

Digital Participatory Tools for Water Resource Management in Rural Communities in India

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ABSTRACT

With almost half the Indian population facing water stress¹, likely to be aggravated with climate change [1], an intersecting crises of environment, livelihood, and social justice can worsen the vulnerability of rural communities that are directly dependent upon natural resources for their livelihood and sustenance. We propose to strengthen social cohesion and community resilience in rural areas of India by leveraging novel digital tools, through a community-based development approach, to build the capacity of community members to improve and participate in local governance, especially related to water management. First, we will design a multi-level water stress estimation process using GIS-based tools to enable communities to understand the historic trends of water stress in their areas. Second, we will build a participatory decision-support tool to assist communities in commissioning natural resource management (NRM) initiatives and changing the cropping patterns to tackle water stress in their areas. The tool will be socialized through community volunteers and contribute towards building more equitable and long-lasting local institutions. Third, we will operate a time-tested voice-based participatory media platform through which communities can discuss and demand relevant water related NRM initiatives to enhance their resilience against environmental and health crises.

This is a high-risk and high-reward proposal, and brings together an interdisciplinary research team with expertise in ICTs including data science and remote sensing systems for social development, forest management and participatory governance approaches, and water management for local needs. The grant will be used to pilot the initiative in two Gram Panchayats in Central India and prepare it for scaling in more geographies. Novel tools will be built such as using machine learning and deep learning methods to process satellite imagery for the recommendation and monitoring of NRM works, a GIS-based participatory decision-support application, and voice-based question-answering and information seeking systems. A Monitoring Learning Evaluation (MLE) framework will be put into place through baseline-endline mixed-methods research. Standard operating processes will be developed to enable wider adoption of the tools by other communities through a network of social sector partners, including government departments. All data and technologies developed will be released in open-source.

1 INTRODUCTION

The world is witnessing an increased frequency of environmental crises, largely arising from anthropogenic changes caused by

human activity^{2,3}. Social groups marginalized by class- and caste-lines are often the ones most vulnerable to such crises⁴. Of significant importance is the availability of groundwater for agriculture: borewells of ever-increasing depth constructed by richer farmers have led to open dug-wells of smaller farmers drying up, and has also impacted the water quality used for irrigation [2]. Government schemes such as MGNREGA and watershed development programmes have tried to improve groundwater availability through rainwater harvesting solutions, but have also suffered in many locations from unplanned works and unfair distribution of assets [3]. Further, in arid areas of extreme water stress, changes in cropping patterns may be the only alternative to cope with the situation.

For rural communities to deal with these challenges, it is imperative to consider groundwater as a commons resource [4]. Communities need to allocate the resource so that it improves equity, and scientific tools need to be built to enable communities to plan supply-side interventions such as NRM assets and demand-side interventions such as changes in cropping patterns. Further, participatory methods are needed to guide the usage of the tools so that communities can build these plans collectively. While this may appear hard, there are strong precedents in developing participatory methods for community-based development. During the COVID-19 lockdown, for example, local networks of volunteers driven by values of care and solidarity managed to use innovative technology tools to fill many gaps that were created in access for the poor to social protection and healthcare [5, 6], and leveraged both bottom-up community organizing and top-down coordination [7]. Creating a sustainable society requires us to build upon these positives, and use appropriate technology tools that can empower communities to improve resilience and bring greater equality.

We propose the following three-pronged approach to improve community capability for water management in two locations in India:

- *Water stress diagnostics:* We will leverage remote-sensing based data products to temporally estimate various hydrological quantities at the micro-watershed scale. High spatial and temporal resolution products related to precipitation, evapo-transpiration, soil moisture, soil types, and land use and land cover (LULC) classification and elevation maps to estimate runoff, can be used to build a fortnightly time series of water balance quantities to estimate changes in the groundwater stock [8]. These can be used to categorize micro-watersheds into fine-grained critical and non-critical classes. We will further couple this to build a village-level vulnerability index to identify populations which are already

¹<https://social.niti.gov.in/water-index>

²<https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health>

³<https://www.unicef.org/environment-and-climate-change>

⁴<https://ruralindiaonline.org/en/stories/categories/climate-change/>

poor, or at a high-risk of falling back into poverty if caught in future water or climate crises. At the village, sub-district, and district-levels, we will use indicators of social welfare expenditure, livelihood, and demographic characteristics, along with proxy indicators of socio-economic development obtained from satellite data, to identify geographies that have been historically disadvantaged, so that fairer resource allocation policies can be developed.

- **Participatory decision-support tools:** We will build tools that use remote-sensing and crowd-sourced data, along with the various hydrological quantities computed above, to recommend and monitor local water related NRM initiatives in the communities. These initiatives, such as setting up rainwater harvesting systems, afforestation and agro-forestry, wasteland development, etc. will be aimed towards generating livelihood and building durable assets that can improve the resilience of communities to adapt to climate change. The tools will be designed to enable participation and discussion amongst the community members to together discover solutions that improve the water stress at their locations. The solutions will span both supply-side recommendations such as for rainwater harvesting structures, and demand-side recommendations such as for changes in cropping patterns to move to less water consuming crops.
- **Participatory media:** We will embed time-tested and scale-tested voice-based participatory media tools to serve four goals. First, provide an information channel to push credible information to communities, and to enable communities to share useful information with one another. Two, empower especially marginalized groups to voice themselves, and channel these voices to draw public and state attention to their problems. Three, ensure that social protection and other welfare measures are equitably distributed, and communities are able to demand accountability in the delivery of these benefits. Four, build greater community cohesion towards cooperation and collective action by nurturing plurality and bringing visibility to all groups.

Underpinning these three elements, we will follow a set of common design principles - of *appropriate technology* and *community-based development*. Drawing upon E.F. Schumacher's notion of appropriate technology [9], we consider its current digital equivalent as technology which is designed in a user-centered manner, and used and managed directly by the community itself [10]. We believe this is essential so that local knowledge and experience shapes the technology and its outcomes, and the community does not lose control over decision-making processes that directly affect their members. With a similar motivation, we define community-based development as planning and implementation processes that are shaped by local communities, and who have the required capability and commitment to undertake this participation⁵. We believe that non-participatory mechanisms stand the risk of missing out upon local insights, which can even lead to harm, and also disempower communities by rendering them as agency-less recipients of top-down decision-making processes rather than as democratic

co-owners in a collaborative and decentralized governance process of planning and implementation.

We will work in two locations: Jamui in Bihar, and Dumka in Jharkhand. Jamui is among the poorest districts in India, with livelihood heavily dependent on agriculture and forest produce, while facing water stress despite being located in a river basin. Dumka, similarly, has a large tribal population dependent upon forest produce, and faces stress from expanding mining initiatives in the district. Both locations have significant out-migration and can benefit from stronger social protection measures locally. We propose an 18-month intervention in one Gram Panchayat each in Jamui and Dumka, during which we will build the required technology tools, identify and train local community volunteers to use these tools, collaborate with government officials to undertake the proposed equality and resilience initiatives, and evaluate the use and impact of these tools. Our goal will be to build a rich set of standard operating processes so that other communities can adopt these tools as well.

We next briefly describe our theory of change, and then outline the three elements of our approach in more detail.

2 THEORY OF CHANGE

Our theory of change can be stated in brief as follows: *With a three-pronged approach of (a) identifying and training community volunteers to map vulnerable social groups in their community and the allocation of NRM assets to them, (b) using participatory decision-support tools to recommend to authorities useful NRM initiatives, and to communities more responsible cropping patterns, and (c) manage a local participatory media platform on which relevant information about environmental aspects is discussed, the proposed intervention model will empower communities to demand social welfare schemes and participate in decision-making processes to strengthen their resilience against water crises, and ensure that the schemes are equitably provisioned and transparently implemented, thereby leading to more sustainable living.*

We hope to make an impact on the following outcome indicators:

- **Water and soil conservation:** Better water management practices will increase groundwater availability and reduce soil erosion, leading to many ecosystem services.
- **Livelihood:** Increased scientific provisioning of NRM assets will generate local livelihood and augment the income of community members. The construction of durable assets such as for water management will further have positive effects on agricultural yield and thus increase the incomes even more.
- **Equity:** Fairness in welfare allocation across social groups will bring fairness and improve the resilience of vulnerable groups.
- **Community cohesion:** Working through community volunteers driven by an ethic of care and solidarity will strengthen community cohesion and enhance their capacity to cope with any future crises.
- **Participation in governance:** Equipped with the necessary training to use digital tools for planning and monitoring of natural resource management initiatives, and participatory media platforms to voice themselves, marginalized groups

⁵<https://www.worldbank.org/en/topic/communitydrivendevelopment>

will be able to participate in decision-making and governance processes which affect their lives.

Our goal is to evaluate this implementation model in two geographies, and based upon the learning to then collaborate with government departments and social sector partners to adopt the approach in more geographies.

Our rationale of working through community volunteers who are trained on various technological and developmental elements mentioned earlier, instead of relying on, for example, external professional staff, is driven by the belief that nurturing an ethic of care and solidarity towards their communities results in robust community institutions. Such institutions can serve to not only operate the envisioned project truthfully and in contextually appropriate ways, they will also encourage wider cooperation and cohesiveness in the community to cope with any future crises, and they will enable marginalized groups to participate in local governance and decision-making processes. We term this as the *commoning* approach [11–13], to emphasize on the need for strong bottom-up structures of mutual support to sustain their communities during times of hardship, and overcome unjust and oppressive structures that result in greater negative impacts on marginalized groups. This is why we term our innovation as the **CoRE stack**, short for *Commoning for Resilience and Equality*.

3 CORE STACK

We next outline our three-pronged approach in more detail, of vulnerability mapping, decision-support and monitoring tools, and participatory media.

3.1 Vulnerability mapping

Community vulnerability is assessed on three dimensions: exposure, sensitivity, and adaptability [14, 15]. Exposure is measured based on past and future projections of environmental hazards such as water stress, droughts, floods, etc. based on the local context. Sensitivity is measured based on dependence of the communities on natural resources such as water for agriculture or forest produce for livelihood. Adaptability is measured based on community awareness and social cohesion that can equip it to better manage future crises, the extent and inclusiveness of social protection, financial stability, etc.

District-level vulnerability indexes for climate change and water stress have been prepared for India [16]. Both Jamui and Dumka are among the most vulnerable districts in their respective states. We will incorporate greater nuance in these indexes by temporally computing water balance equations to accurately determine groundwater changes through an entire year [8]. Our research group has already made good progress in intra-annual LULC classification to determine areas under single cropping (one crop planted in a year, in the Kharif season) or multiple cropping (more than one crop planted in a year, in the Kharif and Rabi seasons), and other more static classes such as forest cover, surface water, and built-up areas. Figure 1 shows sample output over a few years. These LULC outputs will be used to compute evapo-transpiration changes, canopy interception loss, runoff, etc. to construct time-series of groundwater changes.

We will then examine historic social welfare allocations made across hamlets and villages in the intervention panchayats, to identify cases of unfair exclusion and assist the government to formulate vulnerability-proportional welfare allocation to these locations.

We will also obtain accessibility data of social infrastructure such as health facilities and schools from Google or Open Street Maps, or data published by the government on the National Data and Analytics Platform (NDAP) [17]. Socio-economic factors proxied using a wealth index can be obtained quite accurately from classifiers trained on satellite-based data [18]. Figure 2 shows such a sample output from initial work by our group on poverty mapping. Social welfare expenditures will be obtained from the Management Information System (MIS) websites of common welfare schemes [19]. Detailed health indicators have been estimated through co-variate modeling of coarser level survey data at the district-level, allocated to finer spatial scales [20].

3.2 Decision-support and monitoring tools

3.2.1 Site assessment and tracking. India has a rich set of welfare schemes such as MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act), PMKSY (Pradhan Mantri Krishi Sichayee Yojana) for irrigation, NMSA (National Mission for Sustainable Agriculture), etc. aimed at both generating livelihood and creating assets useful for the environment and local communities [21]. MGNREGA works for rainwater harvesting, canal maintenance, check dams for watershed management, tree planting, and land levelling to make fallow lands cultivable, among others, have been observed to bring significant environmental benefits such as to reduce soil erosion, improve groundwater availability, and increase carbon sequestration [22–24]. Site identification for such works can benefit from decision-support systems.

Rainwater harvesting site-assessment, for example, takes into account factors such as the soil type, slope, precipitation, soil moisture, and land-cover and land-use [25, 26]. Remote-sensing data products of digital elevation maps and precipitation are now freely available. Machine learning based land-cover classification algorithms that operate on freely available satellite imagery can provide high resolution accurate maps, rapidly updatable [27, 28]. Soil moisture can similarly be estimated on the basis of land surface temperature and vegetation indexes [29, 30]. We feel it is therefore feasible to conceive of a process whereby such datasets are used to identify candidate rainwater harvesting sites, fairness-based prioritizations are made to ensure the rights of vulnerable communities, and participatory methods are then used to obtain community feedback and consensus to demand fund allocation for the identified sites. Figures 3, 4, and 5 show initial mock-ups for this envisioned application.

A few initiatives are already attempting to provide planning support to MGNREGA officials using GIS-tools pre-populated with remote sensing datasets [31, 32], but they tend to use out-dated or lower resolution data products, sub-optimal algorithms, and may not be participatory to involve the community in the decision-making process. We believe that our envisioned tools will not only enable communities to make more scientifically correct decisions, they will also encourage a participatory approach to planning both supply-side and demand-side interventions.

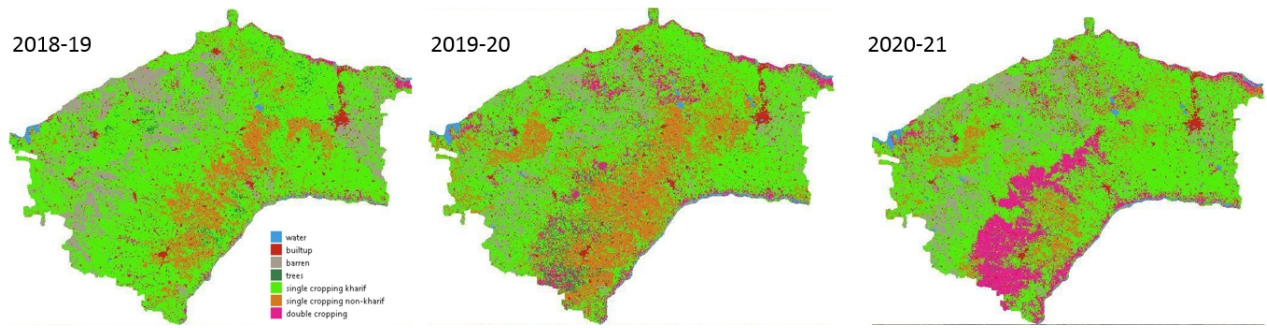


Figure 1: Initial results from our intra-annual Land Use and Land Cover classification system. Time-series of spectral data behind each pixel is used to develop a classification system for cropping intensity.

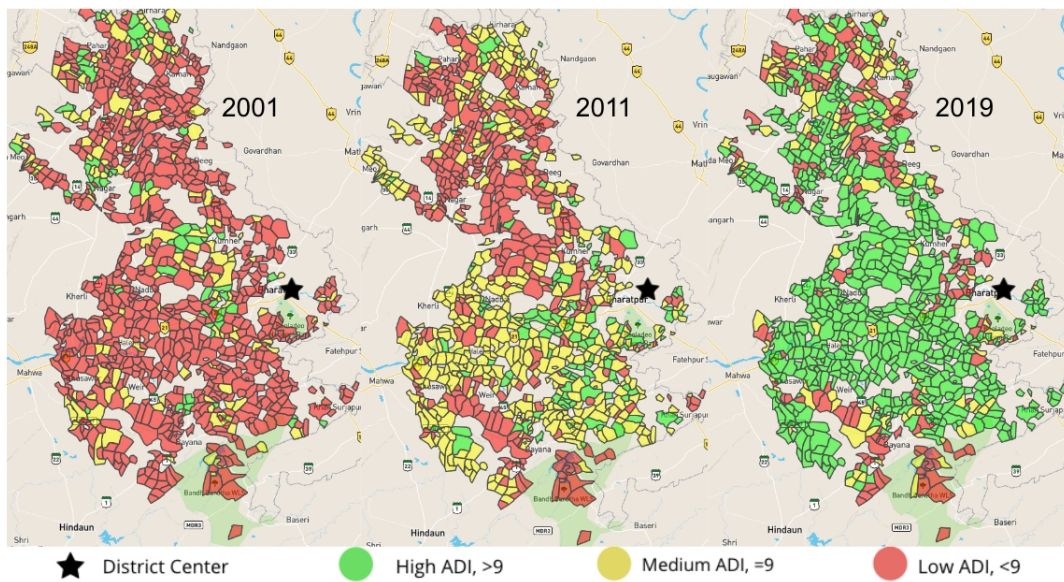


Figure 2: Initial results from our poverty mapping tool: Use of deep learning to output the Aggregative Development Index (ADI) from satellite data. Both daytime and nightlights data are used.

3.2.2 Transparency, participation, and data literacy. We have developed, and are further improving, several methods using satellite data and causal machine learning to obtain up-to-date outcomes archived from natural resource management works through close temporal tracking of the work sites [27]. These models trained on past data will be predictive of future potential of different sites for water management, and can thus equip community volunteers to make data-backed demands for appropriate works from the local administration. This will additionally lead to greater transparency in the decision making processes for work allocation, and track if vulnerable groups are indeed able to benefit from these government schemes.

This endeavour will require us to build the capacity of community volunteers on GIS and data crowd-sourcing tools for community mapping, data literacy, and environmental factors. Several studies have documented the feasibility of such community-based

mapping initiatives in urban settings, which we will attempt to replicate in rural areas. While it was sometimes challenging to capture accurate data [33], and to ensure that it got used by administrative authorities in desirable ways [34], once such data was available it became a strong lever for communities to claim land rights and transparency in land allocation [35]. We believe that similar rightful claims can be made to secure an equitable treatment of vulnerable groups. Such participatory tools will also enable marginalized groups to participate in local governance and decision-making processes [36, 37].

3.3 Participatory media

A social enterprise co-founded by the lead author, Gram Vaani, has been operating several dozen local instances of voice-based participatory platforms in many districts of India, together forming a federated network called Mobile Vaani [38]. The IVR (Interactive Voice Response) channel is the most popular among rural and

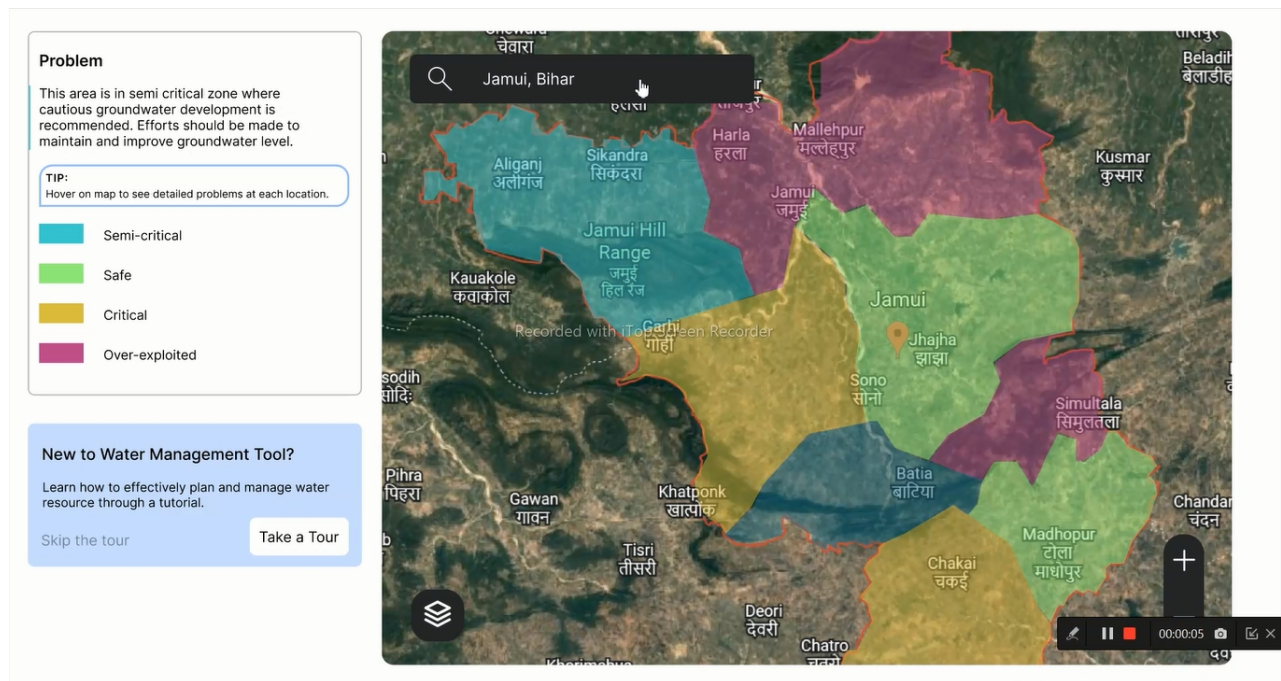


Figure 3: Mock-up of our envisioned decision-support tool to show water-stressed areas: Details will be shown to determine the reason for water stress, e.g. over-exploitation of groundwater, loss of forest cover, increase in built-up area, etc.

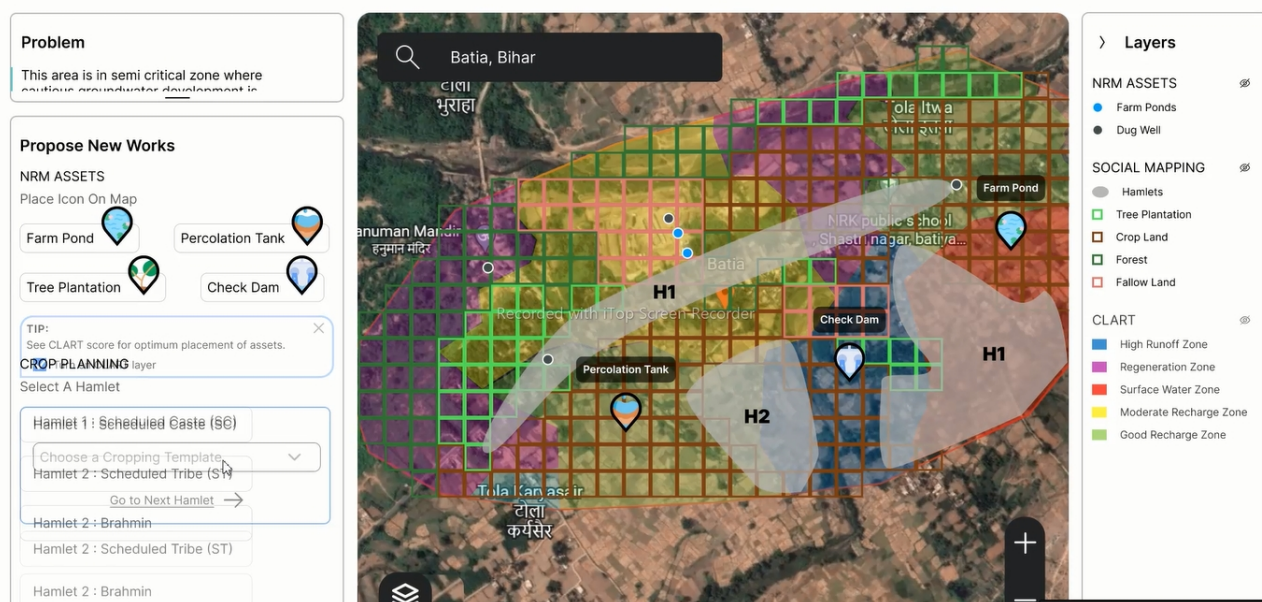


Figure 4: Mock-up of our envisioned decision-support tool to show vulnerable communities and ideal locations for rainwater harvesting structures: Community members will be able to work in a participatory manner and specify different what-if scenarios such as for new rainwater harvesting structures to be created in lands belonging to historically deprived groups. Each grid of cropping land is mapped to the hamlet that mostly owns the land, along with the income, caste, and socio-economic status of the hamlet households.

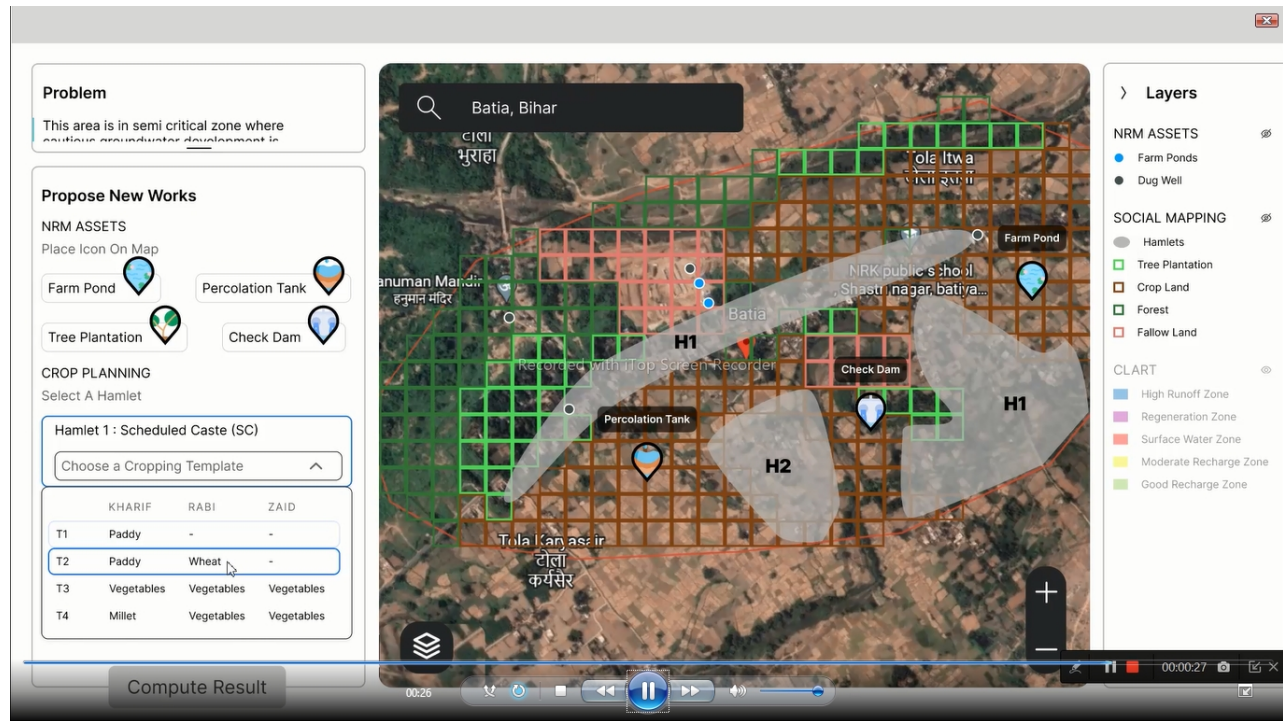


Figure 5: Mock-up of our envisioned decision-support tool to show collective crop planning: Community members will be observe the effects of different cropping pattern scenarios, such as the impact from shifting to less water-intensive crops.

low-income population groups, and an Android app and WhatsApp messenger channels are also now available for users with smartphones and Internet access. On these channels, users can listen to audio content, or record their own voice messages. Voice recordings thus contributed by the people are moderated through a two-level setup - by local volunteers, and then by Gram Vaani's central moderation team; messages deemed acceptable are then published on the platform and can be heard by others. Each platform instance operates independently, hosting its own content, and is coordinated on the ground by local volunteers from that geography. The volunteers publicize the platform among the communities, explain its usage and relevance, and assist the community members in solving issues especially related to social entitlements and the performance of public services [39]. A complementary set of incentives was found to motivate the volunteers for their service to the community: social incentives to contribute meaningfully towards the development of their community, purposive incentives to build their own credibility and acquire useful professional skills through their association with Mobile Vaani, solidarity incentives in working collaboratively with one another and with the Gram Vaani team, and financial incentives largely meant to cover their out-of-pocket expenses in Mobile Vaani related work [40]. Most such local Mobile Vaani instances have been running stably since several years, supported by the volunteers, and have built a strong reputation of providing credible information to the community, serving as a channel for marginalized groups to raise their issues, and assisting them with concrete actions to address these issues.

Gram Vaani already operates two such instances in Jamui that will be leveraged for the proposed work, and a new instance will be set up in Dumka. In both these locations, local volunteers will be trained to continue their ongoing work on running the participatory media platform, and extend it to vulnerability mapping of households as discussed above, and to using decision-support tools for natural resource management. The Mobile Vaani instances will also be used to communicate best practices on climate change, adaptation measures, social welfare schemes, and other such topics. The participatory methodology of Mobile Vaani encourages discussion and deliberation which will further contribute towards faster attitude and behavior change [41].

4 MONITORING, LEARNING, AND EVALUATION (MLE)

A mixed-methods baseline-endline framework will be used to obtain insights for subsequent scaling.

4.1 Outputs

The following tangible deliverables will be produced and tracked.

- Application development: Decision-support application for natural resource management works, populated with datasets and model-computed outputs for use anywhere in India
- Application usage: Number of users using the application, time spent, tasks completion rate on the application

- Alternative land-use plans developed: Community workshops held to develop plans using the decision-support application
- Village Development Plans: Number of proposed NRM assets included in the village development plan for funding under government schemes such as MGNREGA

4.2 Outcomes

These will be measured using KAP (Knowledge - Attitude - Practice) baseline/endline markers.

- Knowledge about water budgeting: Changes in awareness of the farming communities
- Attitude about collective planning: Changes in attitude of farming communities to consult one another for collective planning
- Practice of collective planning: Number of farmers, and the corresponding land area, where crop planning was altered as a result of the intervention
- New NRM assets sanctioned/built: Number of NRM assets sanctioned or built as a result of collective demands put forth by the farming communities

Workshops will also be held for other organizations to use the application in their respective communities, and inputs will be sought about observed outputs and outcomes in their areas.

5 WORK PACKAGES

5.1 WP-1: Decision support app

The GIS-based community mapping app will also carry on it various remote-sensing layers to assist with decision support and monitoring of natural resource management works commissioned in the community. Community volunteers will be trained to use the app. The app will also allow crowd-sourced data collection for community members to file reports related to different works and to transparently view decision-making discussion trails related to the works.

5.2 WP-2: Labeled data for machine learning

Works aimed at increasing agricultural intensification can be tracked through remote sensing methods to develop a coarse estimate of the extent of land used for agriculture [42]. However, finer detailed crowd-sourced data also needs to be collected in-situ about yield estimates and type of crops, which can lead to a rich dataset to train crop identification and yield estimation machine-learning models [43, 44]. We have already initiated a project for staff of community service organizations to contribute new land-use data, and potentially build a diverse dataset through the process.

5.3 WP-3: Research outputs

The project will lead to research outputs in multiple areas. First, remote-sensing methods deployed on the app will require continued research to build classifiers for different land-cover classes and changes therein. Second, site assessment tools for different types of natural resource management works will be refined based on ongoing crowd-sourced data collection. Third, socio-technical challenges such as with the training of community volunteers, their

incentives to contribute towards community-based development, empowerment gained by the community through increased transparency, and the influence exercised on administrative officials to imbibe principles of equality and resilience in their work, will lead to new process insights in executing community-based initiatives. Finally, an evaluation of the outcomes realized through the project will provide insights on the usefulness of the tools in different contexts, and to remove unjust and oppressive structures surrounding marginalized groups.

5.4 WP-4: Standard operating processes

An SoP will be developed for new communities to conduct their own vulnerability assessment, set up a participatory media platform, and utilize locally instantiated decision-support and monitoring tools.

5.5 Timeline

- *Months 01-06*: Collection of new ground-truth data to improve machine learning classifiers for Land Use and Land Cover classification - WP-2
- *Months 01-12*: Completion of decision support machine learning tool for site assessment for different types of water conservation works - WP-1
- *Months 01-06*: Surveys of farmers to understand incentive structures and collectivization challenges - WP-3
- *Months 13-24*: Field pilots to evaluate the tools - WP-3
- *25-36*: Publication of research papers on field evaluation, development of standard operating processes, and dissemination of results to social sector organizations and government departments - WP-4

5.6 Prior work

The following papers already published by our group are relevant for the proposed research [5, 6, 10, 17, 27, 38–41, 45]. Two additional papers are under review: *Tracking Socio-economic Development in Rural India Using Satellite Imagery* and *Whose Participation Counts? Facilitating Equitable Participation in Development via Phygitization*.

6 ABOUT THE TEAM

The team will be led by Professor Aaditeshwar Seth, with research contributions from his PhD, Masters, and Undergraduate students, and implementation and domain support from the Foundation of Ecological Security and Gram Vaani Community Media.

6.1 Aaditeshwar Seth, IIT Delhi

Aaditeshwar Seth is a Professor in the Department of Computer Science and Engineering at the Indian Institute of Technology Delhi, and co-founder of the social technology enterprise Gram Vaani. He is passionate about building appropriate technologies and participatory tools that can empower marginalized and oppressed communities to collectivize and voice themselves. Several million people, and over 150 organizations worldwide, have directly touched technology platforms built by Aaditeshwar's team at Gram Vaani and his students at the ACT4D (Appropriate Computing Technologies for Development) research group at IIT Delhi. Many elements of

their work have also been adopted by government departments and have influenced the use of technologies for development in the social sector. He is a recipient of the ACM SIGCHI Social Impact Award for 2022. His book published in 2022, *Technology and (Dis)Empowerment: A Call to Technologists*, argues that the primary goal of technologists should be to bring equality and overturn hegemonic unjust social and economic structures through their inventions.

6.2 Foundation for Ecological Security

The Foundation for Ecological Security was set up in 2001 to reinforce the massive and critical task of ecological restoration in the country. FES enables rural communities to secure legal rights to their Commons, prepare resource management and governance plans, and access public investment to support environmental improvement. Concurrently, FES engages with government to implement policies and programmes that promote the local management and governance of Commons, channels information systems and technology to improve civic engagement, and partners with research institutions to improve understanding, and bring rigour in field action. Their vision is to build a future where local communities determine and move towards desirable land-use practices based on principles of conservation and social justice.

6.3 Gram Vaani Community Media

Gram Vaani is an Indian social technology enterprise with a mission to reverse the flow of information. We believe in developing and using appropriate technologies and people driven processes to build participatory media networks that can empower communities. Our Theory of Change has organically evolved from the ground up and is based on our experience of working in the rural Information, Communication and Technology space since 2009. Our Mobile Vaani platforms connect (through measurable ways) Corporate, Government Agencies, Non-Governmental Organizations, and Social Enterprises to their target groups not touched by other media channels. Mobile Vaani is Gram Vaani's answer to building a participatory media platform for rural areas, accessible using even basic feature phones. We have built an inclusive and intelligent multi-channel interface - starting with the IVR (Interactive Voice Response) system, further enhanced to include other digital channels like WhatsApp and a new Android Smart app, which allow people to record messages to share with their community and listen to messages left by others. Our flagship deployments operating in 30+ districts across multiple states service over 100,000 monthly unique users who engage and discuss regularly on culture, local updates and announcements, government schemes and knowledge sharing, and have touched over 3M individuals so far. Our users include people from marginal socio-economic groups in remote locations, including less-literate people. We constantly strive to innovate on the use of appropriate technology tools, to help bridge the information asymmetry, and have lately built novel applications using AI and ML tools for automated question-answering, collection of complex data, and navigation tools for chatbots and information search.

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