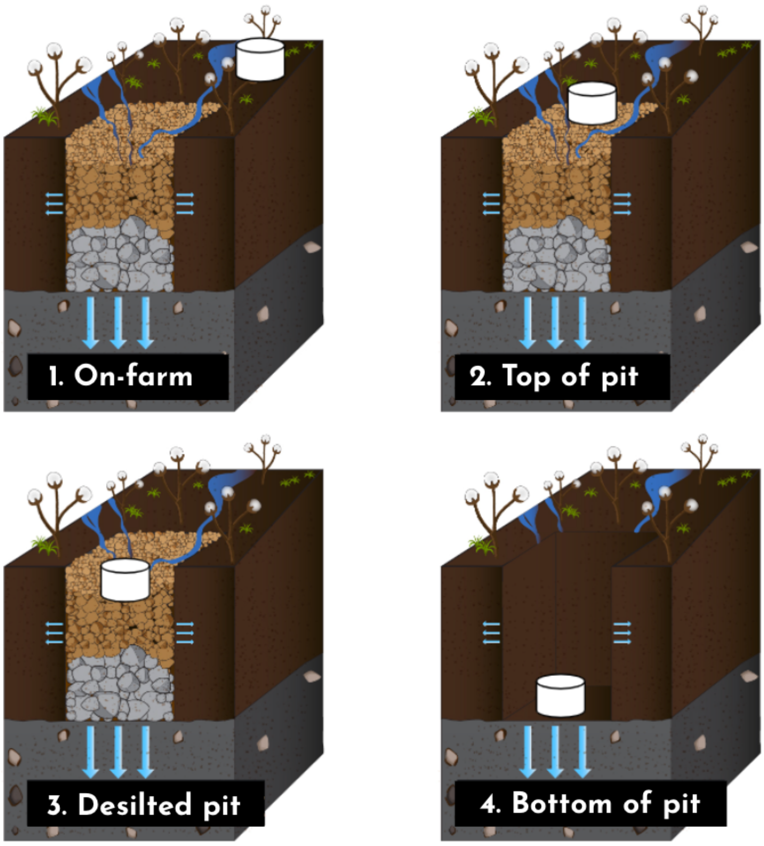


***Figure 13**: The four types of sites where we conducted the infiltration tests. The white cylinders indicate the location of the double-ring infiltrometer test.*

We conducted a double ring infiltrometer test for the on-farm and top of the pit, and a single ring infiltrometer test for the bottom of the pits (due to space constraints). For the third test at the desilted pit, we conducted a pit-filling test. We hypothesised that the on-farm infiltration rate (Test 1) will be the lowest. The pit top *murum* layer's infiltration rate should be higher than the on-farm rate, followed by the pit filling test. We expected to find the highest infiltration rate at the bottom of the pit, as illustrated in the representative graph below. The initial two limbs from the beginning of coordinates represent the rapid rate of infiltration at the start of the infiltration tests, showing how the soil absorbs quickly until it get saturated

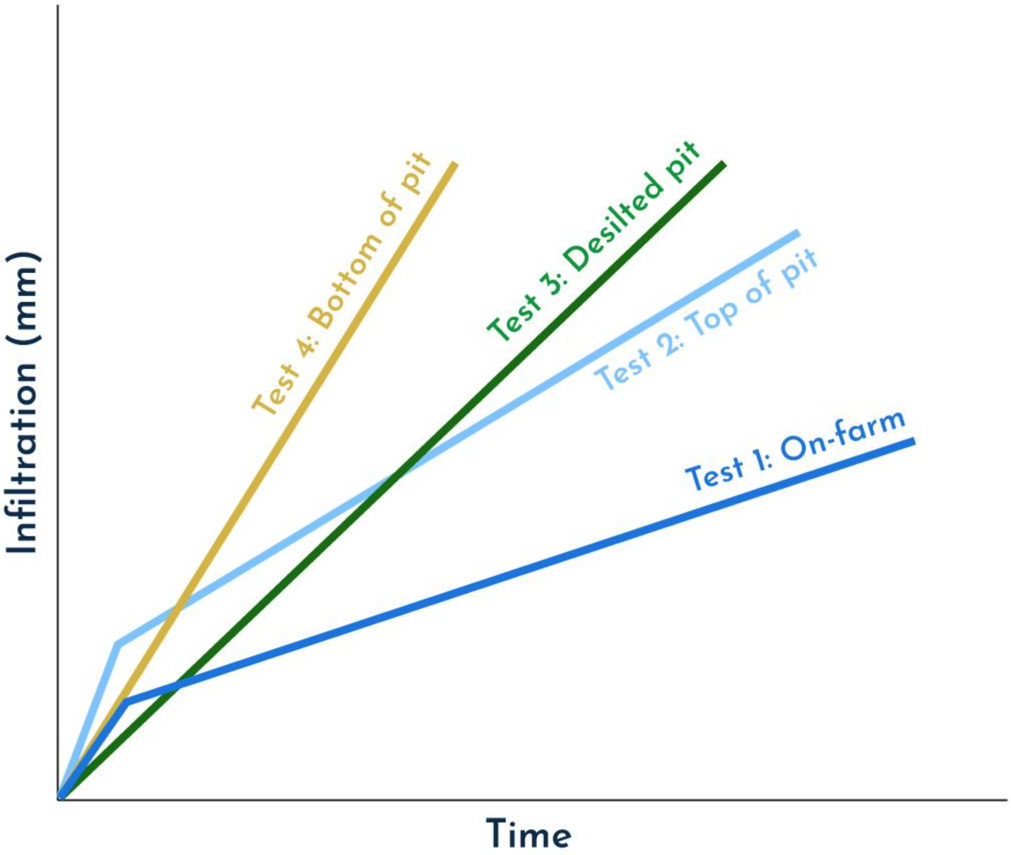


Figure 14: *Hypothetical relative infiltration rate representation assumed for each test.*

Sampling strategy

Our sampling strategy aimed to capture the diversity of the landscape in terms of land use, soil characteristics and slope. Recognising the importance of these three factors, we initially planned to stratify the samples based on slope. However, after analysing the plots with JalTara recharge pits, we found that most pits were located on gentle slopes of just 1-2 degrees, showing little variation across the landscape.

During our reconnaissance visit, we observed a correlation between soil thickness and elevation, with thinner soil on ridges and thicker soil in the valleys. Therefore, we decided to stratify the sampling based on elevation ranges within the watersheds. This allowed us to better capture the variability in soil characteristics related to elevation.

Further, we observed that the pits were constructed in both 2022 and 2023, but more pits were constructed in 2023, prompting us to sample more pits constructed in 2023. Although the programme began in 2021, very few pits were constructed that year.

We selected three elevation ranges for sampling across all three watersheds to ensure better representation. For instance, in the upper watershed, the elevation ranges were categorised as follows: i) 446-517 metres above sea level for low elevation, ii) 517-556 metres for middle elevation, iii) 556-605 metres for high elevation. These ranges were determined by dividing the total number of pits into three equal bins (equal count) and using the elevation data to set the boundaries for each subcategory. Pits from all elevation ranges were sampled for the infiltration tests.

Distribution and selection of sampling points

A total of 22 pits were sampled for infiltration tests across different watersheds and elevation ranges. The distribution of these sampling points is shown in figures 15b below. The specific locations were selected to ensure a representative distribution across villages, with pits chosen randomly within each village, while keeping the elevation relatively constant for the infiltration tests.

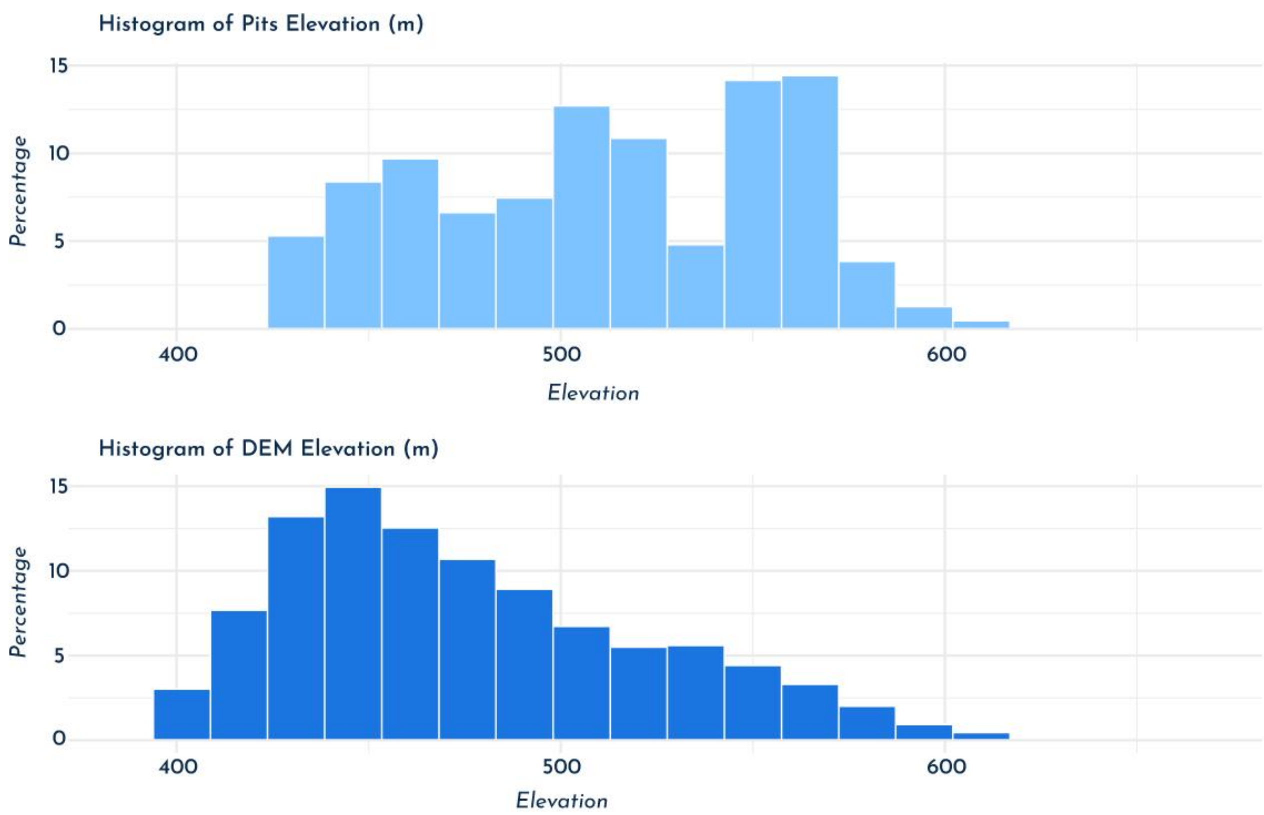


***Figure 15a (top)**: Frequency graph for slope of the 30m x 30m pixels where all JalTara recharge pits (from 2022 and 2023) are situated. **Figure 15b (bottom)**: Elevation histogram for the study area.*

Table 3: Number of samples considered for infiltration tests across watersheds and elevation.

Sampling across watersheds and elevation	Overall		Low Elevation		Medium Elevation		High Elevation	
	2022[1]	2023	2022	2023	2022	2023	2022	2023
Upper Watershed (Poorna)	3	7	2	2	1	3	0	2
Middle Watershed (Doodna)	2	7	1	2	0	2	1	3
Lower Watershed (Godavari)	0	3	0	2	0	1	0	0
Total	5	17						

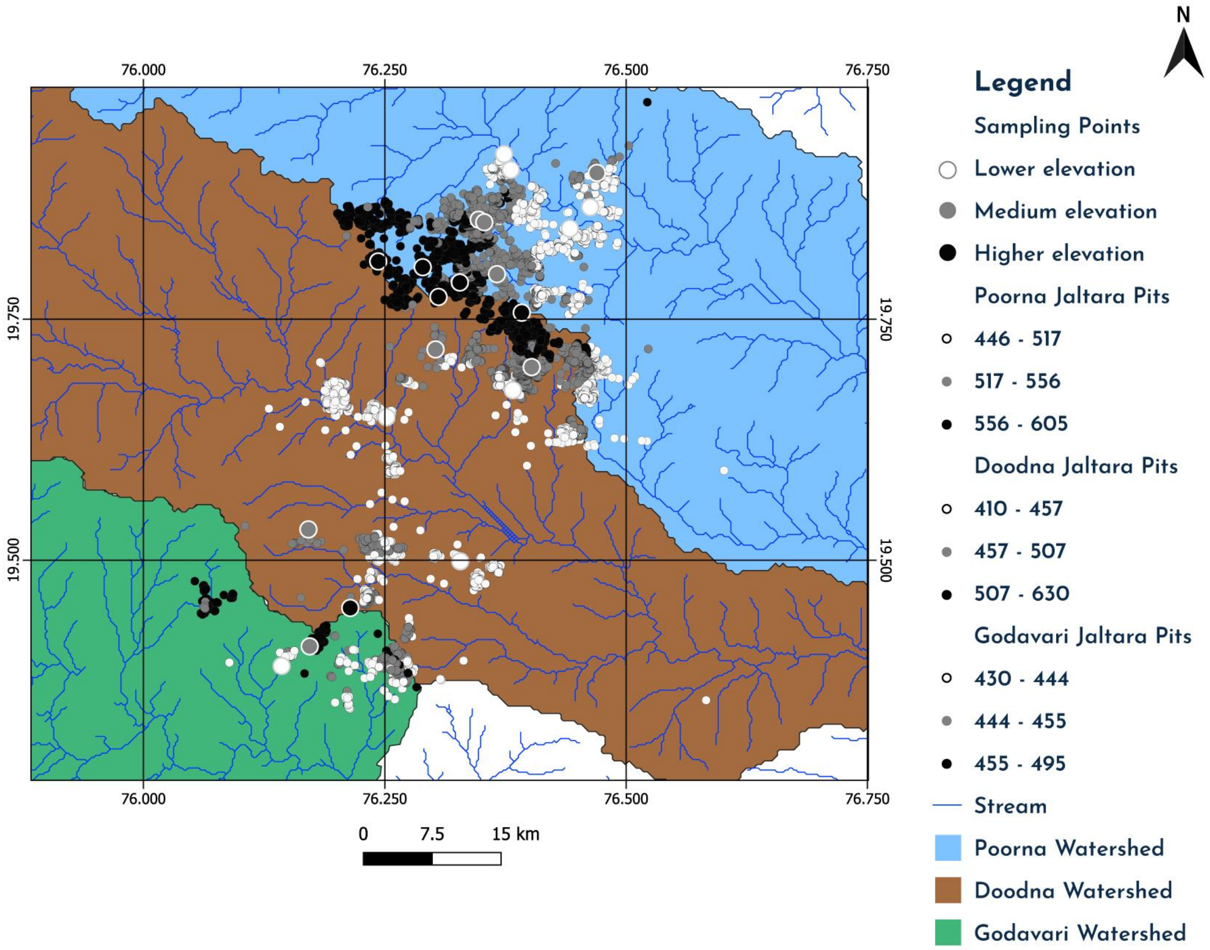


***Figure 16**: Sampling stratification based on the elevation of pits location across the three watersheds and Location of 22 sampling points for the infiltration tests.*

[1] The pits from 2022 and 2023 were stratified and selected with weightage proportional to the total number of pits constructed each year. However, during fieldwork for the infiltration tests, it was noted that farmers with 2022 pits had difficulty locating them due to higher siltation. As a result, fewer pits from 2022 were sampled compared to those from 2023.

Hypothesis 2: Farmer Surveys

Survey design

The farmer survey was designed based on the conversations and observations collected during multiple field visits in the month of January and February in 2024. The survey questions were tested in the field prior to finalisation. Two groups of farmers were interviewed, farmers who owned JalTara pits and farmers who had not adopted them yet. A semi-structured questionnaire was used, in which a few questions were open ended, while others were standardised as multiple choice questions. The questions were placed in a logical order to first capture the context-level details of the farmer such as water issues and irrigation sources. The first set of questions were common for both groups of farmers. The second part of the questionnaire dug deeper with pit-owning farmers.

The survey was **carried out over the months of March and April 2024**. The survey included recall questions, where farmers were asked to recollect information on the past years of 2021 and 2022, in addition to the current year. It is important to acknowledge that what farmers recall is not always accurate; however, in the absence of an alternative, we assumed this approach to be the most appropriate method for understanding the impact of waterlogging over time as an issue in the absence and presence of JalTara pits.

Data collection was done using Google Forms that allowed automatic recording of the survey points in a Google Sheet. These interviews were conducted in person as enumerators visited farmers in their fields. Preceding the survey, the enumerators visited all the pits in the farm to study their condition to ensure that responses were in line with their observations.

Sampling strategy

A statistically significant sample size was estimated using the Slovin's formula considering a 10% margin of error.

$n = N / (1+Ne^2)$ | n: Sample size; N: Population size; e: Margin of error

By the end of 2023, 39,802 farms in Jalna district had JalTara pits. Construction takes place mainly during the dry months of April and May (pre-monsoon), meaning the 2023 pits had undergone one monsoon season when surveys were conducted.

According to the formula, ~100 farmers would need to be sampled for a 10% margin of error. To be safe, **we considered a total sample of 120 farmers having pits**. Additionally, we needed to interview non-pit farmers as a control. **We included 40 non-pit farmers, so that they would account for one-third of the sample**. In all, 160 farmer respondents were targeted.

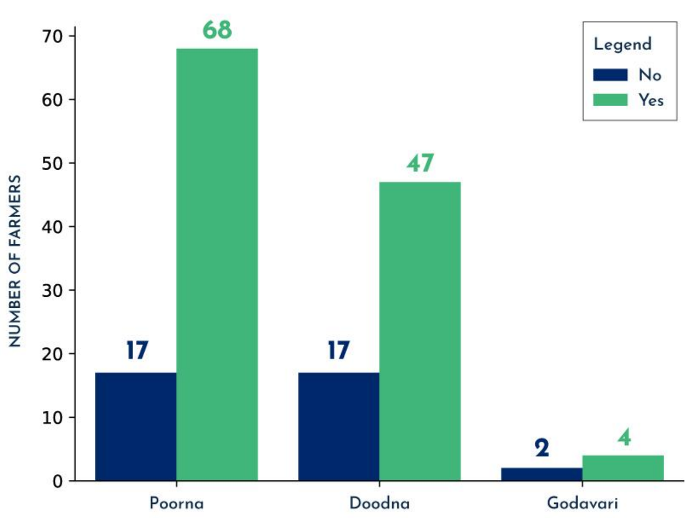
The sampling framework was divided into the three watersheds of Poorna (upper), Doodna (middle) and Godavari (lower). For each watershed, three elevation bands were identified with high, medium and low categories. Since the thickness of the upper layer of black soil is affected by the elevation, lower elevations exhibit thicker profiles of black soil. To mitigate bias associated with the thickness of the black soil layer, stratified the sampling across the elevation categories. Further, the highest number of pit constructions took place in the year 2023, followed by 2022. Very few pits were constructed in 2021.

The pits themselves were geotagged at the time of construction. Using GIS analyses, we were able to identify the names of the villages and where the pits were located. The villages were divided according to the sampling framework (Table 4) and were chosen randomly for the survey. This was done using the index and rank functions in Excel that allow random selection in a list. Within the villages, farmers were chosen using both a convenient sampling and snowballing approach.

Table 4: Sampling representation for the farmer survey

Watershed	Poorna (Upper)			Doodna (Middle)			Godavari (Low)		
Elevation (in metres (m) above sea level)	High	Medium	Low	High	Medium	Low	High	Medium	Low
	556 - 605	517 - 556	446 - 517	507 - 630	457 - 507	410 - 457	455-495	444-455	430-444
2021	6	7	7	NA	NA	NA	NA	NA	NA
2022	10	10	11	5	6	6	NA	NA	NA
2023	8	8	8	8	8	8	1	1	2
Non-pit	24			14			2		
Total	99			55			6		

The enumerators were unable to locate some of the pits in the database. This was especially true in the cases where that village had very few pits (<50). Ultimately, the number of farmer responses captured was less than the sampling number identified through the statistical approach. A total of 156 farmers were interviewed. Of these, 36 were non-pit farmers and 119 were farmers with pits. The three figures below depict that the farmers surveyed are representative across three watersheds, years of pit construction and pit ownership.



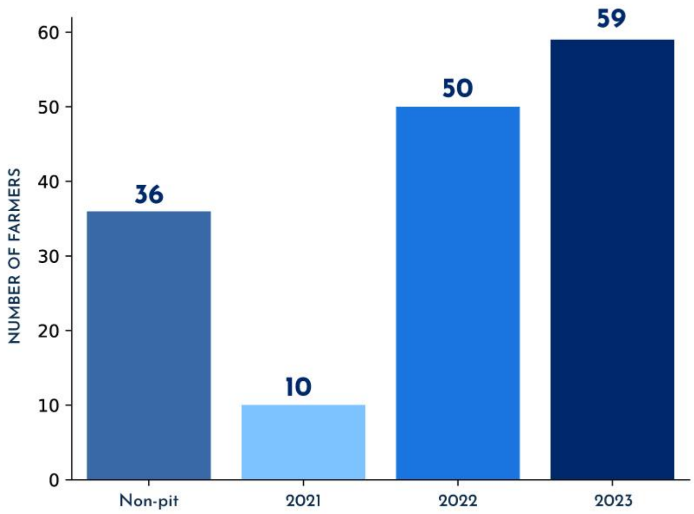


***Figure 17a (left)**: Sampled farmers across the three watersheds who adopted (green) and who did not adopt JalTara (navy blue). **Figure 17b (right)**: Sampled farmers based on year of pit construction.*

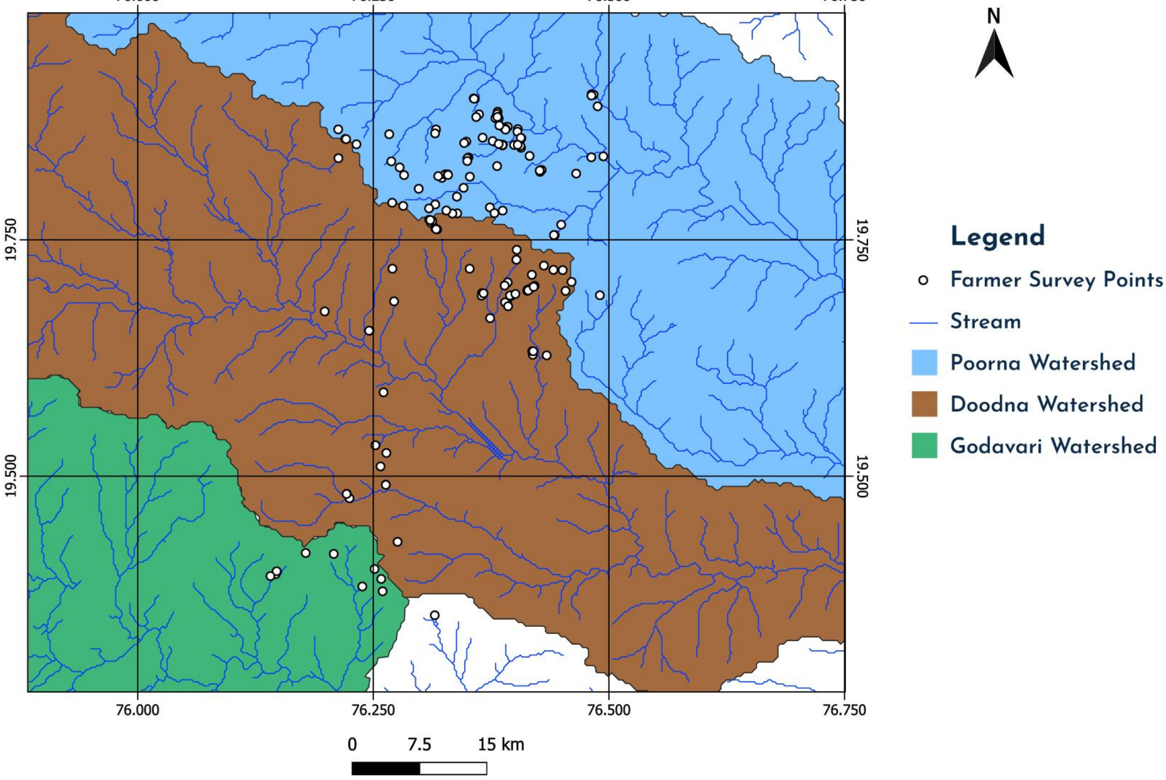


Figure 18: *Location of the points where farmer surveys were conducted across the three watersheds in Partur and Mantha talukas.*

Figure 19: *Farmer field surveys in Jalna.*

RESULTS

Field researchers carry infiltration test equipment to the site. Credit: Lakshmikantha N.R.

Hypothesis 1: Field Experiments

We compared on-farm, top-of-pit and bottom-of-pit infiltration rates in the sampled Jaltara pits. These pits are usually filled with boulders and then covered with 1-2 feet of soil/*murum*.

We compared on-farm and top-of-pit infiltration rates (with the soil covering the pit) to find that **the data show variability** – some pits showed significantly higher infiltration on top of the pit due to less siltation. The plot below illustrates the infiltration rates obtained using a double ring infiltrometer for 20 pairs of samples tested on the field.

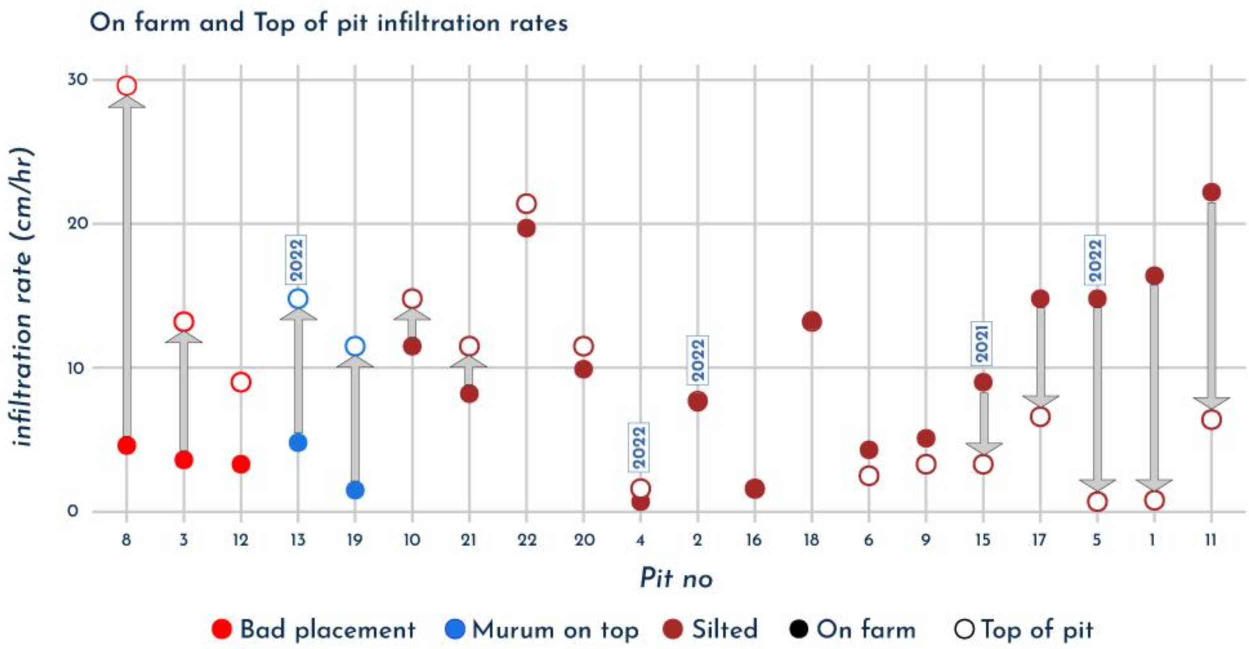


Figure 20: *Infiltration rates. The plot represents on-farm (Test 1 - solid circles) infiltration rates; and top-of-pit infiltration rates (Test 2 - hollow circles) in the same field. The arrow marks show the Increase or decrease in infiltration rate on Top of pit with respect to On farm infiltration rate. Colour indicates location or status of the pit. The Jaltara pits tested were dug in 2023, unless otherwise labelled.*

We found that the on-farm infiltration rates ranged from 0.7 cm/hr to 22.2 cm/hr, with a median rate of 7.7 cm/hr. In comparison, the top-of-pit infiltration rates varied from 0.7 cm/hr to 29.6 cm/hr, with a median of 8.4 cm/hr. These values were obtained from 20 sampling sites. According to the Central Ground Water Board, infiltration rates from the blocks are 1.86 cm/hr for Mantha and 1.38 cm/hr for Partur (CGWB, 2018).

Here, it is clear that there is generally a higher range of rate of infiltration in the top-of-pit test when compared to the on-farm test.

Each pair of on-farm and top-of-pit infiltration rates are represented by the same column with the pit number on X axis. This suggests there are two types of sites:

- Sites where the top-of-pit infiltration was lower than the on-farm infiltration rate (pits: 1, 5, 6, 9, 11, 15, 16, 17, 18)

- Sites where top-of-pit infiltration was the same or higher than the on-farm infiltration rate (pits: 2, 3, 4, 8, 10, 12, 13, 19, 20, 21, 22).

Note: Pit 7 and 14 were exposed (boulder on top); we couldn't conduct the infiltration test on top of it.

A close examination of the data reveals several insights regarding the infiltration rates of different pits:

1. Significant increase in infiltration at the top of the pit:

- Many pits that showed a significant increase in top-of-pit infiltration compared to on-farm infiltration were poorly placed, meaning the pit was not located at a primary drainage location for the farm based on our visual inspection. These include pits 3, 8, and 12 (shown in red).
- Some pits had a layer of murum on top, specifically pits 13 and 19 (shown in blue).

2. Pits were impacted by siltation:

- Out of the remaining 15 pits (shown in brown), 10 pits (numbers 1, 2, 5, 6, 9, 11, 15, 16, 17, 18) were visibly silted (Fig 22), resulting in an infiltration rate equal to or less than the on-farm infiltration rate. This highlights the impact of siltation on reducing infiltration rates.
- The other 5 pits (numbers 4, 10, 20, 21, 22) were also silted but showed a slightly higher top-of-pit infiltration rate compared to their on-farm rate, indicating partial siltation.

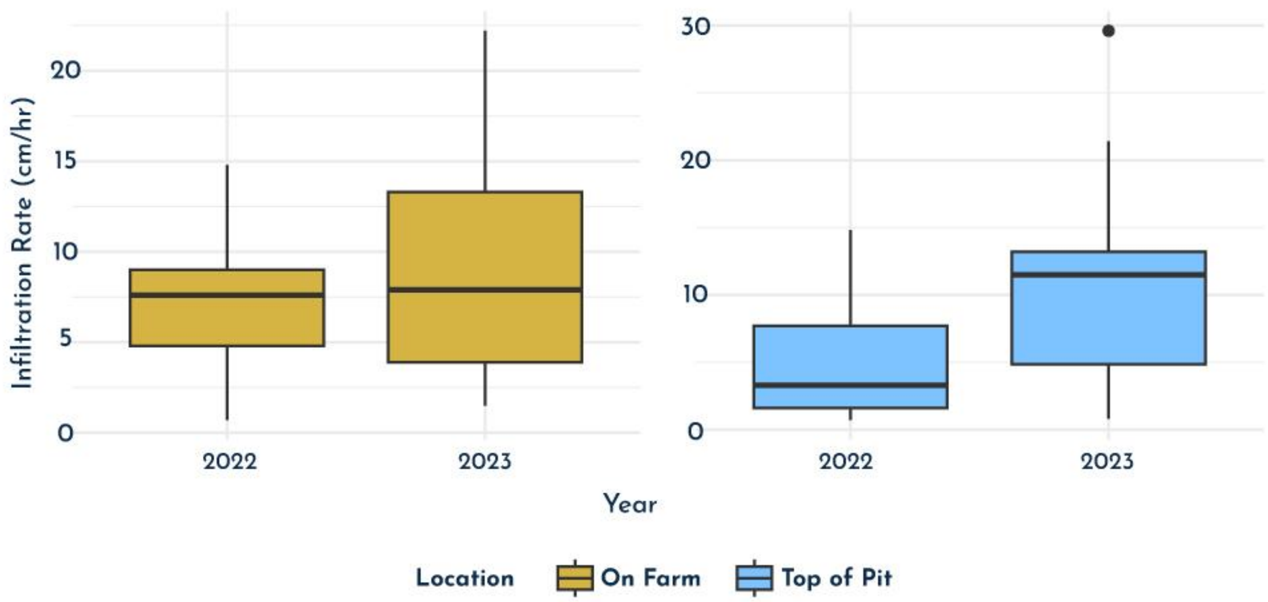


Figure 21: *A comparison of infiltration rates on-farm and top of pit, for 2022 and 2023; On-farm infiltration rate is more or less in the same median range for 2023 pits. Whereas pits constructed in 2022 tend to have less infiltration rates on top of the pit compared to the ones constructed in 2023, indicating more siltation over time.*

Figure 22a (left): *A poorly located JalTara pit (Pit #14) in Dhoksal village in an undisturbed state, where the top is composed of boulders, dried leaves and murum.* ***Figure 22b (right)****: A Jaltara pit with a highly silted top, where an infiltration test was conducted in Hanwant Kheda (Pit #1).*

Based on this information, we investigated why some pits silted up while others did not:

1. No runoff, no siltation; more runoff, more siltation:

- Pits that did not silt up did not receive any runoff. Pits with top-of-pit infiltration rates significantly lower than on-farm rates (indicated by brown fill) had broadly received considerable runoff in 2022 and 2023, as reported by farmers. This runoff deposited fine silt, inhibiting the pits' ability to allow more water to percolate.
- Pits from 2022 have lower infiltration rates at the top compared to those from 2023 indicating that increased runoff accumulation over multiple years leads to more siltation on the pit surface.

2. Higher infiltration rates in some pits:

- **Incorrect placement:** Some pits showed higher top-of-pit infiltration since they were not at the lowest part of the farm and did not receive runoff (pits 3, 8, 12).

- **Marginal improvement**: Some pits showed only marginal improvements in infiltration rates where the murum layer was close to the top soil and mixing of murum and top soil usually happened while ploughing. Four out of five pits in this category were made in 2023, a year in which the rainfall was considerably low. (ranging from 0.2 cm/hr to 3.3 cm/hr). (Pits 4, 10, 20, 21, and 22.)

- **Murum layer**: Two pits (13 and 19) showed better top-of-pit infiltration rates because farmers maintained a murum layer on top. However, even in these cases, soil and murum were gradually mixed during ploughing since the top of the pit is used for cultivation.

***Figure 23a (left)**: Double-ring infiltrometer experiment on pit where top-of-pit infiltration was the lower than the on-farm infiltration rate (pit #5). **Figure 23b (right)**: Infiltrometer experiment on pit where top-of-pit infiltration was same or higher than the on-farm infiltration rate (pit #8).*

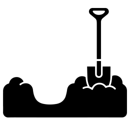
Key Learnings

The findings show that JalTara pits work in theory. They create a conduit past the top black clayey layer to the underlying *murum* layer and thus act as an effective drain. Our study indicates that silted pits did not exhibit any significant increase in infiltration rates compared to on-farm infiltration rates, challenging the initial hypothesis that JalTara pits have a significantly higher infiltration rate (10 to 100 times) than the surrounding fields.

The results also show that pits that were poorly located and did not receive runoff, had infiltration rates that were 3 to 7 times higher than those observed in on-farm conditions. This suggests that the potential for increased infiltration exists, but it is heavily dependent on the proper management and placement of the pits to avoid siltation. There are three key issues that need to be addressed – siltation, location and maintenance.

First, many pits are poorly located to receive runoff.
They are not located along the flow paths of water, which means they end up not receiving any runoff, defeating the purpose of a JalTara pit.

Second, many pits are ‘one and done’.
They receive runoff during heavy storms, but they also get caked with silt and are rendered ineffective after a single year of operation.



Third, the existing designs do not trap silt and are onerous to clean.

Hypothesis 2: Farmer survey

The survey aimed to capture farmers' perceptions of the JalTara method. We interviewed both farmers who had JalTara pits on their field and those who did not. We wanted to get a balanced view of the severity of the challenges related to waterlogging and crop spoilage.

We sampled a representative set of farmers across different elevation gradients, the three watersheds in the region and over three years of construction including 2021, 2022, and 2023. The median farmer in our sample held 6-7 acres where 3-4 pits had been constructed. In terms of cropping pattern, 54.43% of farmer respondents reported that they grow soybean while 18.35% farmers adopted mixed cropping of soybean and cotton. These were comparable across the three watersheds, although the distribution of land holdings skewed higher towards the upper watershed of Poorna. In addition to questions on efficacy, the enumerators recorded their own observations of the pits. They captured substrata characteristics and design features. Design features included the placement of structures, and depth and composition of the pits. We wanted to understand if the runoff generated during a rainfall event reached the pit or not. We also wanted to understand the extent of deviation from the prescribed JalTara design, if any.

Finding 2.1

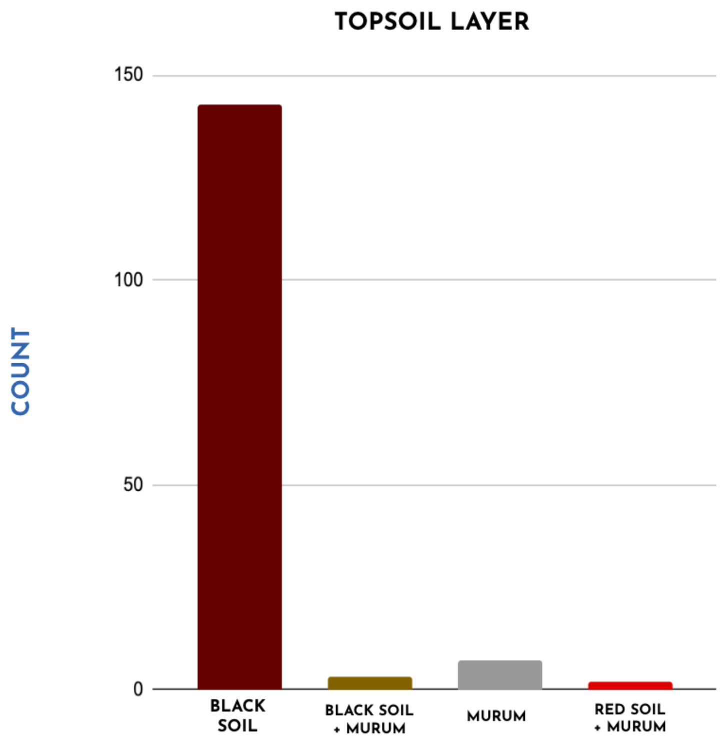
The underground strata were found to consist of black soil underlain by *murum* (weathered rock). There were some locations where the top soil itself was more *murum*-like. We would expect the on-farm rate of infiltration in the soil to be higher in those areas.

Based on the 119 surveys from farmers with pits, we determined that the median depth of the top layer is between 2 ft (Poorna and Doodna watershed) and 3.5 ft (Godavari watershed). As many as 11 farms were found to have top soil layer thickness >6 ft. However, for the most part, the prescribed JalTara pit depth of 6 ft, would accommodate the maximum depth of the top black soil layer.

Finding 2.2

Most farmers surveyed (83%) locate their JalTara pits along the edge of the farm (bund or embankments). However, within that subset, **only a third of those pits were located at the lowest elevation point in the field**, where we would expect runoff to accumulate (Figure A1). As a result, the purpose of constructing the pits is potentially not met in these farms.

Interestingly, it was observed that farmers chose to place the pits close to wells hoping to direct infiltrated water directly to the wells. This suggests that there is a need to build awareness on the importance of capturing runoff.



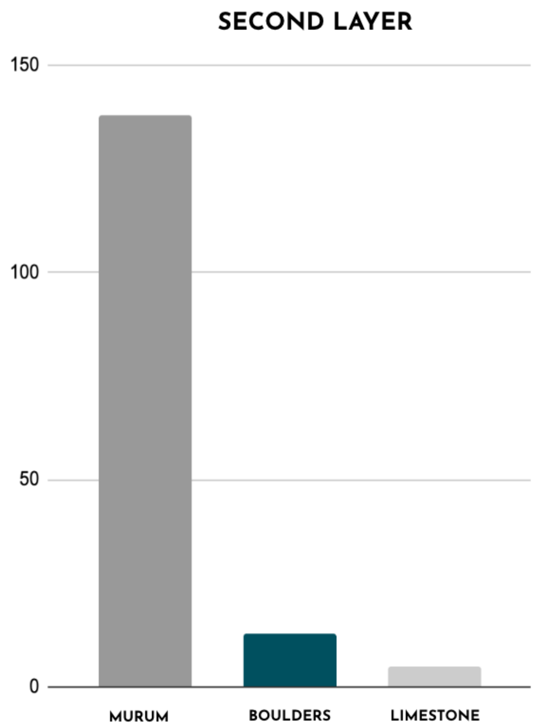
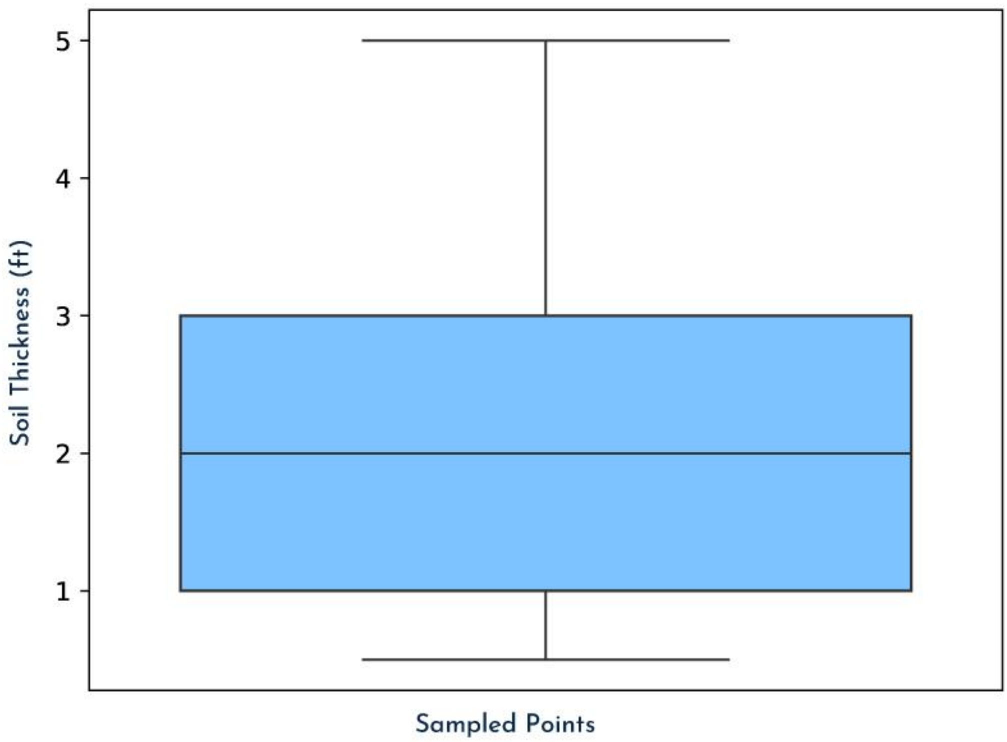


***Figure 24a (left)**: Composition of top two soil layers in sampled farms; Black soil dominates as the topsoil layer in the study area. **Figure 24b** (**right)**: Murum composed the second layer in the ground for 88.5% farmers interviewed. **Figure 24c (below)**: Topsoil thickness across sampled points. The maximum reported thickness of the topsoil layer in the three watersheds remains well below the threshold of 6 ft based on the depth of JalTara pits.*



Finding 2.3

Over half the farmers experienced waterlogging in the months of August and September. However, the **dominant motivation for adoption of JalTara was to recharge wells** (Figure A2).

Because this region is mainly carpeted by dense black soil, JalTara pits were introduced with the intended benefit of preventing crop spoilage by redirecting stormwater runoff to pits, bypassing the topsoil layer. Therefore, it was imperative to investigate if waterlogging in agricultural fields was identified as a major issue in the region.

Reports of waterlogging were almost evenly split among both groups of farmers – those who had and did not have JalTara pits (Figure 25). About 54.4% farmers reported waterlogging while 45.5% do not face this problem at all in their farms. Almost all farmers stated two reasons that drove them to adopt JalTara: i) to curb waterlogging and ii) to enhance groundwater recharge. But only six out of 119 farmers said that water logging was the only motivation.

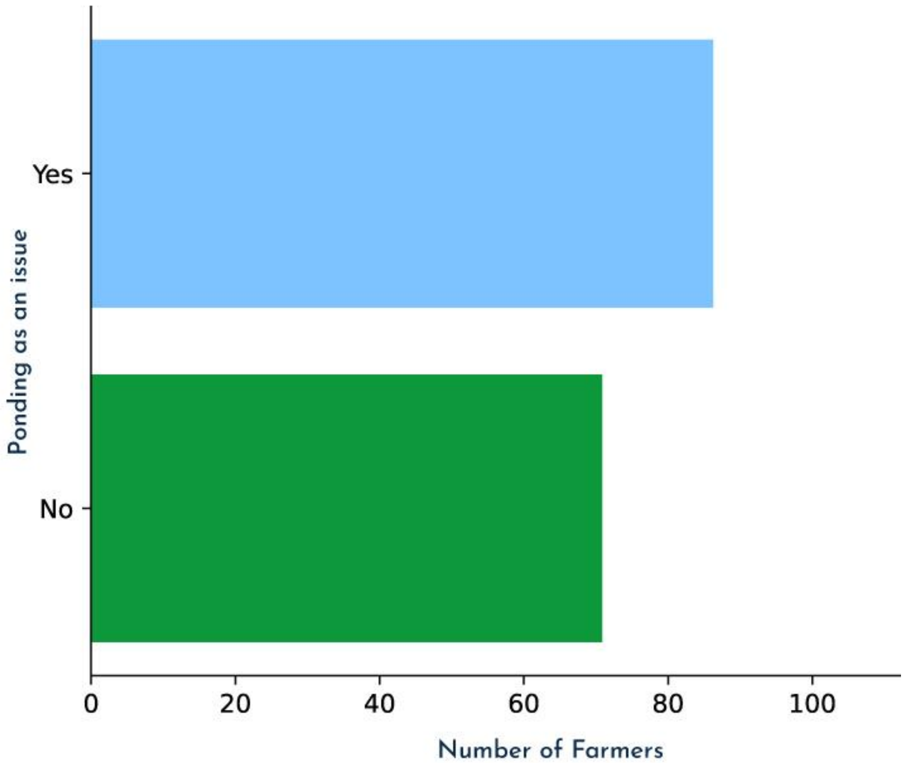


***Figure 25**: Water ponding as an issue by farmers respondents; About 54.4% of interviewed farmers reported waterlogging as a problem, while 45.5% do not face any water logging in their farms.*

Finding 2.4

Farmers with JalTara pits reported benefits such as lower crop loss and decreased ponding days. We asked farmers to recall the causes of crop loss during the *kharif* season in the years 2021 and 2022, and to also share the number of ponding days experienced in their farm for those years. We showcase another set of comparisons between farmers who adopted pits (treatment) and farmers who did not (control) for crop loss and ponding days in the year 2022. Responses to the two questions were triangulated to find trends because this information was based on the farmers' recollections rather than firsthand observations.

Data collected from 28 respondents who adopted pits in 2022 indicates a median improvement in reduced ponding by just one day (Fig 26). In the control and treatment approach, the difference between ponding days among farmers without pits and farmers who adopted pits, was found to be statistically insignificant (p-value = 0.074). It can be concluded that a recall in the number of ponding days by farmers was not found to be useful as a measure of the benefits accrued due to JalTara.

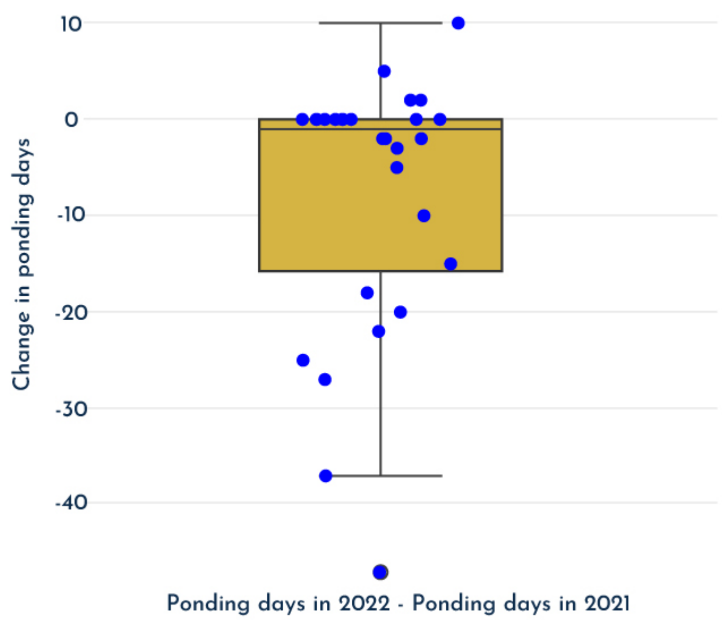


Figure 26: *Change in ponding days for farms with JalTara pits between 2021 and 2022. The mean reduction in ponding days was found to be very low by one day.*

Reporting of crop loss by farmer respondents was more informative as a data point with statistically significant results. There was an overall reduction in crop loss. In 2022, farmers who adopted pits that same year experienced 20% lesser crop loss in their farms as a median observation compared with 2021 (p-value = 6e-5) (Figure 27a). In the upper quartile of farmers, respondents experienced a 0-20% increase in crop loss, and in the bottom quartile a 55-100% decrease in crop loss. To compare across groups, in 2022, farmers without pits experienced an average crop loss of 63% whereas farmers with pits reported average crop loss of 20% (Figure 27b) (p-value = 13e-5). While a majority of farmer respondents were growing soybean, some had also grown cotton in their farms in the years they reported losses.

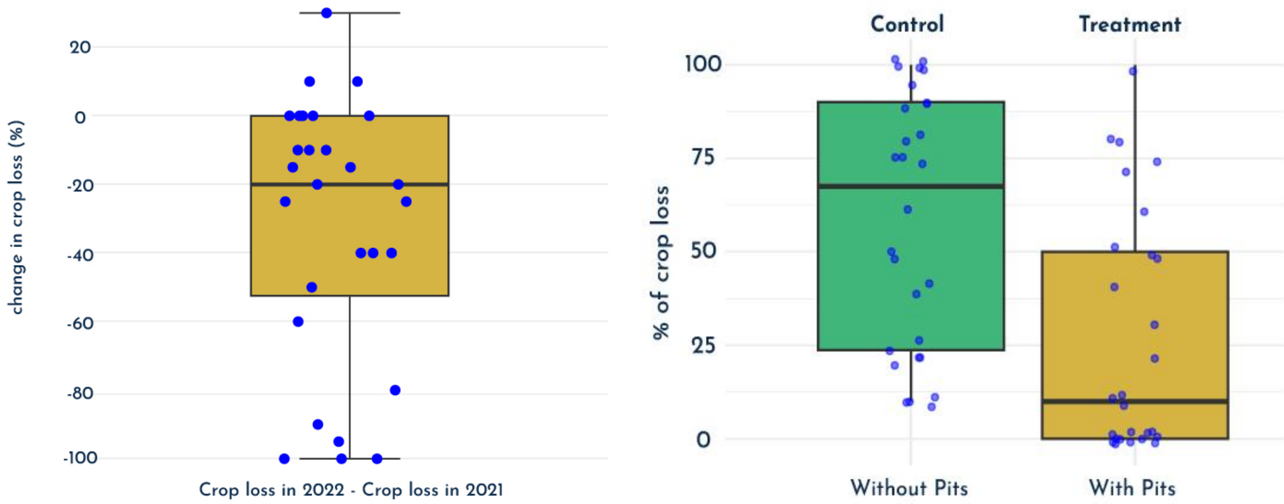


***Figure 27a (left)**: Change in crop loss as per reported numbers by farmers in 2021 (before pits) and 2022 (after pits). **Figure 27b (right)**: A comparison of percentage crop loss reported in 2022 by pit owners (yellow) and non-pit owners (green).*

Data collected from the year 2023 did not feed into the analysis as rainfall recorded that year was considerably lower than normal at 441 mm (Figure 28). Nevertheless, crop losses experienced in both years were attributable to different reasons. Of the farmers who experienced losses in 2022, 75% reported the losses caused by waterlogging, while this changed completely in 2023. Among the farmers who continued to experience losses, in its entirety, the losses were due to water shortage.

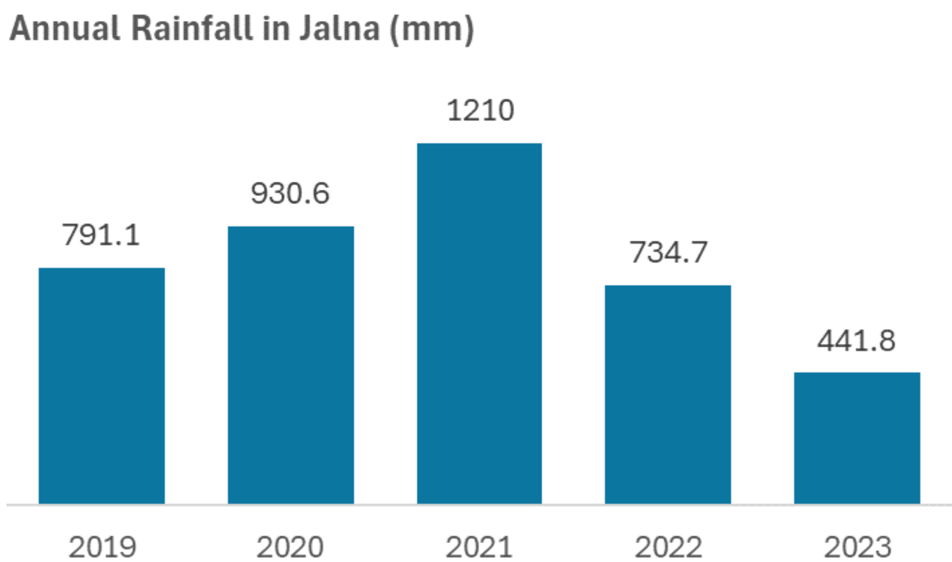


***Figure 28**: Annual rainfall in Jalna district. Jalna received one of the lowest annual rainfalls in 2023 at 441.8 mm. (Source: IMD)*

Finding 2.5

The survey results reinforced observations of heavy siltation noted during the field tests on infiltration capacity.

This was found to be a major factor that limited infiltration and a reduction of waterlogging in farmlands as it prevents infiltration of water.

After a spell of rain, the water that collects on the ground flows, eroding soil, and carrying and depositing particles that clog the pores of the JalTara pit structure. Highest levels of siltation are likely to be found in pits where the majority of the surface runoff is received from a field.

To capture the state of existing pits through the farmer survey, enumerators recorded observations from the field, including a description of the top cover of the pits. This section of the survey was tricky to capture, as differentiating between the three categories of *murum*, soil, siltation, and various combinations was liable to errors. Some pits were covered with black soil that had been removed to dig the pit, while some were covered with siltation deposited from runoff, both of which originate from black cotton soil and appear similar. Given that both also exhibit low hydraulic conductivity, we combined siltation into the soil category to simplify the identification process. We further designated fine grained material in pits into *murum*, *murum*+soil, and soil categories. With this classification the trends are informative.

Given 2021 pits are the oldest, the soil content was found to be the highest here at 60% followed by pits constructed in 2022 at 36% (Figure 29). Since 2023 received very little rainfall, most of the pits constructed that year remain in pristine condition with *murum* on top for 45.8%.

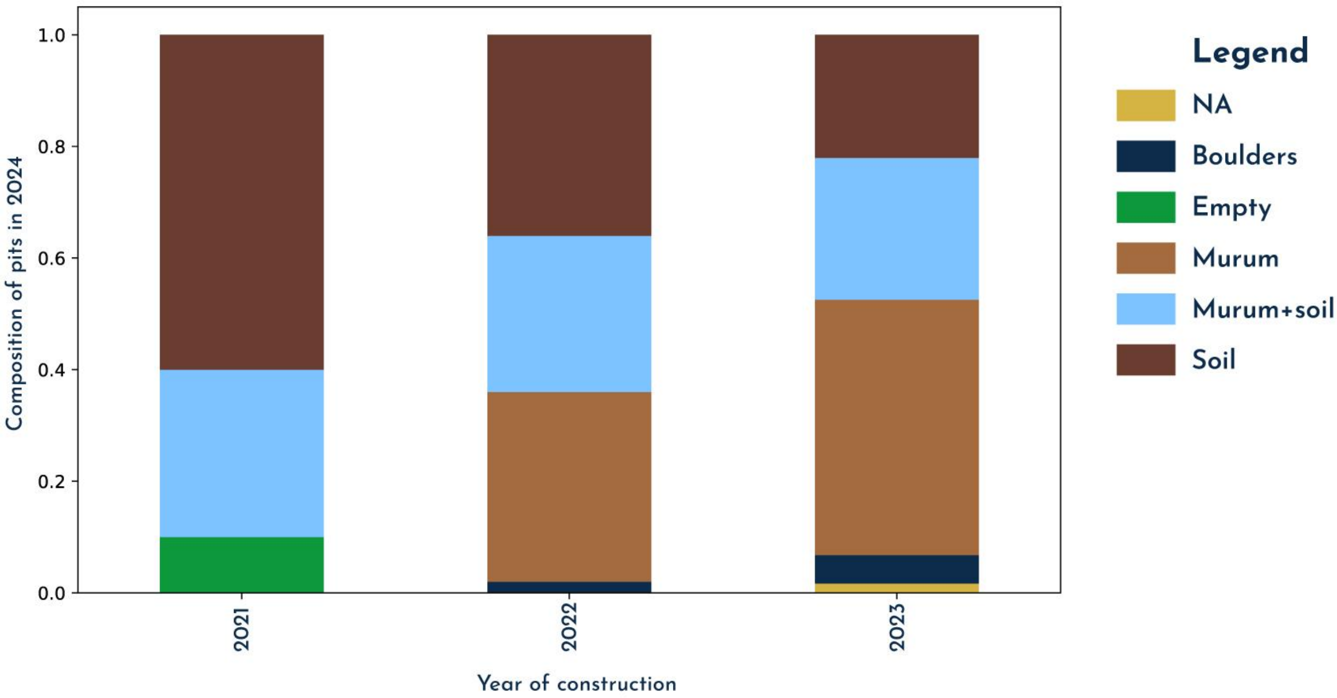


Figure 29: *Pit backfill composition. 'Murum+soil' and 'soil' indicate the presence of siltation that could have occurred due to runoff entering the pits.*

Finding 2.6

Perhaps the biggest gap found in terms of the implementation of JalTara was the lack of maintenance – **only seven farmers out of 119 were found to maintain their pits**.

We investigated the reasons for this to find that a majority of farmers (52.5%) were not aware that maintenance was required. The second highest response (20%) came from farmers who did not find enough siltation in their pits to need maintenance. Many of these responses were also recorded from farmers who have newly-constructed pits (from 2023) and have witnessed very few runoff events since. Farmers who owned pits constructed in 2021 and 2022 also reported that they did not know how maintenance should be carried out.

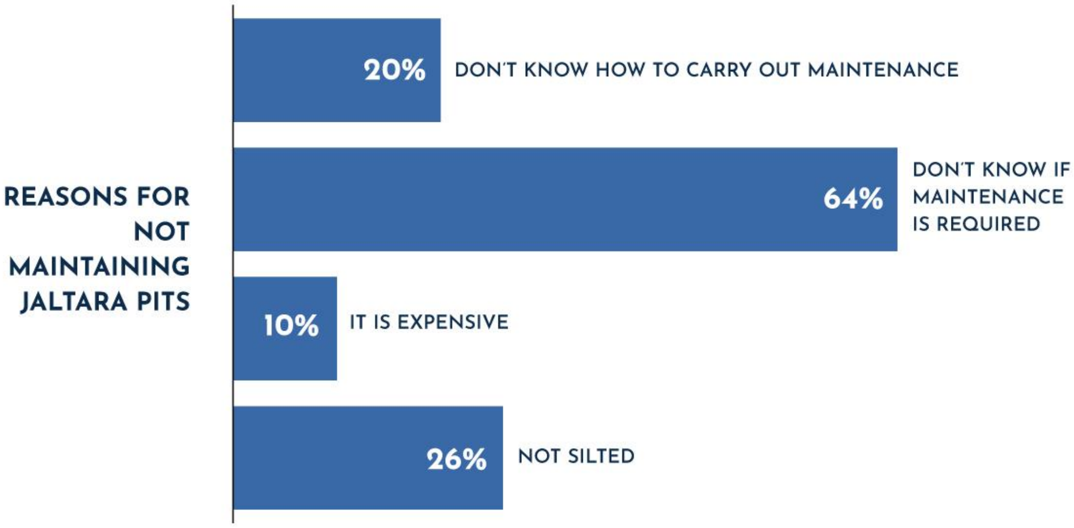


Figure 30*: Reported reasons for not maintaining JalTara pits so far; Farmer survey findings indicate that majority farmers were not aware if any maintenance was needed for JalTara.*

Finding 2.7

We also learnt that the cost of maintenance was not a limiting factor in terms of farmer interest in conducting future maintenance of the pits. This is summarised in Figure 31 where farmers who are interested in carrying out maintenance projected a range of costs associated with it. However, we did not capture who would bear the cost, which could also affect the decision-making process. This is indicated through Figure 32 where it's clear that a majority of farmers think that maintenance will be done through earthmoving machines, like a JCB, that can dig out the rocks from the pits and put it back. It is speculated that hiring such machinery would be someone else's responsibility. However, at the same time, farmers also show ownership towards maintaining the pits as they suggest that manual digging of pit layers and overturning them can be useful to get rid of the siltation accumulated inside.

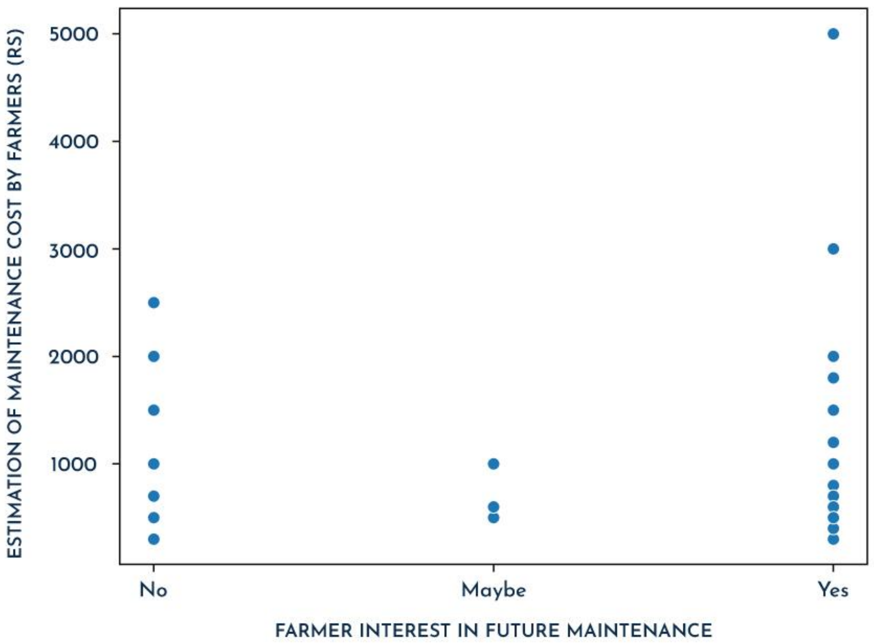


Figure 31: *Farmer interest in conducting pit maintenance related to presumed cost; The choice of uptaking maintenance of JalTara was not influenced by the cost involved.*
(Note: The cost here was projected by the farmers themselves.)

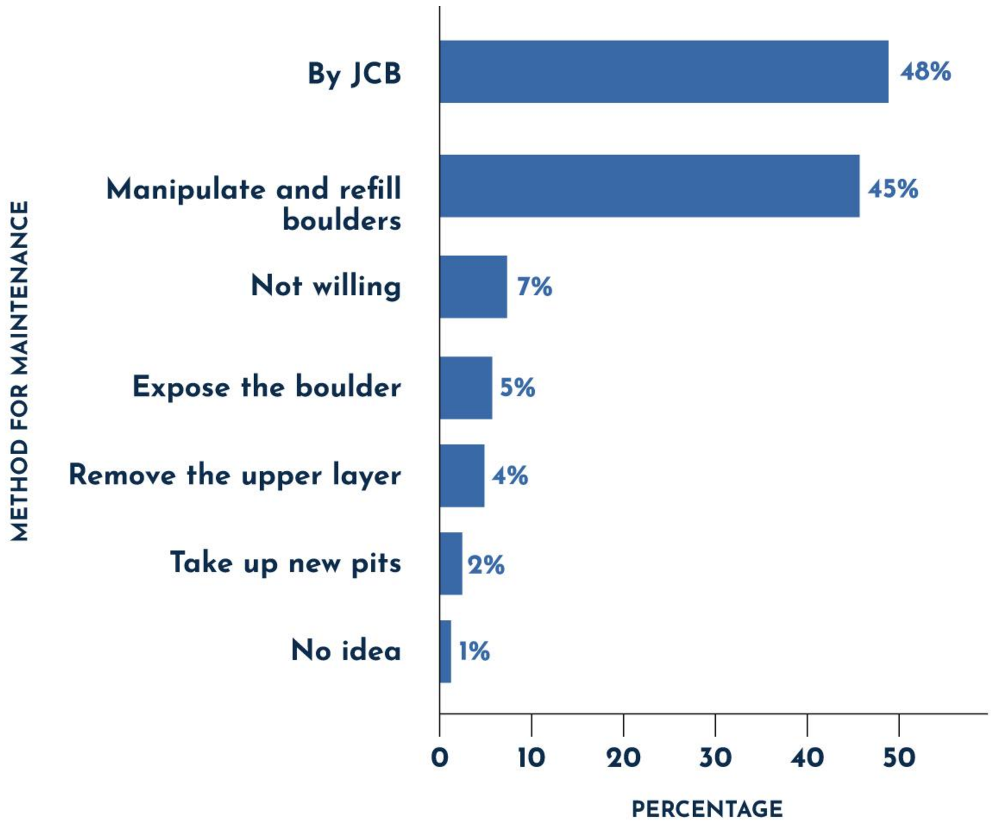


Figure 32: *Preferred method for pit maintenance; Farmers were willing to take up manual work for JalTara maintenance as much as using earthmoving equipment like a JCB.*

DISCUSSION

In this section, we discuss key findings from the study while presenting learnings and case studies studied globally. Challenge of siltation in Managed Aquifer Recharge interventions has remained a prevalent issue. We present methods that can potentially arrest siltation, especially in black soil conditions.

JalTara pits tend to get covered with silt, which decreases its capacity to absorb water and serve its intended purpose. This is one of the key learnings from our M&E study so far.

When the top of the pit is not silted over, we found that the infiltration rate is as high as 30 cm/hr (pit number 7), whereas the silted ones were observed to have infiltration rates as low as 1 cm/hr (pit number 1, 5). Accumulation of silt particles has created a barrier on the pits that does not allow water to percolate at all or at a much reduced rate compared to the soil surface. This was found to be true for all pits that were tested irrespective of when they were constructed, be it in 2021, 2022 or 2023. From this, we understand that the high presence of siltation can result from a few rainfall events within a single year.

Moreover, the disaggregated nature of black soils makes them highly vulnerable to erosion. When water falls as rain, soil particles separate and get transported as sheet or rill erosion (Panigrahi et al., 2021). This has major implications for the benefits accrued from the intervention in the absence of any maintenance of the pits – a point that stood out in the responses we gathered from the farmer survey.

Clogging in Managed Aquifer Recharge (MAR) interventions is a global phenomenon and has been extensively discussed in the literature (Dillon et al., 2016; Lippera et al., 2023; Zaidi et al., 2020).

There are many ways in which clogging can occur and can be classified by its composition – chemical, biological or physical. An example for chemical clogging could be the presence of carbonates and salts in water. Biological clogging is caused by bacteria and algae that form crust like structures internally, and physical clogging is due to the presence of silt (Escalante, 2015). Clogging is also partitioned as internal and external, where internal clogging refers to silt particles that enter inside the infiltration column while external clogging are cake-like deposits on the top.

A study conducted on the recharge bed of a percolation tank in Morocco found 30% of total internal silting within 3 cm of the infiltrating column. As a result, there was a 10-30% reduction in porosity and the infiltration rate decreased by 40-70%. External clogging was as high as 7 cm on top of the surface (Zaidi et al., 2020).

Baseline and modelling studies must be prioritised before planning MAR interventions to understand how to best limit siltation and clogging.

The extent of clogging helps in estimating the lifecycle of MAR investments as well as the cost of maintenance, which can often be larger than cost of installation. Researchers from Germany attempted a one-of-a-kind study to parameterise and model the vertical distribution of intrusive fines in a sand column through lab experiments (Lippera et al., 2023). They found that clogging in porous media can 90% be explained by the d_{50}/D_{50} ratio (d_{50} = median size of suspended particles, D_{50} = median size of porous media grain size). This phenomenon of silt entering inside the porous media is termed as straining. However, there are limitations associated with the findings including that the experiment was performed under constant head conditions, and the concentration of particles was limited to 0.1-1 g/L.

Desilting and land treatment can prove effective to restore infiltration as well as arrest runoff and soil erosion.

Vertisols in India constitute 22.2% of the total geographical area of the country and 15% of the total cultivable area. Additionally, 35% of dryland area is composed of black soil. Therefore, the significance of these soils raise important questions on its management and productivity. In Morocco, Zaidi et al. (2020) recommends scrapping of infiltration beds to remove silt particles clogging the surface and enhance infiltration rates. They also recommended building contour trenches upstream for watershed management in black soils (for slopes up to 20% incline). Trenches can capture the eroded soil, and also impede flow velocity to prevent further downstream erosion (ICRISAT, 1981). Mulch is another recommendation for land management in addition to building trenches for slopes up to 2% (Panigrahi et al., 2021). It adds to the surface friction, breaks runoff momentum and traps silt particles that would otherwise detach and flow away .

RECOMMENDATIONS & NEXT STEPS

View of a farm in Jalna. Credit: Lakshmikantha N.R.

This interim report is a culmination of findings from a series of field observations and studies that have been carried out to retrieve a holistic understanding of the implementation and impact of JalTara pits.

Focusing on hydrogeology, infiltration tests were conducted to understand the soil behaviour and subsurface characteristics. The socio-technical elements were captured through the farmer survey that covered more than 60 villages and 156 farmers. It was designed to collect both quantitative and qualitative data points to gather the beneficiary perspective on JalTara. Based on these evaluations, we present our first set of recommendations that can overcome current limitations and lead to increased benefits.

The JalTara project should be redesigned focusing on suitability of the site and placement, standardisation of design and pit maintenance.

Site suitability

Not all sites that were part of our experiment showed the same subsurface properties. The *murum* layer (weathered rock) underlying the black soil varied in thickness. There were cases where the massive basalt was encountered at a much shallower depth, which affected infiltration rate negatively. The underground strata were seen alternating with vesicular basalt and massive basalt layers, either of the layers can dominate (Figure 8).

As the nature of the rock suggests, vesicular basalts have higher porosity and the ability to conduct water. The presence of vesicles also promotes weathering, creating weathered rock layers. Therefore, underlying the black soil, this layer will prove more suitable for constructing JalTara.

Placement suitability

Within a farm, JalTara pits were found to have varying infiltration rates. This was governed by the extent of siltation present on the top of the pit – siltation is a big challenge as runoff brings silt that gets trapped on the surface of the pits and clog the top layers. Pits with a high amount of siltation showed very poor infiltration rates, while others allowed for quicker percolation of water through them.

Siltation was also an indicator of how much runoff was received by the pits. It was clear that not every pit inside a farm was proving beneficial. The ones located at a relatively higher elevation did not receive runoff at all. From our field visits, we have observed that farmers are able to guide JalTara placement with their knowledge of their field’s terrain and how water flows. Even then, the decision making can go wrong. The same pit located elsewhere can result in more benefits.

Design standardisation

The current design involves filling up the pit with boulders at the bottom and *murum* on the top. Often, this *murum* is sourced from subsurface *murum* dug out when the pit was made. The challenge is that this material gets mixed with the soil, and added back as it is to the top of the pit. The second challenge is that when boulders are not available locally, there is a high chance that the dug material, which contains a mix of *murum* and black soil, is added back. Both of these practices can adversely affect the functioning of a JalTara.

The efficacy of JalTara pits is also affected by another layer of practices. Since the top of the pit is being used for farming, soil and *murum* often get mixed when farmers plough their fields. This too results in siltation.

There is a need for standardising the design implementation for JalTara pits. We suggest two measures here:

- *Murum* as a layer on the top of the pits should be eliminated altogether. Boulders should be filled up till the top of the pit to remove the flexibility of adding soil to the top during farming.
- It is important to introduce silt-trapping mechanisms to increase the lifecycle of the pits before the maintenance process needs to be carried out.

Pit maintenance

Field surveys and farmer interviews have shed light on the need and importance of regular maintenance of the pits. Siltation is a prevalent phenomenon that will render the pits dysfunctional with time. Therefore, it is important to acknowledge the need for maintaining the pits and identifying the best way to do so. Farmers need to be made aware of the necessity, procedure and probable expenses for maintenance.

Figure 33a (left): *A well being dug; these boulders are used to fill JalTaras.* ***Figure 33b (right)***: *Waterlogging in a field.*

NEXT STEPS

Design experiment: Introducing silt trapping in JalTara

The results suggest that while JalTara pits show promise, their design needs improvement to effectively address the siltation problem. To prevent silt from entering the JalTara pit and clogging the layers, we propose two approaches focusing on its design:

One focuses on increasing the residence time for clay and silt particles to settle before reaching the pit. It involves constructing a small earthen bund, 8 inches high, around the pit. This bund allows relatively clear water to enter the pit after some sedimentation occurs outside it, as illustrated in the schematic image.

Additionally, placing mulch or bagasse on top of the pit acts as a second filter layer, trapping clay and silt particles. The mulch or bagasse must be replaced periodically based on the extent of siltation during runoff events.

This design aims to improve the effectiveness of JalTara pits by reducing siltation and maintaining the infiltration capacity of the pits. Currently this design is being tested with instrumentation along with two conventional designs of JalTara.

Improving the JalTara design with earthen bunds and a mulch layer	
Pit filling	Only boulders
Top layer	Mulch or bagasse (plant residue)
Silt trapping mechanism & rationale	Earthen bund around the pit (6x6 ft) forms a wall which gives some time for silt to settle. The water overflowing the bund with fine silt will be trapped by the bagasse on top of the pit, acting as a secondary filter. The mulch or bagasse can be replaced based on the amount of siltation.

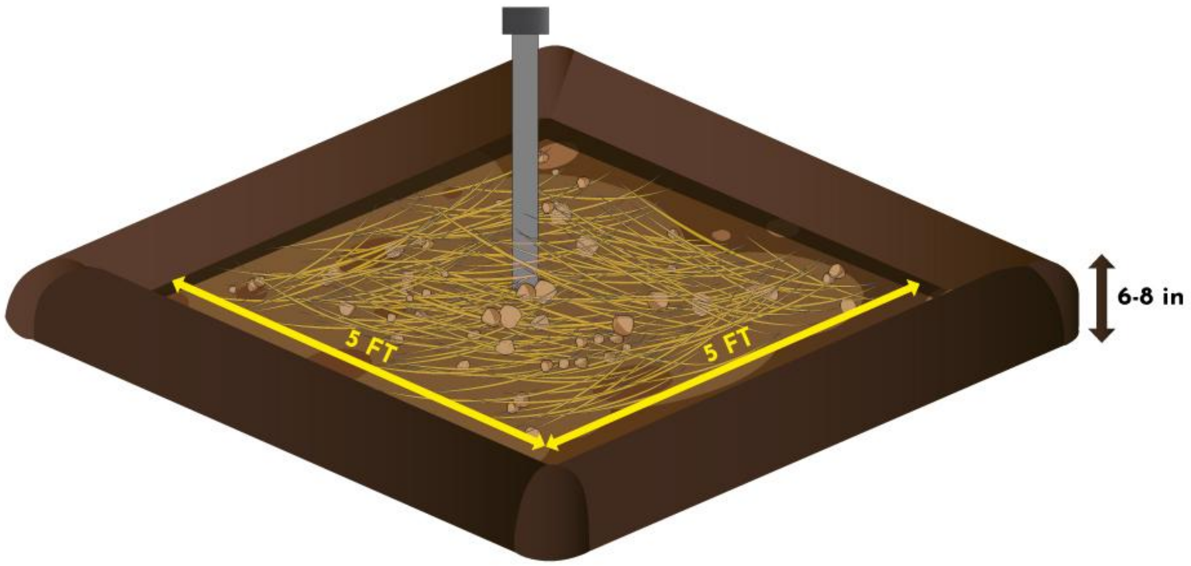


Figure 34*: Modified JalTara pit design; Earthen bund around the JalTara pit and a bagasse/mulch covering it as another filter.*

Hypothesis 3: Modelling to understand runoff capture in JalTara pits

In-situ monitoring: Deploying pressure transducer inside the pits

Three pits were set up to study the JalTara system during storm events: two conventional JalTara designs and one with a silt-trapping bund, discussed above. Each pit was equipped with a perforated 4-inch PVC pipe, wrapped with mesh to prevent clogging, serving as an observation well. A pressure transducer was placed at the bottom of each pipe to monitor the processes occurring in the pits during a storm. Additionally, a surface pressure transducer was installed in each pit to measure inundation levels during storm events.

To understand field dynamics related to inundation and infiltration, a control plot was selected for each setup. These control plots were instrumented with a surface pressure transducer to observe how non-JalTara farms function, providing a baseline for comparison with JalTara farms.

Automatic rain gauges were installed near the fields to monitor rainfall at regular intervals. A pressure transducer was placed above ground near the rain gauge to record atmospheric pressure. This data helps calculate the water head by comparing atmospheric pressure with the water pressure measured in the pits by pressure transducers.

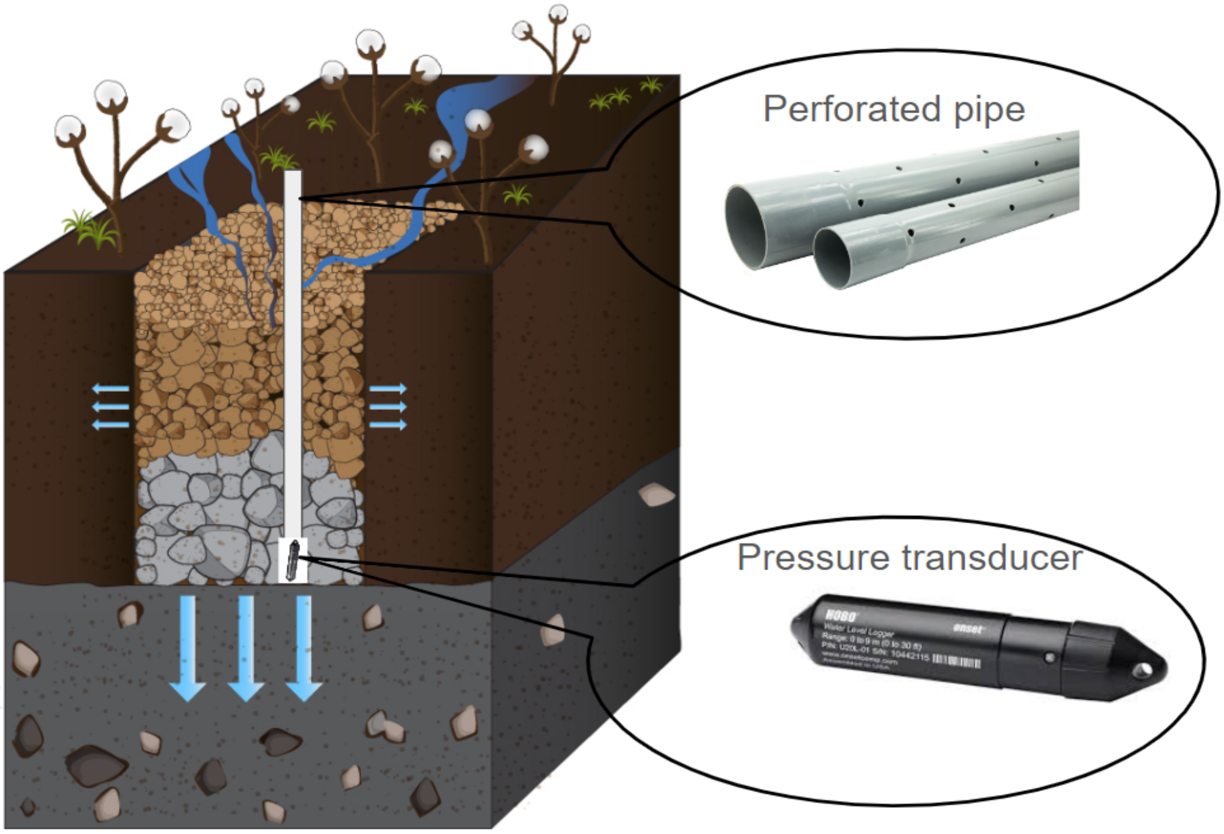


Figure 35: *Schematic sketch of pressure transducer installed through a perforated PVC pipe inside the JalTara pit.*

In addition to the above experimental setup, a magnetic float-based buzzer was designed and fabricated to help local farmers and field coordinators monitor the percolation inside the pit. The buzzer emits a beep when it comes into contact with water, indicating the water level. This device is attached to one end of a measuring tape. After a rainfall event, the facilitator will measure the water level inside the JalTara pit at regular intervals using the buzzer. This manual measurement will complement the data collected from the instrumented pits, providing a better understanding of pit processes at multiple locations.

Four additional sites were selected and equipped with the perforated PVC pipe, allowing for manual water level measurements in the pit after rain events.

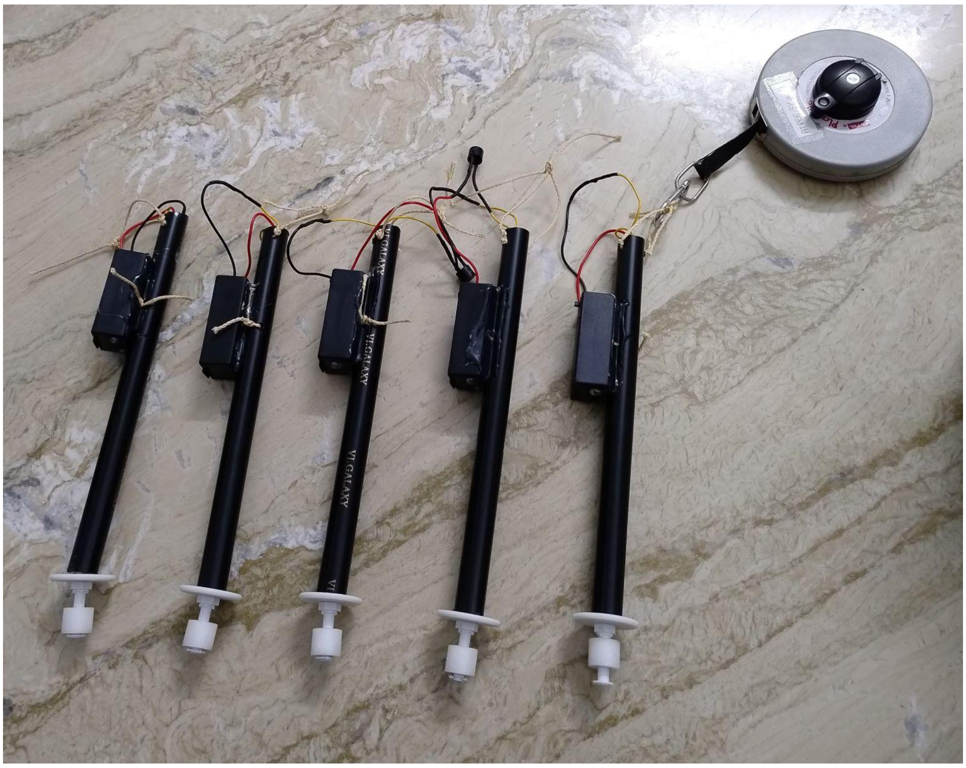


Figure 36: *Magnetic float-based buzzers*

Farm-scale modelling is essential to accurately assess runoff generation and infiltration processes in small agricultural catchments, particularly for the JalTara pits, where rainfall event-based runoff and heterogeneous soil profiles need to be considered. This makes the Multiple Wetting Front (MWF) model the most suitable choice over the SCS Curve Number and Green-Ampt methods.

Since many JalTara pits get water from the farm itself, the runoff often won't flow from one farm to another farm. Even if it crosses farm boundaries, the catchment area including cumulative farms seems to be small (1-5 acres), reiterating the need for a farm-scale model.

The models explored in this regard are: i) SCS curve number method, ii) Green-Ampt's method and iii) Multiple Wetting Front model.

The SCS curve number (CN) method is one of the most common methods used to predict the runoff, but SCS-CN considers only total rainfall volume at daily scale, and does not consider rainfall intensity and duration, making it unsuitable to understand the runoff generation in the farms with JalTara pits. These are the sites where we would like to know the rainfall event-based runoff generation to analyse the processes in the recharge pit as a response to the runoff generated.

Green-Ampt's method is time based and can simulate runoff considering rainfall intensity, duration and the infiltration process. But one main drawback of the Green-Ampt method is that it considers the soil profile to be homogeneous, and assumes uniform antecedent moisture distribution across the soil profile. Since JalTara recharge pits exploit the fact that there is a high permeable layer underneath the low permeable black clayey top soil, it is important to capture the processes without assuming uniform wetting fronts considering a homogenous soil layer.

The ***Multiple Wetting Front (MWF)*** model was selected for modelling as it is flexible to simulate hydrological outcomes at topsoil and vadose zones. Rather than assuming a homogeneous wetting front, the MWF model considers multiple distinct wetting fronts. This approach recognises the importance of possible development of several wetting fronts due to variation in rainfall, intensity, duration and soil properties, where each wetting front represents a boundary where the soil moisture content significantly changes.

Hypotheses 4: Paired watershed study

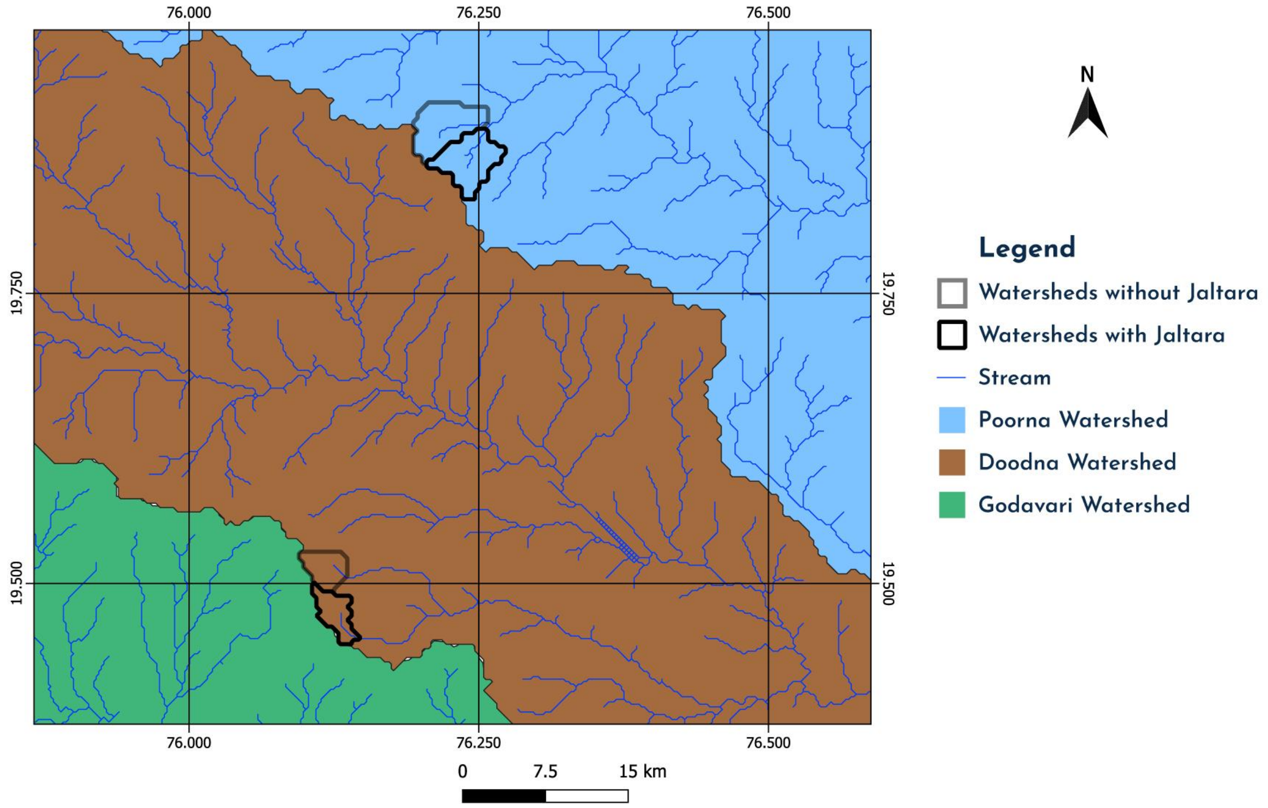


Figure 37*: Two Paired watersheds selected with and without JalTara pits*

To understand the large-scale impact of JalTara pits on groundwater levels, two pairs of paired watersheds were selected. The first pair (in the Poorna watershed) each cover approximately 24 square kilometres (sq. km), while the second pair (in the Godavari Watershed) covers about 13 sq. km each. Each watershed pair was chosen based on similarities in soil type, slope and catchment area, ensuring comparable rainfall conditions.

Within each watershed, one open well per one sq. km is being monitored to track changes in the water table and the longevity of groundwater availability. Measurements are taken before the monsoon (once), during the monsoon (twice), and post-monsoon (monthly).

In the first pair, the watershed with JalTara pits had them constructed in 2023. In the second pair, the watershed with JalTara pits had them constructed in 2024. This study aims to assess the impact of JalTara pits and their efficacy over time by comparing these watersheds with their respective controls, i.e. in plots that lack JalTara pits.

Figure 38a (left): *Field researchers taking pre-monsoon static water-level measurements in a well located in a paired watershed.* ***Figure 38b (right)***: *Perforated PVC pipe installed in the modified pit design implemented in a farm for measurements with a pressure transducer for further tests.*

Adoption of tens of thousands of JalTara pits has created a significant hydrological intervention in the region. Such a development, like others in the sector, need to be assessed fully to understand its potential to address water security.

Halfway through the course of this research, we have already gathered key insights on an important intervention being implemented in the arid fields of Marathwada. It has been understood that if done right, JalTara pits have the ability to redirect rainfall runoff into the aquifers, prolonging availability of groundwater in the region. Farmer interviews have revealed that benefits gained from JalTara pits are large enough to take better ownership and carry out regular maintenance.

Each season that we have covered so far, post-monsoon and summer, has allowed us to understand the necessity of water management in this semi-arid region of Maharashtra. The upcoming monsoon period is also much anticipated as we have laid out the groundwork to measure impacts of JalTara at both field and watershed scales. This report marks this milestone – documenting our progress so far, articulating the learnings yielded from our field research and analyses so far, and charting next steps to plug remaining gaps.

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Annexure I: Multiple choice responses in pit-owning farmer survey

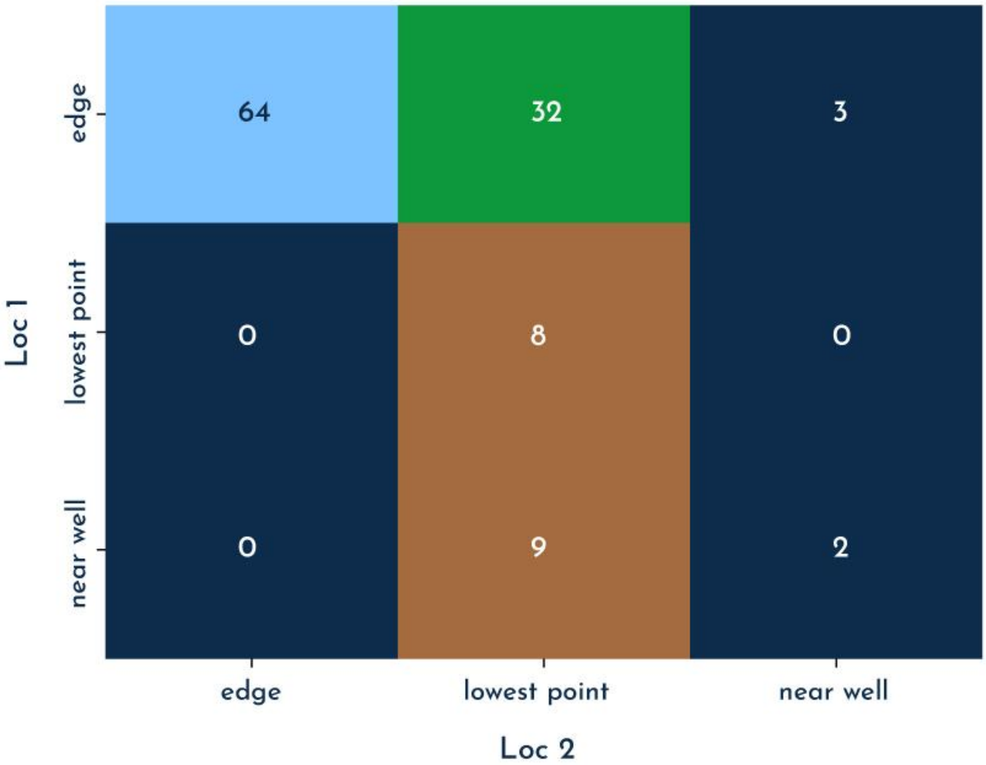

Figure A1: *Location of JalTara pits in the farms*

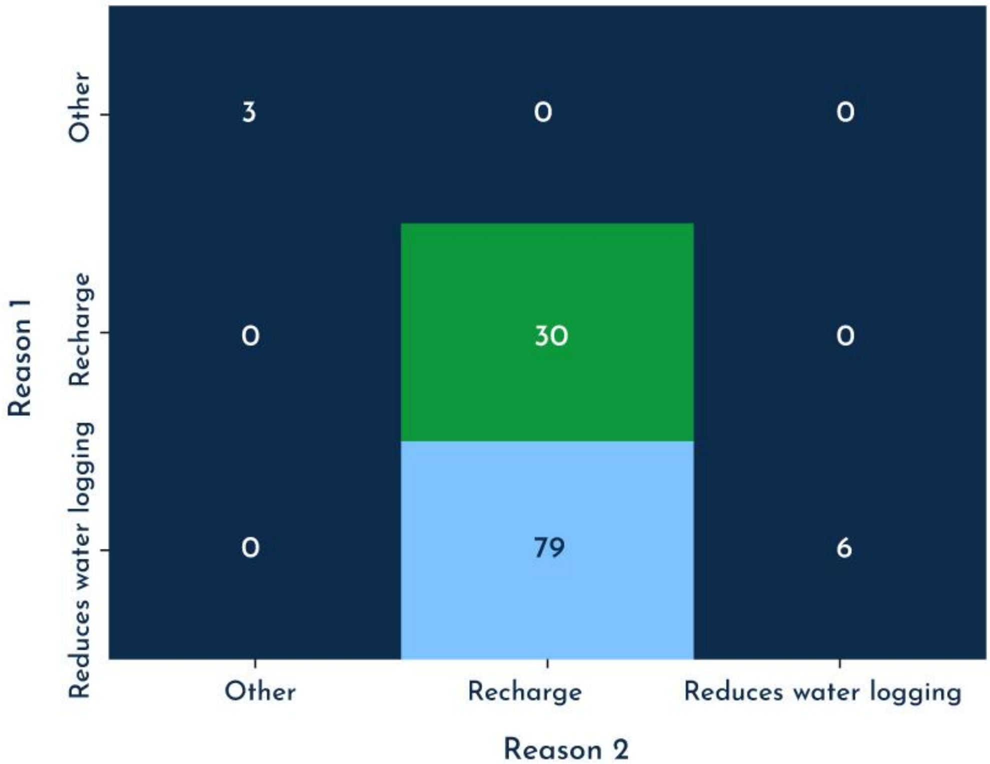

Figure A2: *Motivation among farmers to adopt JalTara pits.*

Annexure II: Observation record sheets for double-ring infiltration test

Sr No	Information	Entries		Time (mins)	ml (cm3) of water added to maintain 5cm head
1	Date			1	
2	Village			2	
3	Farmer Name			3	
4	Temp			4	
5	On pit or On farm?			5	
6	For On farm, Distance from the pit			6	
7	For On pit, top of the pit characteristics			7	
8	No. of pits in the farm			8	
9	Location of testing site on the farm			9	
10	Rainfall in last 15 days			10	
11	Irrigation in last 15 days			12	
12	Water level in the well			14	
13	Time from last tillage			16	
14	Type of ploughing			18	
15	VMC % in adjacent dry soil			20	
16	VMC % in wet soil after test			25	
17	Is the field harvested or not			30	
18	Previous crop			35	
19	Current crop (If Not Harvested)			40	
20	Black soil depth			45	
21	Soil profile details (3 layers)			50	
22	Catchment area for the pit infiltration			55	
23	Water head during infiltration test (cms)			60	
24	Infiltration test location (Lat Long):			65	
25	Any observations or comments:			70	
				75	
				80	
				85	
				90	
				95	
Please click pictures of the testing site				100	

with NoteCam		105	
		110	
		115	
		120	

Annexure III: Farmer survey questionnaire

Section 1 Introduction

1.1 Time and Date of survey (yyyy-mm-dd hh:mm)
1.2 Name of the respondent
1.3 Age of the respondent (in years)
1.4 Name of the village
1.5 Number of pits in the village
1.6 What is the area under agriculture in the village (area, units) ?
1.7 How many farmers have JalTara pits in the village?
1.8 How many acres of agricultural land does the respondent have?

Section 2 General water availability

2.1 What are the issues you face with water?
2.2 What is the ground top layer made of and what is its thickness (ft)?
2.3 What is the texture of the soil below the top layer and their depth (ft)? (Kindly specify for each layer in the ground)
2.4 Enter the details on crops grown by the farmer last year
2.5 Is your field irrigated or non-irrigated?

- ☐ Irrigated
- ☐ Rainfed

2.5.1 What is the power of the pump used for irrigation (HP)?
2.5.2 What is the main source of irrigation on your farm?

A. Open dug well

2.5.2.A.1 When was the well constructed? (year)
2.5.2.A.2 What is the depth of your well? (in ft)
2.5.2.A.3 Measure the water level in the farmer's well (in ft or mbgl)?
2.5.2.A.4 Water level in the well in June 2022? (level, unit)
2.5.2.A.5 Water level in the well in November 2022? (level, unit)
2.5.2.A.6 Water level in the well in June 2023? (level, unit)
2.5.2.A.7 Water level in the well in November 2023? (level, unit)
2.5.2.A.8 What is the depth at which concrete rings have been put in the well (in ft)?
2.5.2.A.9 In which months the well does not have water?

B. Borewell

2.5.2.B.1 When was the borewell dug (year)?
2.5.2.B.2 How many borewells are there in your farm?
2.5.2.B.3 What is the depth of your borewell(s) (in ft)?
2.5.2.B.4 For which months does the borewell(s) not supply water?
2.5.2.B.5 What is the average depth of casing (in ft)?

2.5.2.B.6 Did you have to deepen your borewell or dig a new borewell in recent years? If yes, then by how much?

C. Rainfed
D. Canal Command

2.6 What % of farmers in the village have their own wells/borewells?
2.7 Have any of your neighbours' wells/borewells failed in the last 5 years?

- ☐ Yes
- ☐ No

2.7.1 If yes, since when have the wells/borewells gone dry? (year)

2.8 Does your farm undergo waterlogging after heavy rains?

- ☐ Yes
- ☐ No
- ☐ A bit
- ☐ Don't know yet
- ☐ Other

<in case of Yes or A bit as response>
2.8.1 In which months does water logging typically occur? (You can select more than one.)
2.8.2 What is the number of days of waterlogging in the field experienced in 2021?
2.8.3 What is the number of days of waterlogging in the field experienced in 2022?
2.8.4 What is the number of days of waterlogging in the field experienced in 2023?
2.8.5 What percentage of your farmland undergo water logging in general?
2.8.6 What area of the farm experienced water logging in 2021 (in acres)?
2.8.7 What area of the farm experienced water logging in 2022 (in acres)?
2.8.8 In what other ways is your farm affected by water logging?
2.8.9 What area of the farm experienced water logging in 2023 (in acres)?
2.8.10 What percentage (%) of each crop was lost in 2021?
Crop, loss percentage:
2.8.11 Why were crops lost in 2021?

- ☐ Less rainfall and therefore, water shortage
- ☐ Damage due to heavy rainfall
- ☐ Water logging/ponding
- ☐ Other (please specify)

2.8.12 What percentage (%) of each crop was lost in 2022?
Crop, loss percentage:
2.8.13 Why were crops lost in 2022?

- ☐ Less rainfall and therefore, water shortage
- ☐ Damage due to heavy rainfall
- ☐ Water logging/ponding
- ☐ Other (please specify)

2.8.14 What percentage (%) of each crop was lost in 2023?
Crop, loss percentage:
2.8.15 Why were crops lost in 2023?

- ☐ Less rainfall and therefore, water shortage
- ☐ Damage due to heavy rainfall

- ☐ Water logging/ponding
- ☐ Other (please specify)

2.8.16 Is there an outlet that allows water to flow out of the field?

- ☐ Ditches or Nallas to allow water to flow away from the field
- ☐ Field pipes that direct water to dug wells
- ☐ Other (please specify)

2.8.17 Do the above methods help in reducing water logging inside the farm?

- ☐ Yes
- ☐ No

2.9 Does water from one field flow to the other during storms?

- ☐ Yes
- ☐ No

2.10 Any other information about open wells/ surface irrigation?

2.11 What is the state of groundwater quality in your well?

A. No contamination

2.11.A Do you use groundwater from your field for drinking?

B. There is contamination.

2.11.B What could be the sources of contamination in the groundwater?

2.12 Do you have a JalTara pit(s) in your field?

- ☐ Yes
- ☐ No

Section 3: About JalTara Pits

3.1 In which year were the JalTara pit(s) created on your farm?

3.2 What is the size of your pit?

3.3 What is the number of pits in your field/plot?

3.4 Why did you opt for pit construction in your field? (You can select more than one)

A. Reduces water logging in the field and therefore, crop spoilage

B. Leads to groundwater recharge

C. Other (please specify)

3.5 How do you know that recharge in groundwater is because of JalTara?

- ☐ Increase in number of continuous pumping hours
- ☐ Increase in the number of months with water in well
- ☐ Other (please specify)

3.6 How much has the water logging problem been reduced because of JalTara?

- ☐ Same water logging
- ☐ Less water logging
- ☐ Water logging eliminated
- ☐ Don't know
- ☐ Other (please specify)

3.7 From how many acres does this pit collect water?

3.8 Where are the pits located in the field? (You can select more than one choice)

- ☐ Corners of the field
- ☐ Along the bunds
- ☐ At the lowest point in the field
- ☐ Other (please specify)

3.9 What is present inside the pit?

- ☐ Soil
- ☐ Murum
- ☐ Small boulders/gravel
- ☐ Boulder
- ☐ All of the Above
- ☐ Empty

3.9.1 What is the method followed to add gravel/boulders and murum inside the pit? (Describe in detail)

3.10 What is the composition of the top layer of the pit? (Mention the soil type and vegetation on it)

3.11 What is the thickness of the murum layer on the top of the pit (ft)? If it is not murum, which soil type is present and its thickness (ft)

3.12 How much is the siltation in the pits?

- ☐ Low
- ☐ Medium
- ☐ High

3.13 Have you carried out any maintenance of the pits?

- ☐ A. Yes

3.13.A.1 What type of maintenance do you do for the pits?

3.13.A.2 How often do you have to carry out the maintenance?

- ☐ Twice in a season
- ☐ Once in a season
- ☐ Once in a year
- ☐ Haven't done any maintenance yet
- ☐ No idea

3.13.A.3 What is the cost involved in maintaining the pits?

3.13.A.4 What is your benefit (farm-level benefit) in maintaining the pits?

- ☐ B. नाही / No

3.13.B.1 Why have you not carried out the pit maintenance (you can select more than one) ?

- ☐ Not silted
- ☐ Don't know if maintenance is required
- ☐ Don't know how to carry out maintenance
- ☐ It is expensive.

3.13.B.2 Are you willing to maintain the pit?

- ☐ Yes
- ☐ No
- ☐ Maybe

3.13.B.3 If you have to, how will you carry out the pit maintenance in the future?

3.13.B.4 What would be the cost involved per pit for maintenance if you have to guess?

3.14 How many acres of rabi crop did you plant in the year 2021?

3.15 How many acres of rabi crop did you plant in the last season (year 2022)?

3.16 How many acres of rabi crop did you plant in this season (year 2023)?

3.17 Is there any change in the water level in your well before and after the pit(s) were constructed?

- ☐ No
- ☐ Large increase
- ☐ Small increase
- ☐ No change in water level

- [ ] I don't know

3.18 Is there any change in crop yields before and after the pit(s) were constructed?

- [ ] A. Yes
  - 3.18.A.1 How have the crop yields changed?
    - [ ] Increased
    - [ ] Decreased
  - 3.18.A.2 For which season crop yields have changed?
    - [ ] Kharif
    - [ ] Rabi
  - 3.18.A.3 Why have the crop yields changed?
- [ ] B. No
  - 3.18.B.1 Why have the crop yields not changed?

3.19 Has the cropping area in your farm changed after JalTara pits?

- [ ] A. Increased
  - 3.19.A.1 For which seasons cropping area has increased? (You can select more than one.)
    - [ ] Kharif
    - [ ] Rabi
    - [ ] Zaid
- [ ] B. Decreased
  - 3.19.B.1 Why has the area under cropping decreased?
- [ ] C. Remained the same

3.20 Did you observe water entering into the pits in 2021?

- [ ] Yes
- [ ] No

3.21 Did you observe water entering into the pits in 2022?

- [ ] Yes
- [ ] No

3.22 Did you observe water entering into the pits in 2023?

- [ ] Yes
  - 3.22.1 When was the last time that there was rainfall that generated runoff that could reach the pits?
  - 3.22.2 How many times did the pits receive water during last year (2023)?
  - 3.22.3 Please enter any other information.
- [ ] No

3.23 What is the height of the bund in your farm?

3.24 How is the bund maintained?

3.25 Are there any other factors that would affect the infiltration in the area like tilling of land, slope and location of pits, or any other factor?

3.26 In the case where the JalTara pits are not covered with soil on top, are you willing to give up your land from farming on the pits?

Annexure IV: Spatial depiction of responses from 22 pairs of infiltration tests

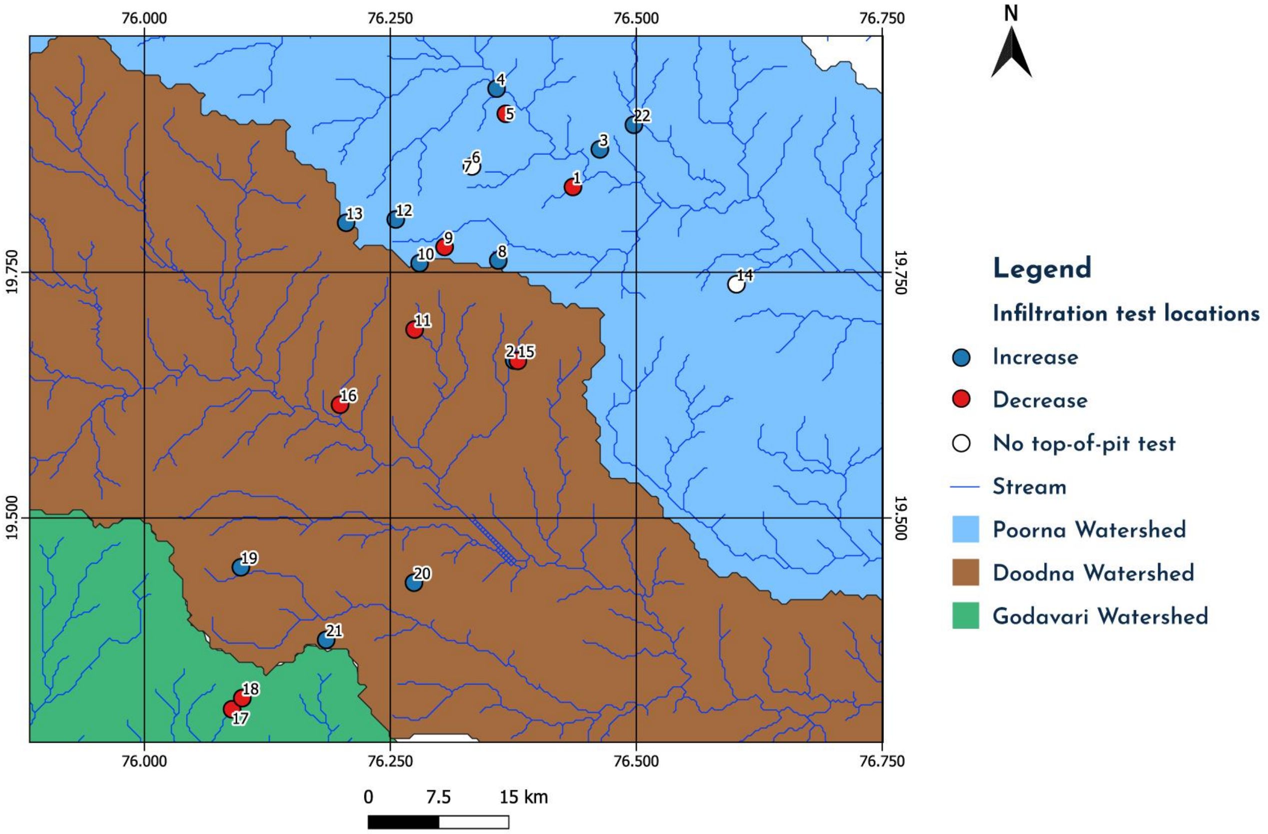

Figure A3: *This figure shows the distribution of pits showing increase or decrease in infiltration when compared to on farm infiltration rates.*

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