ADAPTATION FUND

PROGRAMME ON INNOVATION:
LARGE GRANTS PROJECTS

REQUEST FOR PROJECT FUNDING FROM THE ADAPTATION FUND

Climate Smart Agricultural Water Management in Man and Khatav Taluka of Satara, Maharashtra, India

SINGLE COUNTRY/ REGIONAL INNOVATION PROJECT/PROGRAMME PROPOSAL

PART I: PROJECT/PROGRAMME INFORMATION

Title of Project/Programme:	**Climate Smart Agricultural Water Management in Man and Khatav Taluka of Satara, Maharashtra, India**
Country/ Countries:	**India**
Thematic Focal Area[1]:	**Agriculture**, **Water Resource Management**
Type of Implementing Entity:	**National Implementing Entity**
Implementing Entity:	**NABARD**
Executing Entity:	**Indian Institute of TechnologyBombay, India**
Amount of Financing Requested:	**2.56 Million USD**

Project / Programme Background and Context:

Climate Change and its Impacts on Agriculture, Water and Food

The Intergovernmental Panel on Climate Change (IPCC), Working Group II, Assessment Report 6 (AR6) has assessed the negative impacts of global warming on the food security and nutrition of hundreds of millions of people in low and mid-latitudes with high confidence (Pörtner et al., 2022). Following Sustainable Development Goal 2 (end hunger), to meet the food security of the projected 10 billion population in the 2050s, agricultural production will need to expand by approximately by 70% (World Bank, 2020). By 2030, due to the required agricultural intensification, the global food, water, and energy demands will increase by 35%, 40%, and 50% as compared to the present (NIC, 2012). As a consequence of high water demand, water scarcity will increase, reducing agricultural productivity. The current practices do not maximize agricultural productivity nor minimize the water use (Davis et al., 2017). The working group 2, Assessment Report 6 of IPCC, also highlighted that the current global agricultural practices are environmentally unsustainable (Pörtner et al., 2022).

[1]Thematic areas are: Agriculture, Coastal Zone Management, Disaster risk reduction, Food security, Forests, Human health, Innovative climate finance , Marine and Fisheries, Nature-based solutions and ecosystem based adaptation, Protection and enhancement of cultural heritage, Social innovation, Rural development, Urban adaptation, Water management, Wildfire Management.

Agricultural intensification took place in India in the last 5-6 decades to meet the food demand of the growing population. Indian crop production meets the country's demand and plays a significant role in global food security. Since 1950, the total crop production in India has shown a steady increasing trend (Barik et al. (2016), Figure 1 (a)). However, it is alarming that the per-capita food production has declined over the last decade (Fig 1 (b)). Food production has increased in both Kharif (Monsoon) and Rabi (Winter) seasons, but the increasing rate is higher for Rabi, which demands irrigation in the absence of rainfall (Fig. 1(c)). The yield has improved in the last 50-60 years (Figure 1(d)), with a significant increase in irrigation (Fig. 1(e)). An increase in groundwater abstraction intensified the irrigation water applications (Fig 1(f)). Groundwater pumping has also increased agricultural costs and electricity consumption, which may negatively impact food prices and security.

Post-1950, India witnessed a declining monsoon rainfall — the major water source. The decrease in water availability and increased water demand for agricultural intensification resulted in a significant rise in irrigation. Moreover, the Government supported such activities through subsidized electricity for groundwater pumping. However, this policy resulted in uncontrolled and inefficient groundwater use and depletion. Maintaining water and food security have become conflicting objectives and demands for innovative out of the box adaptation strategies for improved yield that has co-benefits of water savings, and reduction of climate vulnerability and risk. The ultimate objective of such a strategy is "**more crop per drop**", which is possible with the application of new technology for monitoring soil and plant after evaluation, use of improved weather forecasts that are made accessible to the stakeholders at farm scale through regional modeling, multi-scale optimization with conflicting water and food objectives and implementation through communication and stakeholder participation. Here we aim to do the same for the arid villages of district Satara in Maharashtra, India.

Pilot Case-study

Maharashtra, located between Central India and the west coast, plays a major role in producing food crops. The state produces 5.8 % of the nation's food. The state has a very strong rainfall variation, with very high rainfall of more than 3000 mm on the western side to as low as 600 mm on the eastern side. The district of Satara is located in the south-western part of Maharashtra, approximately between 17° 5' to 18° 11' North and 73° 33' to 74° 54' East (Figure 2). The overall area of the district extends across 10480 km^2. It has 7 sub-divisions and 11 administrative sub-units. Satara has around 1719 villages governed by 11 panchayat samitee's and 1501 'Gram Panchayats'. Satara is moderately populated (in the Indian context) with a total population of 30,03,922.

The majority of Satara's population lives in rural area. According to the 2011 census, around 81% of the population lives in the rural area. The district's literacy rate is 82.87% with 53.19% of the population below the poverty line making them highly vulnerable to climate change. The centrally located Satara and Karad taluka are developing to be urban and have relatively higher population density while eastern taluka like Man, Khatav are rarely populated (e.g. Man is the least populated area in Satara district with 127 persons / sq. km). Among Satara's total population, around 43.24% are land cultivators while around 21.94% work as agricultural labourers. Farming is one of the primary occupations for the majority of Satara's population. Around 63.5% of land is under agricultural activities. The western region is hilly and only 1% of its land is under agriculture while more than 50% land in the eastern region (including Man, Khatav and Koregaon taluka) is under agriculture. Sugarcane, Jowar, Bajra, Rice, Cereals and Pulses are major food crops that are typically cultivated while Ground-nut, Safflower, Chillies and Cotton are the most typical non-food crops. Kharif, Rabi and Summer seasons are the major time of year for cultivating and harvesting crops. The economic growth of the district is strongly tied to the agricultural yields.

Satara has a moderate climate. The maximum temperature climatologically reaches 39^0 C during summers (March – mid-June) and minimum of 10^0 C during winter (Nov.-March). Satara is moderately humid during monsoon season but is usually dry during winters and summers. Even within the district, rainfall shows a large variability over various parts. A large gradient in seasonal mean rainfall is observed between the western and eastern regions. The western region, including Mahabaleshwar taluka has typically >6000mm rainfall while the eastern regions that includes Man and Khatav taluka have <600mm of seasonal rainfall. The central talukas of Koregaon and

Satara receive moderate rainfall. The low rainfall in Man and Khatav poses severe challenges for water availability for agricultural practices.

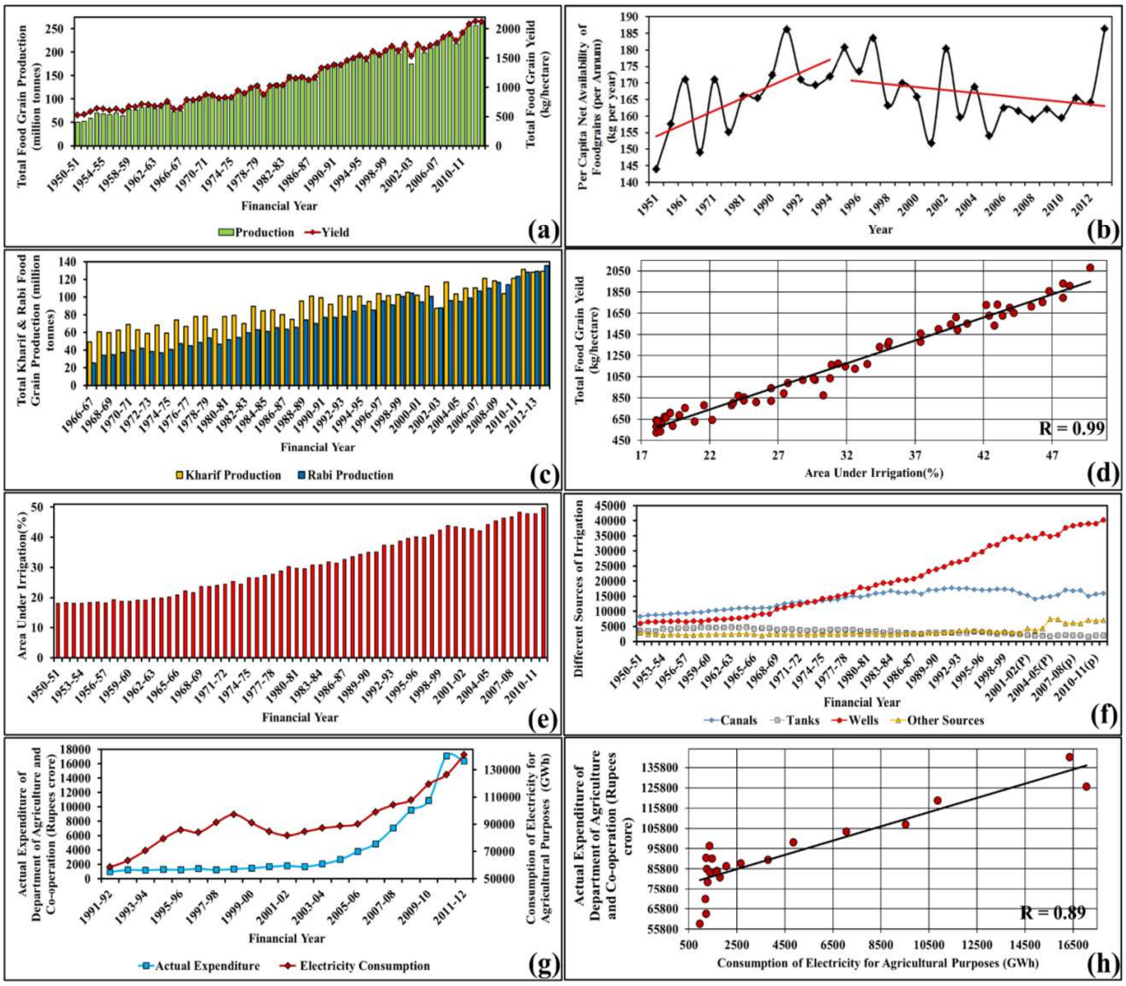

Figure 1: The Food-Energy-Water Statistics for India (Source: Barik et al., 2016, all data collected from Agricultural Census, Government of India)

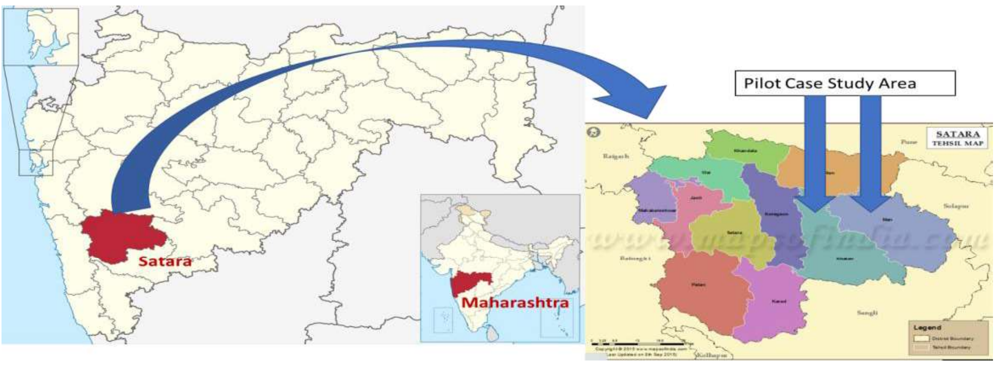

Figure 2: Case Study Area: The Tehsils, Man and Khatav, the driest regions in Satara

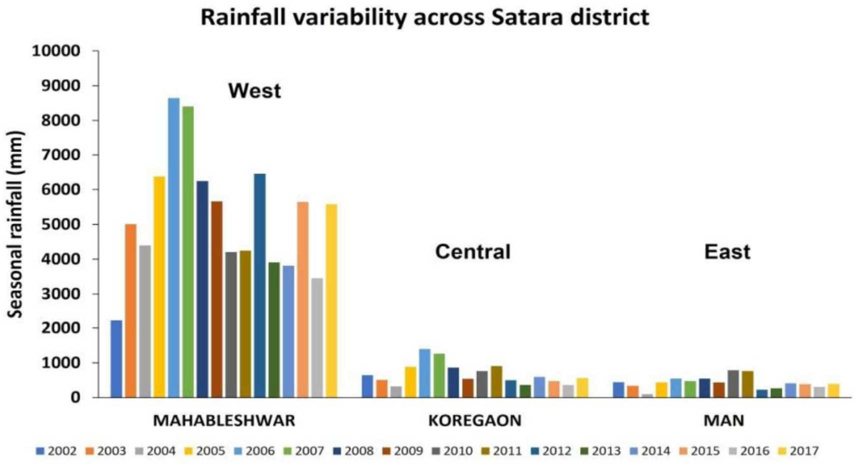

Figure 3: Rainfall in 3 representative Talukas in Satara District

Medium to deep black soil is typically found in the central to eastern region while weathered / fractured Basalt rocks are typically found in the western hilly region. The eastern region, talukas like Man and Khatav heavily depend on groundwater for its water needs, especially for drinking and irrigation purposes. Dugwells and Handpumps are mainly used to access the ground water and most of the abstractions hence, remain unrecorded.

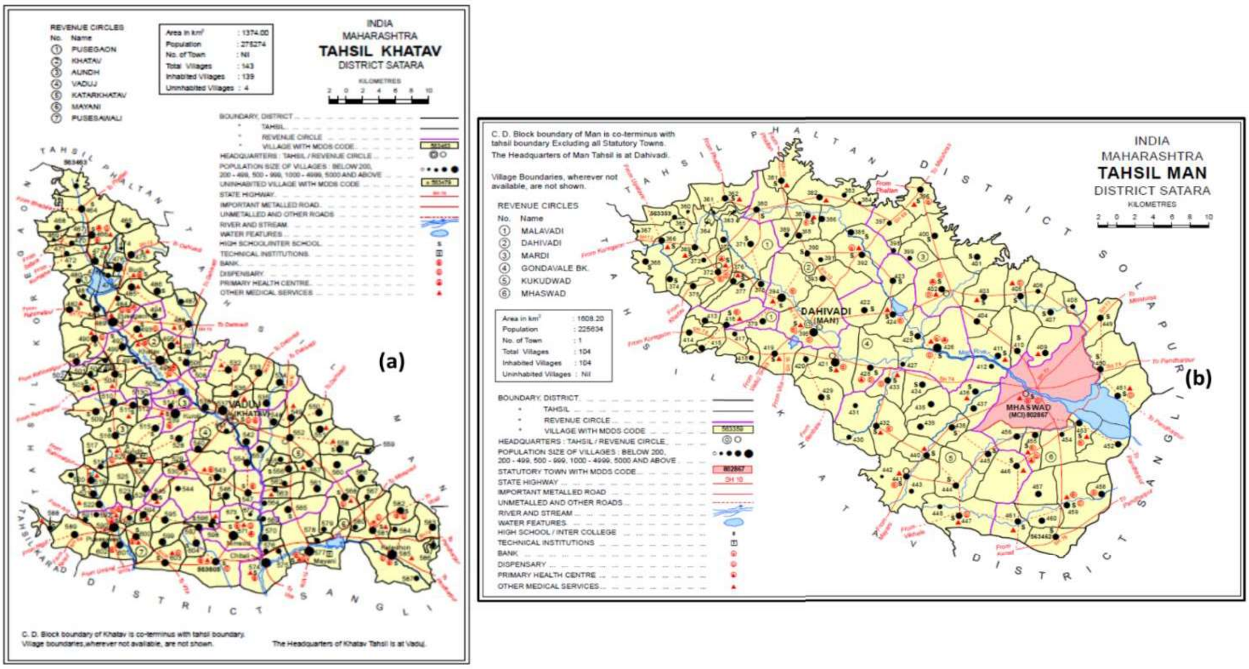

Figure 4: Tehsil (a) Man and (b) Khatav in Satara District

We identified our pilot study areas in the Satara district as the dry Tehsils (Talukas) Man and Khatav. The Man Tehsil has 104 villages, and the Khatav Tehsil has 143. We propose to pick up a few villages after extensive stakeholders' meetings to understand the farmers' willingness to adapt to new technologies. These two tehsils have high vulnerability to climate due to dry conditions and socio-economic factors. The dry Tehsils in the Satara district have faced significant migration to the nearby cities Pune and Mumbai (https://timesofindia.indiatimes.com/city/mumbai/hit-by-drought-rural-folks-pour-into-mumbai-pune/articleshow/13157693.cms). The remaining population is dominated by the most vulnerable group, women, aged people and children. The agricultural activities in these regions are also often driven by them and hence, any improvement in agricultural productivity will have a co-benefit of improving the economic conditions and lifestyle of the vulnerable population.

With wide variations in the rainfall, the average rain of Satara is moderate; hence, the district is not being listed as a vulnerable district. However, the two talukas Man and Khatav and extremely dry with annual rain < 600mm, but remains often unnoticed due to the high rainfall over other regions of Satara. This makes the two talukas really vulnerable to climate. Furthermore, these two talukas have a very high socio-economic vulnerability due to high migration of male abled population to the nearby cities. Recent study also ashows (Vittal et al., 2020) that the drought hazard has increased in these Talukas. Hence, these two districts need a special attention.

Identifying Gap

While developing a participatory agricultural water management model, interactions with farmers over less vulnerable district (Nashik) of Maharashtra (Roy et al., 2021) revealed that the improved weather forecasts by the India Meteorological Department mostly remain unutilized. The gap identified by them are: (1) resolution mismatch, (2) handling uncertainties related to accuracy, (3) translating information to farm-scale, (4) non-availability of tools specifically designed for local farmers, (5) non-availability of good monitoring technologies. The gap is more for the vulnerable districts and dry regions of Satara, Man and Khatav. To summarize, the major research and implementation gaps are the followings:

1. There is no existing framework or guideline to make the agricultural activities climate-smart handling conflicting objectives.
2. Worldwide there are significant advancements in drone, sensor, and satellite-based technologies for agricultural monitoring. But there is no existing guideline on the rationalization of measurement networks, application of drones, and merging of multi-source, multi-resolution soil and plant data.
3. Evaluations of new technologies for Indian agricultural case studies and the benefits of the applications are neither demonstrated nor recorded.
4. The accessibility of the vulnerable farmers to the weather forecasts is not good, despite the release of agricultural advisories in local languages. This is attributed to scale mismatch, lack of coupling between monitoring and forecasts leading to management decisions, non-availability of tools, and lack of guidelines for the farmers to handle uncertainty and inaccuracies.
5. There are limited studies on analyzing the resilience of the present crop system in the changing climate scenarios.
6. The guideline on sustainable crop practices for a changing scenario meeting water and food demand with a co-benefit of improving farmers' income is not available, even globally.
7. The protocol for the use of climate risk framework in improving sustainability through technological and socio-economic interventions (specifically for the vulnerable groups) is missing for the Indian regions. Hence, there is non-availability of any policy framing grounded on scientific understanding and technological innovations.

Institution Background

The Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay proposes to develop solutions with implementations based on new scientific findings and technology innovations for the district of Satara. Such an analysis will be the first proof of concept not only for India but for entire South Asia. The lack of solutions on agricultural climate adaptation meeting conflicting objectives for the global south are also reported in the IPCC reports AR6, WG II.

The Indian Institute of Technology Bombay (IIT Bombay) is recognized worldwide as a leader in the field of engineering education and research. As part of our 2030 vision, we aspire to be among the top 50 universities in the world. In this journey, the key is to establish and promote research in several Centres of Excellence (CoEs) that pertain to strategic areas of national and international significance. CoEs are the hubs that focus on interdisciplinary research, partnerships, and multiple academic offerings, and are incubators of state-of-the-art applied research. The Interdisciplinary Program in Climate Studies is one such CoE started in 2012 with the support from the Department of Science and Technology, Government of India. This is one of the first doctoral programmes in India which is addressing the research and education of climate change with the aim to undertake interdisciplinary, problem-driven research for end-to-end solutions covering the causes and consequences of and responses to climate change; to build long-term scientific capacity and systems for study of regional climate change and climate futures; to enable the creation of a pool of multidisciplinary researchers to serve the growing need for climate change scientists and professionals to serve R&D and policy needs in private, public and governmental institutions; and to provide critical assessments to support policy and governmental decision-making on air and water resources and climate mitigation and adaptation measures.

To address the agroclimatic problems, mentioned above, IIT Bombay has identified the following partners:

1. Technology Innovation Hub (TIH): A section 8 company set up at IIT Bombay with support from the Department of Science and Technology. TIH will be involved in innovating and implementing new technologies related to sensors and drones for agricultural monitoring.
2. BHUGOL GIS Pvt Ltd: Bhugol GIS Pvt. Ltd. is an enterprise built on decades of research experience. Founded and Incubated at Society for Innovation and Entrepreneurship (SINE) at the Indian Institute of Technology Bombay (IITB). BHUGOL GIS is a technology and analytics firm with its own proprietary tool, GRAM++. GRAM is an acronym for Geo-Referenced Area Management, featuring robust Mapping, Data Analytics and Image Processing capabilities. BHUGOL will be developing the geospatial portals and apps.
3. Society for Empowerment of Villages & Agriculture (SEVA): SEVA is the leading NGO in the field of Agriculture, Water, Watershed, Sanitation, Environment, and Livelihood. SEVA works with people residing in villages at a micro level, and facilitates participation of rural people in the process of development of rural India. SEVA has an outreach of about 200 villages in the Satara District of the Western region in Maharashtra.
4. India Meteorological Department: India Meteorological Department (IMD) is the official Government of India weather service provider. IITB signed an MoU with IMD on 2nd May 2022 to share data and tools for developing and implementing better climate services.

Proposed Approach in Brief

Aligned with the SDGs on food and water security, the Interdisciplinary Program (IDP) in Climate Studies at IITB proposes holistic approach for climate-smart agricultural management. Such an approach involves new sensing technologies, better weather forecasts and climate projections, improved data-driven models, operation research techniques, and field implementation. We will focus on weather scale (3-7 days) forecasts for near real-time irrigation management, extended-range predictions (2-4 weeks) for better water arrangements within crop seasons, seasonal predictions for season-specific management, and climate projections for crop area design, meeting water and food security. We propose collaborating with Technology Innovation Hub, IIT Bombay to introduce new technologies of drones, sensors, and robotics in agriculture and their evaluations. The objectives will be to provide intelligent climate advisories to small and medium-scale farmers and involve them in participatory approaches. Evaluating the proposed models and new technologies in the field with the farmers of the Satara districts is one of the primary objectives of the proposed work. The entire work should reduce agricultural climate risk, which is defined as the products of hazard, vulnerability, and exposure. The work will involve computational work related to climate, hydrology, AI-ML and operation research, fieldwork related to the pilot implementation of new technologies and monitoring, participatory model development in the field, and planning for upscaling over a larger region. Such a holistic approach will be the first of its kind in India, and we believe such work will guide the country to upscale our approach in meeting the water and food security in the climate-stressed future.

Project / Programme Objectives:

The proposed project aims to develop and implement new technologies for agricultural adaptation to climate change for water and food security. The new scientific findings and technological innovations will be implemented and tested for the driest and most vulnerable Talukas of Satara district Maharashtra, Man and Khatav. A significant fraction of the population in this region live below the poverty line and are highly vulnerable. A substantial proportion of the male population from these regions have migrated to nearby cities Mumbai and Pune, making the population dominated by women, aged people and children, which has further increased the vulnerability over the last decade.

The objectives of the proposed works are:

1. **Stakeholders Meeting and Participatory Framework**
   a. Consulting stakeholders (farmers, farmer leads, Government officials) to understand the present agricultural problems faced by them due to changing climate
   b. Communicating climate change impacts and possible future regional trajectories of water and agriculture from different storylines.
   c. Explaining the need for community participation in implementing adaptation technologies.
   d. Understanding the farmers' willingness to participate while selecting the villages for pilot case studies.
   e. Involving vulnerable populations, such as women and poor farmers, in developing real-time management strategies and long-term adaptation.
   f. Performing a detailed survey and assigning high priorities in installing field technologies on the farms of the most vulnerable farmers.
2. **Monitoring the soil moisture and crop stress at the farm scale in 1-2 tehsils of Satara using the concept of IoT**
   a. Installation of soil moisture sensor network
   b. Rationalization of the measurement network.
   c. Soil moisture and crop stress mapping with drones
   d. Retrieval of satellite data of soil moisture at a coarser resolution
   e. Merging of multi-sourced data to generate near real-time soil moisture maps
3. **Regional Climate and Hydrological Modeling**
   a. To model regional weather and climate in Satara district dynamically and statistically
   b. Generation of regional scale weather and climate information from village to district scale.
   c. Hyper-resolution hydrological simulations at village levels.
   d. Farm scale ecohydrological and agricultural modeling.
   e. Generation of future hydrological scenarios impacted by Climate Change
4. **Irrigation Water Management**
   a. Development of optimization model for farm scale irrigation water management
   b. Water management decisions at weather scale (1-7 Days)
   c. Water management decisions at extended range scale (2 weeks to 4 weeks)
   d. Development of portal and app for water management
   e. To develop a participatory framework involving farmers
5. **Agricultural Risk Assessment**
   a. Collection of high-resolution socio-economic and agricultural data at high-resolution administrative level.
   b. Development of Hazard and Vulnerability map for different crops.
   c. Development of Agricultural Risk map for Satara district
   d. To develop a framework for agricultural and socio-economic intervention guidelines for reducing risk in the future.
   e. New technology evaluations and their possible roles in risk reduction.

6. **Crop planning for the future to reduce adverse climate impacts**
    a. To develop multi-objective optimization model to decide on future crop applications with objectives
        i. Maximization of kcal production
        ii. Minimization of water use
        iii. Maximization of farmers' profits
    b. Involving crop modelling and generation of app for easy visualization and implementations

The broad goal is to bring sustainability to agricultural water management through short-term irrigation advisory and long-term crop switching. The irrigation advisories will merge IOT/ IOE systems with satellite observations, hyper-resolution modeling, and weather and sub-seasonal forecasts. The primary objective is to develop out of the box approaches to make the agricultural advisories accessible by the farmers for their own farms, irrespective of the installation of sensors on that specific farm. We plan to cover a minimum of 5 villages in the two talukas. We envisage a minimum of 10% water saving by introducing cost-effective new technology. The long-term crop switching will ensure the satisfaction of multiple conflicting objectives of maximizing food production, maximizing farmers' profits, and minimizing water use. We will demonstrate the reduction of climate risk through such interventions. The project will add significant value to the existing Laxmanrao Inamdar Lift Irrigation scheme (worth Rs 247 crore) sanctioned under the PMKSY (Per drop more crop) for the drought-prone Man Khatav taluka with the innovative application of new technologies. The developed technology can be upscales to 27,000 hectare, which the irrigation scheme is covering.

Project / Programme Components and Financing:

Project/Programme Components	Expected Outcomes	Expected Outputs	Countries	Amount (US$)
1. WP1: Stakeholders meeting and continuous interactions/ feedback with farmers	Pre-project, Periodical and end of project stakeholders meetings	Quantitate understanding of needs willingness to participate, and effectiveness of the project	India	252000
2. WP2: Introducing new technologies in extensive agricultural monitoring	• In-situ and drone based measurement of the soil moisture and temperature with sensors.	Unique data set measuring high spatio-temporal resolution soil properties	India	760516
3. WP3: Merging multisource data for the generation of agricultural map and soil moisture map.	• Setting up in-situ and satellite-based monitoring systems to collect hydro-meteorological and soil variables. • Micro-climate measurement using in-situ sensors • Merging satellite, drone and in-situ observations using AI/ML for high resolution soil moisture estimation	Hyper resolution climate information at farmscale merging several data set	India	142568

4. WP4: Hyper-resolution climate and hydrological modeling	• Assessing the potential of Weather Research and Forecasting (WRF)-Hydro to simulate accurate weather and land surface forecasts at farm scales. • Setup Hydroblocks to simulate soil moisture in the order of 30 meters resolution. Couple WRF- Advanced Research WRF (ARW) with Hydroblocks in an attempt to better resolve the weather and soil moisture information at hyper resolution.	Short and long term IMD weather forecasts translated to farmscale	India	237613
5. WP5: Farm scale optimization for irrigation water management	To develop farm scale irrigation water management tool based on weather forecasts and monitored soil moisture at the root zone using sensors and further to scale it up to taluka level for multiple plots with different crops.	An optimised irrigation schedule produced to cater specific needs of farmers	India	142568
6. WP6: Participatory modeling and resolving field scale implementation challenges	To develop tools to support implementation of rural water management plans through participatory approach.	Formation of Climate Smart farmers group	India	142568
7. WP7: Agricultural risk assessment and risk minimization	A set of risk maps that will aid in identifying and prioritizing the regions more vulnerable to climate change by incorporating the effect of all possible influencing dimensions affecting crop production.	A library of risk maps to help farmers in making short and long term decisions	India	142568
8. WP8: Future crop allocation to produce more food per drop	To develop optimization model for decision support focusing on strategic decisions that is generic and scalable for other regions.	A guideline for the optimal choice of crops that promotes more crop per drop	India	142568
9. WP9: Geospatial portal and app development	Development of cloud-based Geospatial web portal and Mobile application for dissipation of spatial and various other information to the users.	Mobile app and web portal to gather and disseminate advisory to farmers and NGOs	India	**187733**
10. Project/Programme Execution cost (9.5% of Project Component Cost)				**204317**
11. Total Project/Programme Cost				**2355019**
12. Project/Programme Cycle Management Fee charged by the Implementing Entity (if applicable) (8.5% of Total Project Cost)				**200177**
Amount of Financing Requested				**2555197 (2.56 Million USD)**

Conversion rate to INR: 1 USD = 80 INR

Overall, we propose a framework applicable for the localized crop with downscaled weather and climate services for agricultural water management. The agricultural monitoring will be performed with an optimum number of sensors, drone surveys and merging sensors, drones, satellites and modeling. This will significantly reduce the cost, making Internet of Things (IoT) and Internet of Everything (IoE) popular for India. The entire system and technology will be transferred to either Agricultural Department, Govt. of Maharashtra, India or India Meteorological Department (IMD) for continuing the services after the project. We envisage that the successful completion of project will be the beginning of wide usage of cost efficient IoT and IoE in agriculture in India.
Other than the technical components, the unique strength of the proposal is its components on:

- Encouraging knowledge exchange and learning to support scaling of innovations
- Multi-stakeholder partnerships to innovation
- Pooling of many different actors' knowledge and expertise - universities and research organizations, government bodies and private actors
- Involvement of the younger generation, since youth is a key stakeholder group in both forging climate change solutions and benefitting from their success
- Involvement of agri-dependant highly vulnerable population in an arid region
- Participatory framework involving and modeling heuristic decision-making of the farmer for a complex system with different crops/ crop stages/ farm operations

Projected Calendar:

Indicate the dates of the following milestones for the proposed project/programme

Milestones	Expected Dates
Start of Project/Programme Implementation	January 2023
Mid-term Review (if planned)	December 2024
Project/Programme Closing	December 2026
Terminal Evaluation	October 2026

PART II: PROJECT / PROGRAMME JUSTIFICATION

A. Describe the project / programme components, particularly focusing on the concrete adaptation activities, how these activities would contribute to climate resilience. For regional projects describe also how they would build added value through the regional approach, compared to implementing similar activities in each country individually. For the case of a programme, show how the combination of individual projects would contribute to the overall increase in resilience.

Climate change resulted in enormous stress on agricultural productivity and, subsequently, water and food security over India's vulnerable and dry regions. The proposed project aims to develop adaptation strategies for sustainable farming practices and water and food security. We propose to bring innovative out-of-the-box ideas and concepts together to improve the farm practices through farmers' participation in making them climate-smart. We propose to work on sensors, drones and satellite observations, IoT-based farming, use of weather forecasts, making the forecasts suitable for farm-scale decision making, developing management decisions, bringing sustainable crop practices, and disseminating the information by the geospatial portal and user-friendly apps. The primary objective is to make every step of agricultural water management practices climate-smart to reduce the adverse impacts of climate change. We also propose to plan for long-term intervention grounded on climate and agricultural science to make the agricultural system in the vulnerable regions climate resilient by reducing climate risk. The overall framework is presented in Figure 1.

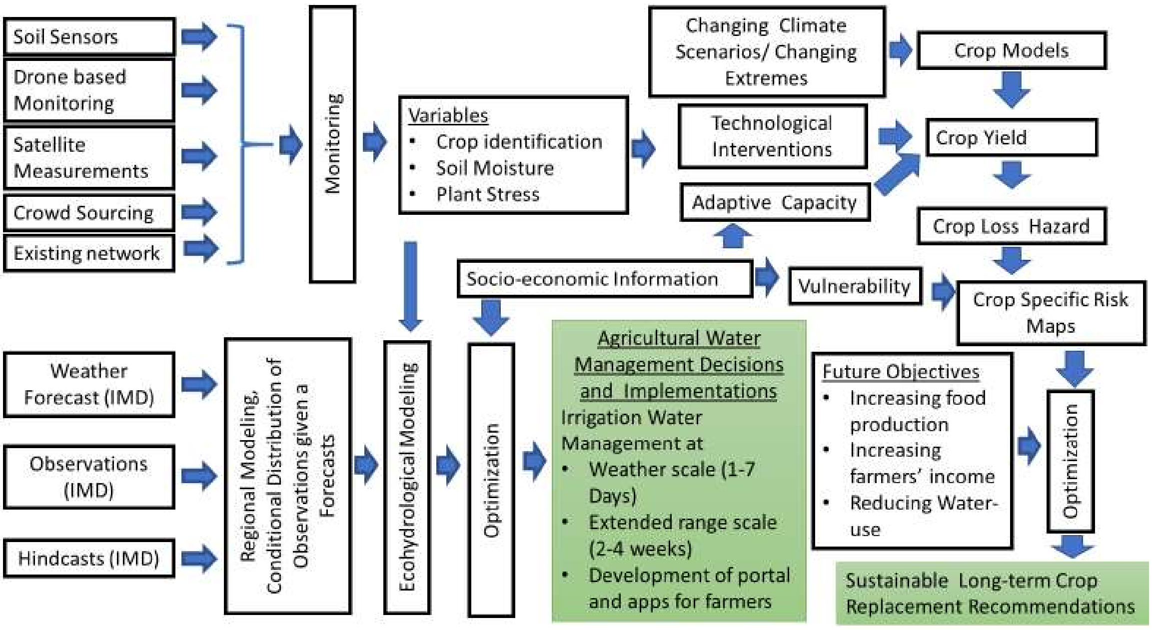

Figure 5: Overall Proposed Framework

As shown in Figure 5, we envision two outcomes, as shown by the green blocks, both targeting "more crop per drop" making the practices water efficient. The first outcome is associated with setting up IoT based framework for farm-scale water management. The approach will start with installing soil moisture sensors, flying drones, and satellite retrieval of soil-plant data. The real-time geospatial soil and plant health information will be generated by merging multi-source data and will be used in a hydrological and ecohydrological model. Weather forecasts will be made accessible to the farmers through the development of intelligent tools taking care of associated errors and uncertainties. The geospatial farm scale information and downscaled weather forecasts will be combined in a unique stochastic optimization framework for computing the optimum water application. For making arrangements for the water well in advance (say, 2 weeks), extended range predictions will be used. The decision information will be disseminated to the farmers through apps and portals. Our adaptive tool developed with the farmers of Maharashtra having a monitoring facility showed 10-30% of water savings (Roy et al., 2021), the real challenge is how to incorporate the IoT based monitoring system to the network.

While the real-time decision framework helps to save water, finding the most sustainable climate resilient crop practices is also necessary. A wrong crop practice was mainly responsible for severe agricultural drought and farmers' suicide in one of the dry regions of Maharashtra, i.e., Marathwada (Zachariah et al., 2020). Hence, using the correct crop to meet food demand with minimal water use is a pathway to climate adaptation for water and food security. The other adaptive pathways include the technological and socio-economical interventions that result in low vulnerability reducing the agricultural climate risk. The experience of working with farmers with new IoT-based technologies will give us data/ information about the technology evaluation that may feed into the risk framework. The whole approach will involve collection of granular data, farmers' interviews, crop modelling, using the information in a multiobjective optimization framework and feeding the results into policy framing. Such a framework will also be upscaled to understand the efficacy. The uniqueness of our adaptive participatory framework is that it works at both the scales, weather and climate. The approach interacts among both scales, gives options for the stakeholders' participation, targets improved yield with minimal water use, and provides long-term water and food security guidelines. The whole project will have the following Work-Packages (WPs):

WP1: Stakeholders meeting and continuous interactions/ feedback with farmers
WP2: Introducing new technologies and implementing IoT in extensive agricultural monitoring
WP3: Merging multi-source data for the generation of an agricultural map and soil moisture map
WP4: Hyper-resolution climate and hydrological modeling
WP5: Farm scale optimization for irrigation water management
WP6: Participatory modeling and resolving field scale implementation challenges
WP7: Agricultural risk assessment and risk minimization
WP8: Future crop allocation to produce more food per drop
WP9: Geospatial portal and app

WP1: Stakeholders meeting and continuous interactions/ feedback with farmers:
Technology development, implementation, and success depend on understanding the stakeholders' needs, willingness to participate in the implementation activities and feedback on the developed technology. This is a continuous process that results in the improvement of the system gradually making an impact.

Pre-project stakeholders meeting
The process starts with a pre-project stakeholders meeting. This will be a two-way communication meeting, where the efforts will be first made to understand the problems faced by the farmers, specifically those who live below the poverty line. Many of the farmlands in these regions are led by women considering the migration of men to the cities. The problems faced by the vulnerable community will be noted and recorded through the meeting. We also plan to communicate Climate Change, its growing impacts on agriculture through animation and posters written in local language. Adaptation planning works with a climate-aware community. We will make the community climate literate and, at the same time, explain in simple language our plans and what way the proposed technology will make the agricultural practices climate-resilient. We plan to invite villagers through the contacts of our identified NGO, who has been extensively working in the areas of Man and Khatva.

Understanding the villagers' willingness is the key in identifying the sites where the major IoT installation will occur. We already had a few discussions with the state Government of Maharashtra (Additional Chief Secretary, General Administration) in this regard. The whole ecosystem has agreed to co-operate and help IITB to initiate the project.

Periodical stakeholders meeting
There will be periodical stakeholders meetings at the starting and end of crop seasons (May: starting of Kharif, October: End of Kharif and start of Rabi, February: End of Rabi season). The meetings will have the following objectives:

A. Joint planning for installation and expansion of soil sensor networks.
B. Joint planning for flying the drones.
C. Selecting and designing platforms for information dissemination
D. Getting feedback from the farmers on advisories for a continuous improvement process
E. Technology evaluation from stakeholders' perspective
F. Analysing the cost-benefit and understanding the co-benefits of the proposed technology implementation.
G. Interactions between the project review committee and the stakeholders.

End of the Project Stakeholders meeting
Many technology development and implementation projects end without a proper technology transfer; hence, they are not maintained after completion. We want to ensure the technology application will continue with a bigger upscaling plan. We plan to have an end-of-the-project stakeholders meeting with farmers and the district officials. The purpose is to make the district officials aware of our technology development with the efficacies. It is also important to get the feedback from farmers for improvement plans. The district or state officials for an upscaled implementation will use such input.

WP2: Introducing new technologies and implementing IoT in extensive agricultural monitoring
In the WP2, we propose to introduce IoT-based agricultural monitoring with the help of drones and sensor networks. We will select the installation locations based on the pre-project stakeholders meeting outcome.

Drone based Agricultural Sensing
The aerial UAV based sensing component (Fig. 6) of the project would involve flying of multi-rotor UAV equipped with sensors over the target area to collect relevant data about soil moisture, stress, etc. The use of UAV offers more flexibility of operation as it can collect high resolution data on demand, at almost any time of the year as compared to satellite data.

The UAV will cover the target area using autonomous navigation schemes for complete area coverage, and a flight team consisting of a pilot and technician will be present on ground to take control in case of emergencies. The flight team will operate the drone, collect the data and back it up at a central data storage facility for further analysis.

The current plan is to conduct aerial data recording operations for 120-150 days in a year, with a focus on the crop season. Per day the aerial missions can cover around 20-30 acres of land in a flying time of 5-6 hours. The initial focus would be to cover the area of 1-2 villages in a tehsil. Data analysis will be offline as it would require considerably more time than the data collection.

Parameters such as soil moisture, temperature, crop water stress, etc. will be measured or inferred from data collected by the sensors on the UAV. The sensor package could include multispectral cameras, hyperspectral cameras, L-band radiometers, etc. The mission parameters such as flight altitude and speed of the drone will depend on the sensor package used, and data resolution and rate requirements posed for aerial sensing applications.

The initial months of the project will be utilized to set up the software and hardware infrastructure for the drone flights as well as conducting field trials for efficient data collection. Some flights will also be carried out in areas equipped with the in situ sensors in order to correlate the aerial data with the ground sensor network and validate the AI-ML pipelines used for processing the data collected.
It is noteworthy that the drone based survey will provide the baseline data prior to modeling and will give us information about uncertainty of soil moisture within a farm. Such uncertainty information will be considered in the optimization framework of WP5. The drones will not be used on a regular basis because of its cost and through experiments we will come up with guidelines for cost-efficient optimal use.
There are certain regulatory requirements that need to be fulfilled for flying drones for various applications. In accordance with the criteria set forth by the Indian Government, the Ministry of Civil Aviation (MoCA), and the Directorate General of Civil Aviation (DGCA), a drone equipped with a sensor payload would weigh a few kilograms and would fall into the following classification bracket: Small Drone: Greater than 2 kg and less than or equal to 25 kg. A small drone may not fly higher than 120 meters above ground level or faster than 25 meters per second.
To operate such a drone prior approval from the Digital Sky online platform would be required. To obtain this approval, a certificate of airworthiness must be obtained from the Quality Council of India or from an entity approved by the Quality Council of India. Also, a unique identification number (UIN) must be obtained from the DGCA and should be attached to the UAV before operating it.
The operator must hold a remote pilot certificate to operate the drone. This certificate is obtained from the DGCA for a fee after receiving a certificate of training and a skill test report from an authorized training provider. The operator should also adhere to the drone flying zone restrictions for the operating airspace and should have sought prior operating permissions for the same. We will follow all the Government guidelines for this WP.

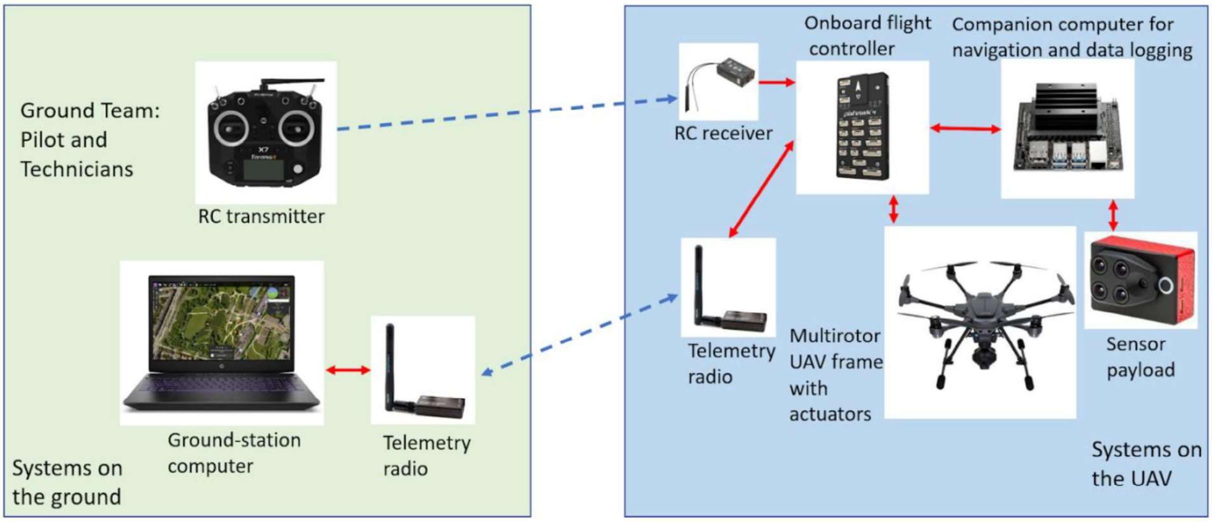

Figure 6: Drone based Agricultural Sensing

Soil Sensor Technology and deployment

Soil moisture content plays a vital role in soil chemistry, plant growth, and groundwater recharge. Water in the soil serves as a critical nutrient, an essential component for photosynthesis, and a carrier of soluble food nutrients. The soil moisture can be measured with the help of proximal soil sensors. They are based on the capacitive measurement technique wherein permittivity of the soil has been measured by the charging time of the capacitor that is formed by two electrodes/probes of the sensor with the soil as medium. Accordingly, The soil moisture is monitored by the sensors.

Soil temperature is the key factor that affects the growth of the crops, fertilizer decomposition, formation of microclimate inside soil and accumulation of organic material. The soil temperature sensors work on the principle of the thermistor. They are specially packaged and sealed to work in the underground environment. The factors affecting soil temperature include solar radiation, the water content of the soil, bulk density, slope of soil, etc.

The dielectric permittivity of the soil is the ability of the soil to hold the electric charge. It can be measured with electromagnetic sensors. The permittivity of soil depends upon in-situ soil particles, water content, and temperature. With the increase in soil temperature, molecular vibrations will increase, impeding the rotation dipole moment of water molecules present in the soil. Thereby, the dielectric permittivity of soil decreases with an increase in the soil temperature.

Considering the spatial variability of soil condition (moisture, temperature, electrical conductivity), and the type of crops, sensors will be installed following the maximization of entropy principle. This will further consider constraints on deployment (in terms of permissions, cost, etc.), and farmers' willingness.

There are two types of methods used for soil moisture measurement Capacitive or Frequency Domain Reflectometry and Time Domain Reflectometry (TDR) with accuracy level 3% and 1% respectively. Given there are multiple sources of uncertainties in the entire project process, such a little difference will not matter in the final decisions. Considering the cost we will first use capacitive method and if needed will switch to TDR. The whole objective is to obtain a cost-effective sustainable solution through combination of different approaches.

Sensor Networking

Precision agriculture requires the deployment of many sensors that monitor various parameters to produce information, which is used to enhance the soil health and productivity. Such a large information system generally aggregates data from several sensors to produce timely alerts to the farmers. To make this system affordable, it is necessary to reduce the cost of these deployed sensors. However, the low cost sensors usually are very simple devices that monitor a given set of parameters with neither the ability to coordinate with other sensors nor process their own information. Instead, a central processing system, which is usually located in the cloud, is employed where different artificial intelligence models are used to transform a given set of data points to feed into the merged monitoring system (WP3). This architecture requires a wireless network infrastructure that can transfer information from individual low cost end devices to the cloud. Since the communication range of the end devices is limited, we generally employ a gateway router between end devices and cloud. The Low Power Wide Area Networks (LPWA) can be used for connecting a large number of end devices to the cloud. These networks enable low power devices to transfer data at lower data rates to longer distances (a few kms and tens of kms in urban and rural areas respectively). Several LPWA technologies exist, whereas some of them are proprietary (LoRa, SIGFOX, INGENU, TELENSA), the others are open source (NB-IoT, LTE-M from 3GPP). However, the proprietary technologies have the advantage of being readily deployable. One potential realization of the deployment of sensors and wireless networks is shown in Fig. 7. Each sensor station has several nearby sensors and a transceiver. The sensors may be deployed on or near the station (a few meters from). Each transceiver located on a sensor station can communicate with gateway routers, which can be deployed on the ground and can store data, which in turn can be transferred to the cloud.

A reliable, scalable and deployable solution must provide accurate, rugged and cost-effective option. We propose to use FDR based technology for the soil moisture measurement sensors and LoRa based communication technology to provide a realistic solution for deploying the technology.

With the choice of cost-effective sensors though less accurate (capacitive or FDR based) as compared to the TDR based sensors, we would rely on AI/ML methods for data analysis for improvising the accuracy of sensor set-up. We expect that with the use of cost-effective solution, we would have flexibility of selecting replacement of sensors instead of servicing in case of faults occurring over time. Moreover, exploring a cost-effective solution is worth investigating due to its advantages in facilitating scalable solution for customers. Based on the results of the initial experiments on achieving desired accuracy we will investigate the desired outcomes with another type of sensor.

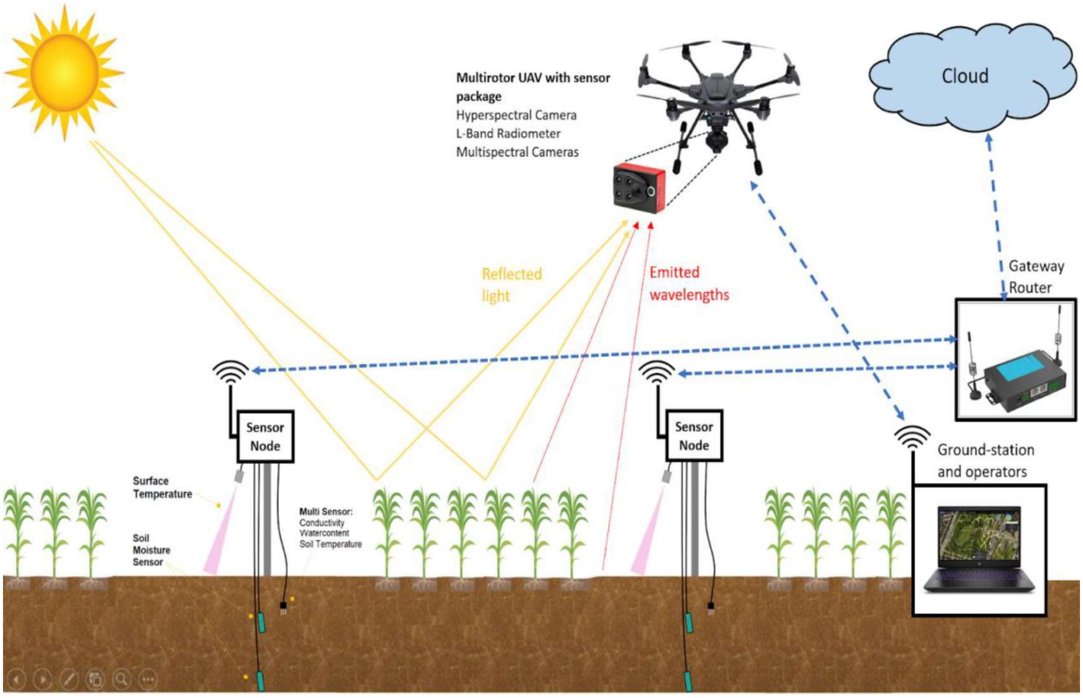

Figure 7: Proposed IoT based Monitoring with Sensors and Drones

WP3: Merging multi-source data for the generation of an agricultural map and soil moisture map

Soil moisture is estimated using in-situ sensors, hyper-resolution models (WP4), drone-mounted sensors, and satellites. Each of these sensing systems has its own limitations with respect to spatiotemporal resolutions and overall accuracy. In-situ sensors provide the most accurate information on soil moisture variations at the field scale. However, there are operational constraints to setup in-situ sensors everywhere. Besides, drone-based information provides soil signals from a slightly larger area, and satellites provide information in the order of kilometers. In order to support irrigation water management at field scales with larger spatial extents, there is a need to utilize the strengths of each of the measurement systems by merging the local-scale soil moisture (in-situ and drone-based outcomes) and regional-scale soil moisture (satellite and land surface model-based outcomes). This process would ensure reliable soil moisture observations at the field scale, which can be further used in ecohydrological models to prepare farm-scale irrigation outlook. Through this objective, we plan to collect data using the abovementioned sensing systems independently and later develop algorithms that would utilize the strengths of machine learning for merging soil moisture data collected at different scales.

Typically, satellite sensors can be used to estimate SM in microwave frequencies using radars (active remote sensing) or radiometers (passive remote sensing). Radars are capable of providing information at fine spatial resolution to estimate soil moisture. However, as a tradeoff, the temporal resolution and accuracy gets compromised significantly. Low frequency radars have a revisit time of around two weeks, which is too coarse for short-term agricultural water management purposes. Moreover, the impacts of soil roughness is more prominent in radar signals, which interfere with soil moisture information. In this context, passive microwave sensors offer potential solution to provide soil moisture information at finer temporal scales. Figure 8 depicts the average soil moisture variations in each month in Satara district. Maps are prepared using Soil Moisture Active Passive (SMAP) radiometer enhanced 9 km soil moisture product. The spatial variations depict the impact of monsoons in the district, wherein the western part, which is a forested region, while the eastern part including Man taluk is predominantly dry throughout the year. It may be noted that SMAP product has the ability to capture the changes in soil moisture patterns due to precipitation as well as human influences although the resolution is coarse. To depict the coarseness of the dataset, Figure 9 presents the soil moisture pixels over Man Taluka. Although the taluka is around 1400 km^2, only a few pixels encompass the region, typically one pixel covering multiple villages together. Given the spatial variations in the land cover, soil texture and agricultural practices, there is a need to estimate soil moisture at finer spatial scales.

Radiometers, either mounted on satellite or drone, provide brightness temperatures. In low frequencies, brightness temperature variations are sensitive to changes in dielectric properties of soil, which in turn are influenced by the changes in water content of the soil. A radiative transfer model is a physics-based scheme that simulates brightness temperatures as a function of soil dielectric and soil temperatures. Retrieval of soil moisture from brightness temperatures of passive microwave sensors involve inversion of radiative transfer model to estimate soil dielectric constant and using a dielectric mixing model to estimate soil moisture as a function of soil dielectric constant, and soil texture information. The radiative transfer models also have parameters to represent effects of scattering of electromagnetic radiations due to soil roughness and vegetation structure. The structure of the radiative transfer model and its parameterizations results in notable errors in soil moisture retrievals (Konkathi& Karthikeyan, 2022). Through this project, we aim to develop retrieval algorithms that would suit the study region. With certain modifications the developed algorithms can be used with both drone-based and satellite measurements.

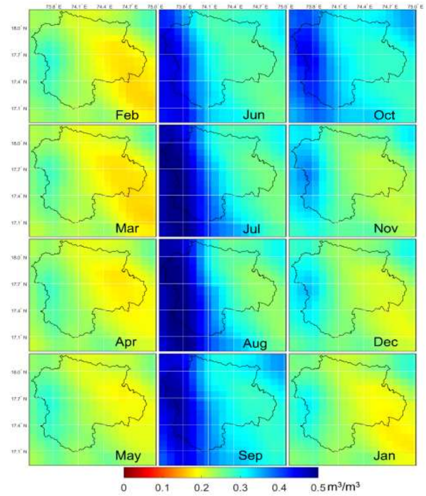

Figure 8. Spatial maps of monthly average soil moisture from SMAP at 9 km resolution over Satara district, Maharashtra

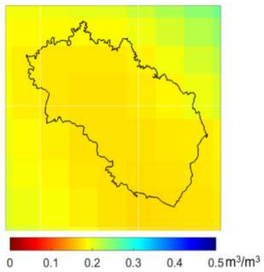

Figure 9. Average soil moisture during March month in Man taluka, Satara district, Maharashtra

Few attempts have been made to obtain high-resolution soil moisture (SM) by merging from multiple sources. Research in the past focused on merging SM from these sensors by recognizing their merits (Tomar et al., 2016;

Das et al., 2017; He et al., 2018; Sure & Dikshit, 2022). Besides, efforts have been made to simulate high-resolution SM using a land surface model and data assimilation (Nayak et al., 2018). Attempts have been made to obtain high-resolution SM using fine-scale optical and thermal satellite sensors (Wei et al., 2019; Fang et al., 2018). The use of optical sensors is hindered by the presence of clouds, which makes SM downscaling techniques challenging. Recently, ML algorithms have become popular for retrieving SM at high resolution. These algorithms primarily map the coarse resolution satellite SM and ancillary geomorphological and environmental variables with in-situ SM measurements (Abbaszadeh et al., 2019; Karthikeyan & Mishra, 2021, Fig 10).

In this method, we shall first collate the in-situ SM data, crowdsourced data (from farmers), drone-based soil moisture, and new soil moisture probes that shall be installed as part of this project. Soil moisture estimated using in-situ sensors, drones, and satellites will have contrasting spatial support. So, a systematic data acquisition process shall be designed to establish synergy between the three sensing systems (Fig. 11). Based on the heterogeneity of the crop type and soil texture in the study region, in-situ soil moisture sensors shall be installed at strategic locations. Later, the drone-based acquisitions shall be carried out in proximity to in-situ sensor locations to ensure maximization of the spatial extent of observation-based soil moisture. The in-situ and drone-based soil moisture shall be merged to create unified observational data. Later, satellite data (obtained from Soil Moisture Active Passive (SMAP) sensor) along with in-situ/drone-based observed soil moisture shall be used to predict soil moisture at ungauged farm sites. For this purpose, we shall use climate (precipitation and land surface temperature), vegetation (Normalized Difference Vegetation Index – NDVI, Enhanced Vegetation Index – EVI, Gross Primary Productivity – GPP), geomorphological (soil texture), and elevation information as predictors in a machine learning framework. Similar framework was successfully tested over the Contiguous United States (CONUS) recently, where satellite soil moisture is downscaled to 1 km resolution (from 9 km native resolution).

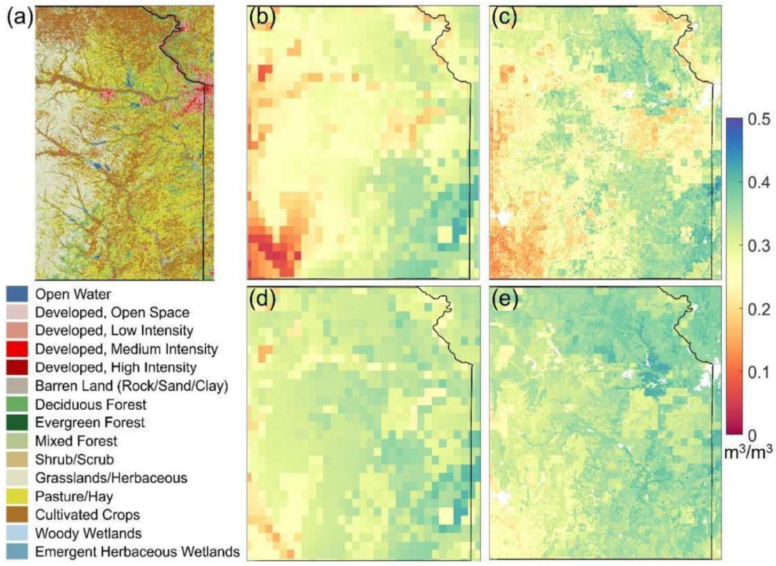

Figure 10. Comparison of 1 km surface and root zone SM maps with SMAP L4 data on 9th April 2015 covering a portion of Kansas state. (a) 2016 LULC map, (b) SMAP Level 4 9 km surface SM (0–5 cm), (c) Predicted 1 km surface SM, (d) SMAP Level 4 9 km rootzone SM (0–100 cm), (c) Predicted 1 km rootzone SM (Karthikeyan & Mishra, 2021).

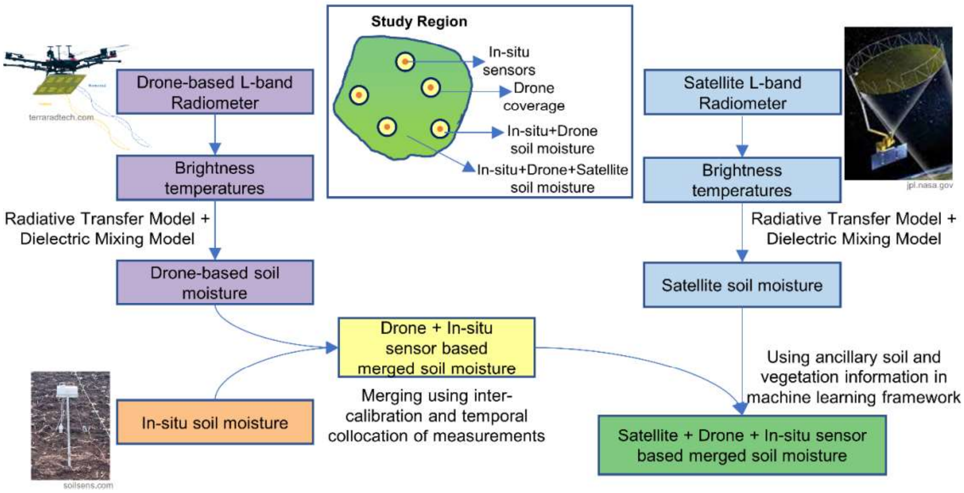

Figure 11: Schematics of WP3

WP4: Hyper-resolution climate and hydrological modeling

One of the major gaps between the improved weather forecast system of IMD and farmers is the mismatch of resolution. The finest IMD forecasts are available at 12km resolution, whereas a typical agricultural farm has a size of 50mX50m. Based on our experiences and interactions with farmers from another district of Maharashtra, Nashik, we found that the farmers regularly receive the agricultural advisory from IMD, but they are clueless on how to apply such advisories for their irrigation management decisions. This can be resolved with hyper resolution climate and hydrologic modeling (Figure 12).

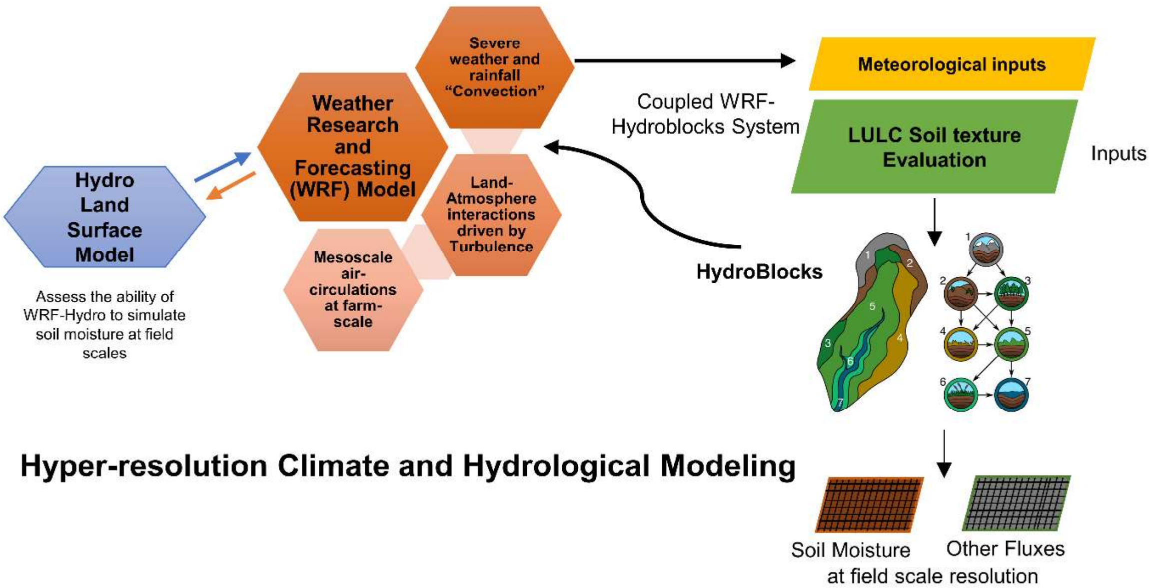

Figure 12: Schematic of WP4

The hyper-resolution climate information will be achieved with the Weather Research and Forecasting (WRF) Model with Advanced Research WRF (ARW) (Skamarock et. al., 2019), which is a limited-area, non-hydrostatic mesoscale model with terrain following eta-coordinate system (Lo et. al., 2008). WRF serves the research and operational needs such as numerical weather prediction (NWP), data assimilation, and parameterized-physics research. WRF uses dynamical downscaling, producing high-resolution outputs for a specific area by using coarse resolution data from the General Circulation Model (GCM) as boundary conditions and combining physical principles associated with continuity, momentum, and thermodynamic processes (Le Roux et. al., 2018). Due to the high spatial resolution of the WRF model, the surface characteristics, such as topography and land use, are better represented, and the WRF model directly resolves mesoscale atmospheric processes such as tropical disturbances or orographic effects (Maraun et al., 2010; Rummukainen, 2010; Böhner& Bechtel, 2018). The WRF model domain will be centered over the Satara district (17°N, 73°E) with three nested domains (D1, D2 and D3) with horizontal grid-sizes of 9km, 3km and 1km with each domain involving 100x100 horizontal grid points and 64 grid points in the vertical. We will perform both one way and two way nesting to test their performance in resolving the dynamical feedbacks and resolving the spatial structure of soil moisture and other parameters. Imposed boundary conditions will be updated every 3 hours using ERA5 reanalysis data, from the European Centre for Medium Range Weather Forecast (ECMWF). The timings and length of the simulations will be decided to align with the observational datasets.

The atmospheric component of the WRF model offers several physics options that involve different parameterisations for microphysical processes, boundary layer turbulence and atmospheric convection. This study will use physics options involving the Rapid Radiative Transfer Model (RRTM, Mlawer et al., 1997) with Lin microphysics scheme (Lin et al., 1983). The control simulations will be set with the Betts-Miller-Janjic (BMJ) cumulus parameterisation (representation of convection in storms and rainfall Janjic, 1994) and Yonsei University (YSU) planetary boundary layer turbulence scheme (Hu et al. 2010). An additional set of sensitivity experiments with other turbulence and convection parameterisations will also be performed to select the physics-suite with the best ability to perform over the study region. To better represent the land surface interactions and feedbacks in WRF, a hydrological model is integrated into the WRF model resulting in the WRF-Hydro scheme (Gochis et al., 2015). Although this model accounts for lateral land surface flows, its utility for high-resolution agricultural applications is yet not explored.

We also propose to use statistical downscaling using weather generator and transfer functions. The objective is first to obtain the relationship between large scale circulation and local rainfall, and temperature. The relationships are then applied to the large scale forecasts to obtain farm scale information. Weather generators typically generate a sufficiently large number of ensembles for performing uncertainty analysis.

Soil moisture plays a critical role in accurate irrigation water management activities. Typical Land Surface Models (LSMs) such as Variable Infiltration Capacity (VIC) and Modern-Era Retrospective analysis for Research and Applications (MERRA) are intended for macroscale applications such as basin hydrology and climate change. However, these models are not appropriate for finer-scale agricultural applications, where soil moisture heterogeneity should be accurately modeled. Literature suggests varying controls of soil moisture concerning changing spatial scales. While meteorological forcings largely control soil moisture at macro-scales (e.g., watershed scale), it is influenced by soil texture properties at a finer resolution. Soil texture plays a vital role in manipulating the soil hydraulic conductivity and consequently, the lateral movement of water in the soil. Therefore, for farm-scale applications, a hydrological model should account for vertical and lateral movement of water in the soil accurately.

HydroBlocks is one model that accounts for the water, energy, and carbon balance to simulate land surface processes at hourly temporal and spatial resolutions as high as 30 meters. HydroBlocks is a fusion of two models, Dynamic TOPMODEL and Noah-Multi Parameterization (Noah-MP). While improving the spatial heterogeneity and representing sub grid level interaction between the land surface components, it is also necessary to keep a hold on computational time. A fully distributed model can resolve the land surface process at fine-scale but it may also be computationally expensive. Thus, it also requires some level of approximation so as to have a tradeoff between the efficiency of the model in simulating land surface process at fine resolution and minimum computational time. HydroBlocks clusters hydrologically similar areas based on proxies for drivers of spatial heterogeneity like NDVI, permeability, accumulation area, location details, etc. into the Hydrological Response Unit (HRU), clusters of similar hydrologic classes, shown in Figure 13 using K-means clustering technique. In other words, HRUs are points in a watershed that exhibit hydrologically similar properties. HydroBlocks thus employs Noah-MP in an HRU framework to give soil moisture details at fine resolution.

TOPMODEL, a hydrological model developed by Beven and Kirkby (1979), is one of the earliest models which uses topographical data in formulating the model. Over time, many updates have been released for the model and it has gained popularity as a rainfall-runoff model and found applications because of its simplicity and open-source code. The Dynamic TOPMODEL deploys kinematic wave routing for subsurface flow between hydrologically similar points. The new update has diluted the original TOPMODEL assumption of aggregating hydrologically similar points only through a single parameter called topographical index. Instead, any hydrologically significant parameters that define the spatial characteristic and take account of the effective upslope contributing area can be used for grouping (Metcalfe et al. 2015).

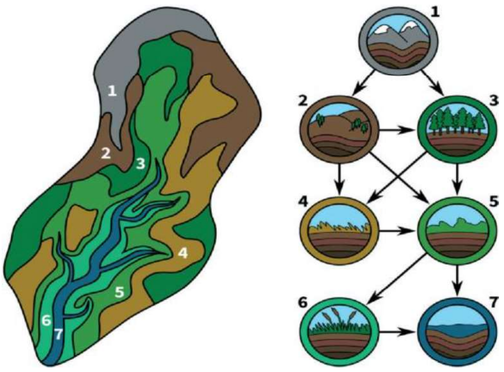

Figure 13: Interactions of HRU and representation of spatial heterogeneity in HydroBlocks (Chaney et al. 2016a)

Noah is a community land surface model developed jointly by National Centers for Environmental Prediction, Oregon State University, Air Force and Hydrology Lab – NWS. It is coupled with atmospheric model Weather Research and Forecast (WRF) and has found wide applications. The Noah version 3.0 computes energy fluxes over the surface model after considering a single combined layer for vegetation and soil surface. As LSMs includes representations of a greater number of physical, chemical and biological processes in the land-atmospheric interactions; an inclusion of all the parameterizations in a single model was not implemented before the development of Noah -MP (Niu et al. 2011; Yang et al. 2011). The Noah MP is an upgradation to Noah LSM with an inclusion of multi physics options. The Noah-MP materializes the idea of a single model for ensemble forecasting and resolves some of the limitations of Noah LSM. A separate layer for vegetation canopy and thereby computing fluxes for canopy and ground surface separately.

HydroBlocks require information on soil properties, including clay content, sand content, and organic matter, along with the land cover and elevation data to simulate soil hydraulic parameters. Figure 14 presents the land use land cover map of Satara district for the year 2020. It may be noted that the district is predominantly covered with crop lands followed by rangelands and built-up area. In addition to the above inputs, model requires meteorological inputs of rainfall, 2-m air temperature, longwave radiation, shortwave radiation, wind, surface pressure, and specific humidity to resolve vertical hydrological processes. We will attempt to utilize globally available soil and meteorological datasets to set up the model to verify their quality. Emphasis will be laid on the surface and rootzone soil moisture simulations obtained from the model and assessing their utility in irrigation water management. Given the ability of Hydroblocks to simulate farm-scale soil moisture accurately and the WRF-ARW to resolve mesoscale weather processes, a fusion of these two models could potentially produce accurate farm-scale forecasts that can be utilized for irrigation water management. To the best of our knowledge, this would be the first attempt wherein such a fusion shall be carried out, especially in Indian conditions.

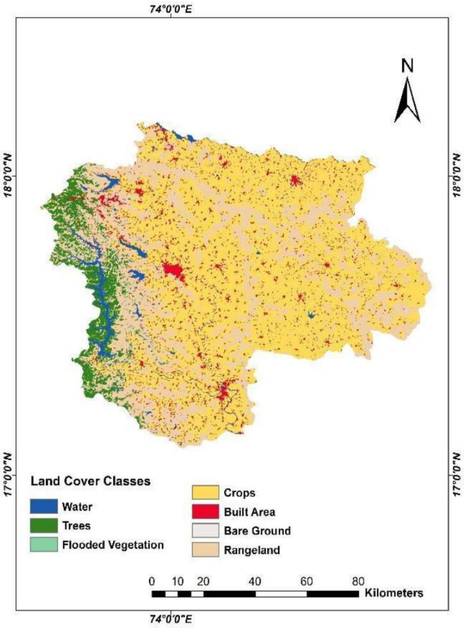

Figure 14. Land Use Land Cover (LULC) map of Satara district.

WP5: Farm scale optimization for irrigation water management

IMD weather advisories are released regularly; however, the challenging task for the farmers is to convert the advisories into a decision model considering present soil moisture, plant needs, and uncertainties associated with the forecasts. Our discussion with farmers of Maharashtra revealed that farmers need to make two decisions for irrigation. The first one is to identify the exact amount of required irrigation at the farm, and the second is to make arrangements for water, well in advance by understanding the details of application amount and frequency for the next 2-3 weeks. The amount of irrigation should be optimum to minimize water use without any loss in the yield. The weather forecasts (1-7 days) help in deciding the irrigation application amount, and the extended range predictions (2-4 weeks) help us in making water arrangements well in advance (Fig. 15). Both of these are currently available by the IMD; however, the farmers are not aware how to translate them into farm scale water management decisions, given the existing uncertainty, bias and inaccuracies in the forecasts/ predictions. The other key issue is to convert meteorological information into decision-ready fine resolution hydrological information within a short time (few hours). The short time availability between the release of forecasts and the actions has always remained a major issue, that is needed to be resolved with innovations ideas during the applications.

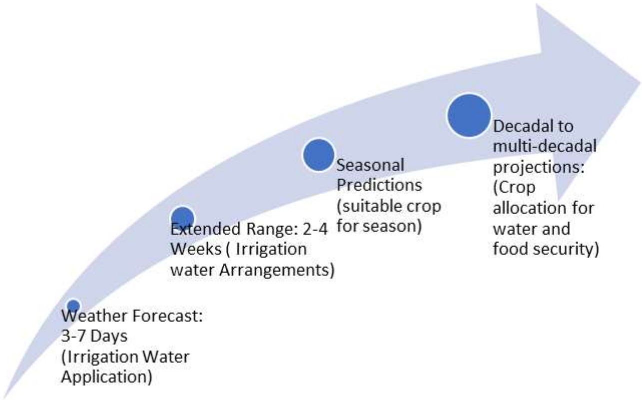

Fig 15: Different Scales of Forecasts/ Predictions

While the WP4 provides the fine resolution information, conversion of such information into decisions needs to address uncertainties and inaccuracies. Our past experience of working with the farmers of another district in Maharashtra, Nashik, resulted in the development of technology for irrigation decision tools (Roy et al. 2020). The core component of the technology is a stochastic optimization that minimizes water application with no water stress assurance with a probability value given by the users (Fig. 16). The stochastic component comes from the uncertainty in the rainfall. We considered the distribution of rainfall given a forecast and generated multiple rainfall values as a part of Monte Carlo Simulations within the optimization. Such a stochastic framework took care of uncertainty in the forecasts and made sure that the water-stress was minimized.

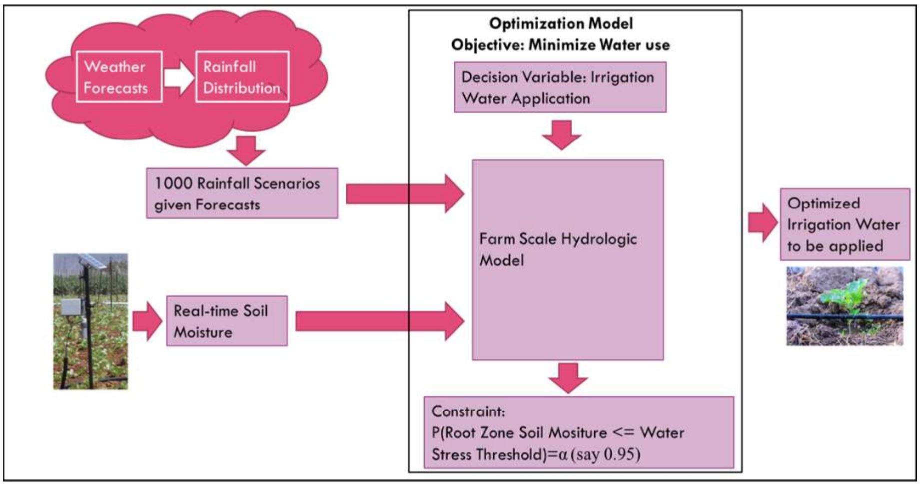

Figure 16: Weather Scale Irrigation Decision Tool

Such a framework can be extended to 2-4 weeks if we generate a series of weather data using a weather generator and consider probabilistic constraints. The other challenge is that we cannot have sensors in all the farms due to limitations posed by the cost. Hence there is a need to merge datasets from multiple sources. The merging will come from WP2 and WP3, which will be fed into the present WP. The resulting advisories will be disseminated through WP9.

WP6: Participatory modeling and resolving field scale implementation challenges

Most times agricultural advisories are not well employed by farmers, due to less representativeness, capacity to understand and lack of preparedness to climate change extremes e.g. floods and droughts (Dheebakaran et al., 2020; Heath et al., 2020) and the data that drives these models. These advisories mostly follow the top-down approach with advisories coming from the government agencies, while on the ground adapting to them may be difficult/not available. It is also necessary to create feedbacks from the farmers on these advisories to the supplying agencies, so that the advisories may be improved. Such infrastructure is not available widely, however can be integrated with ongoing initiatives such as Smart Village and Pradhan Mantri FasalBima Yojana. This can also lead to improved selection of climate change adaptation and mitigation measures at the village scales (Lacombe et al., 2019). Interventions and adaptation measures are more needed during irrigation seasons (non-monsoon/ Rabi/ late Kharif periods when surface water is limited) as groundwater has been depleted considerably for supporting crops during climate change extremes (Chinnasamy et al., 2021).

As a result the farmers are moving away from State and Central weather advisories as they are not reliable or lack the ground reality. Since they are the key stakeholders, it will be apt to have them on board while data collection is done (as a PPP approach) and engage in water management plans and infrastructures which will again be monitored using the PPP framework. The major objectives in this work-package are to support farmers with localized water availability information through smart metering and monitoring, to empower farmers in making decisions on crop type and crop acreage for current water availability, to identify/test suitable climate change mitigation and adaptation management plans that can increase crop productivity and crop yield and test their efficiency on the field.

Moreover, the current management scenarios are reactive and never solve the core issue. For e.g. in Fig 17, there is a serious issue on groundwater depletion. In such a scenario the natural tendency is for the government to approach the banks and get short term reliefs such as rationing of water, bringing water through the trains etc. What can aid in such a scenario is to create a Public Private Participatory (PPP) approach that can aid in data collection through smart tools. This can then be combined with other observational data and satellite data to arrive at long term sustainable solutions. Such data collection can lead to improved representativeness of the climate change extreme scenario and also aid in creating ownership among farmers that can use this data individually for their cropping patterns. This process is aimed to be cyclic and dynamic in terms of getting in field measurements to update the models for advisories and in aiding to improve the efficiency of the management plans. The participants will also form a group of trainers for using training materials for other stakeholders.

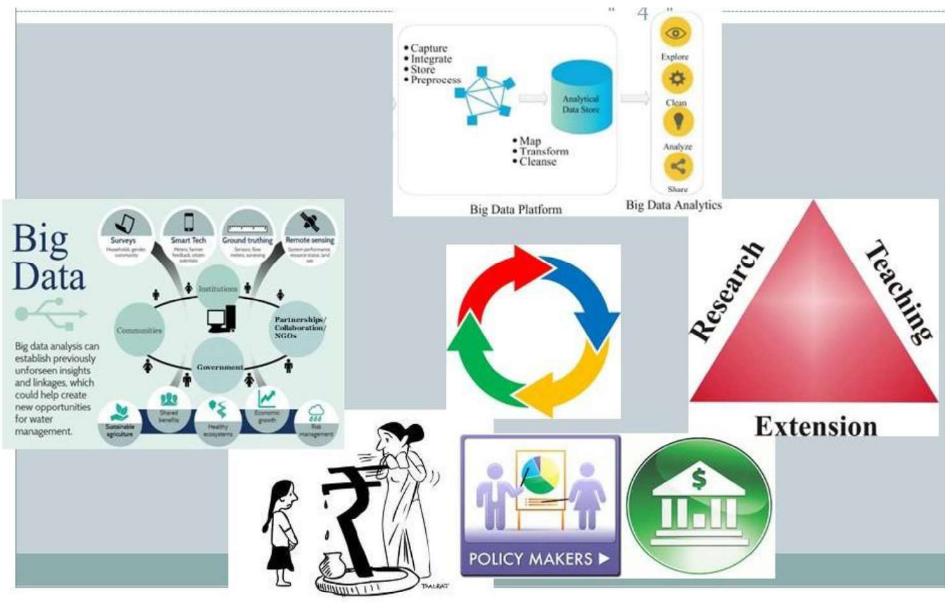

Fig 17: Public Private Participatory Approach for agricultural management

Method: Forming Climate Smart Farmer Groups:

The proposed project aims to start with providing better climate advisories to farmers, better assessments of their supply side (surface and groundwater availability), leading to improved decision making by Climate Smart Farmer groups for crop type, crop acreage and irrigation method. Based on the above advisories there is a need to understand total water available for the upcoming cropping season. In this project section, this is achieved by monitoring and mapping surface and groundwater resources using near sensing (sensors), crowdsourcing (surveys and app-based devices) and remote sensing (satellites and drones). Data collected from these platforms will be fed into site-specific hydrological models to understand the water balance and availability before cropping. In addition, the water infrastructures (e.g. wells, checkdams, canals, etc.) will be mapped and data collected regularly (through low cost intervention methods) to monitor water availability and assess the interactions between climate, land and water.

Capacity building and Improved decision making and management of crops:

The data collection from farmers would require certain capacity building activities. These activities will be included in training programs, through identified village volunteers, and capacity built for proper data collection, data archiving and management. Since the data comes from the farmers, they have more confidence/ownership and leads to better understanding of the issue. With better community information on water availability, the farmers can make communal decisions on what crops and acreage for the village, which can lead to equitable share of water. Also, the Climate Smart Farmer groups (CSF) can use better water saving mechanisms for irrigation. On this note, an increase in crop water productivity is also achieved by using demand side management.

WP7: Agricultural risk assessment and risk minimization

Extreme events such as precipitation extremes, drought, and heat waves are significantly rising, exposing the Indian population to high risk associated with such events. In such a scenario, a proper understanding of the physics behind climatic uncertainty and mapping the associated risks are required to devise appropriate adaptation responses and strategies. Despite proactive initiatives by the Government to communicate weather and management-related information to farmers, climate change impacts are not being given the due attention it deserves. The proposed study focuses on understanding the nexus of climate-hydrology-agriculture and its need to assess climate change impacts on agricultural risk and vulnerability, which encompasses two major objectives.

(1) to simulate a crop model for understanding and assessing the influence of climatic variables on agriculture at a village scale. The crop simulation models have the provision of conveying user defined management practices (including fertilizer, irrigation supply, shift in sowing dates, etc.) as inputs, which can help generate different scenarios that can lead to distinct agricultural outputs, and thus play a major role in developing reliable agricultural management strategies. A framework for deriving a well-grounded risk map by linking climate-hydrology-agriculture is thus essential to help farmers adapt to different top-down approaches and adapt the future climate change impacts on agriculture. The entire Satara district of Maharashtra will be considered as a test bed to demonstrate the proposed unified framework (Fig. 18).

(2) To derive an agricultural risk and vulnerability map (following IPCC, AR5 and AR6 frameworks) with multiple hydro-climatic indicators for both historical and future periods at a village-scale for the entire Satara district of Maharashtra. A data envelopment analysis (DEA) will be performed to map vulnerability in a geographical information system (GIS) framework considering multiple agro-hydro-climatic parameters (Fig. 19). However, the proposed standalone approach will be a generic one, which may be implemented in any district across India.

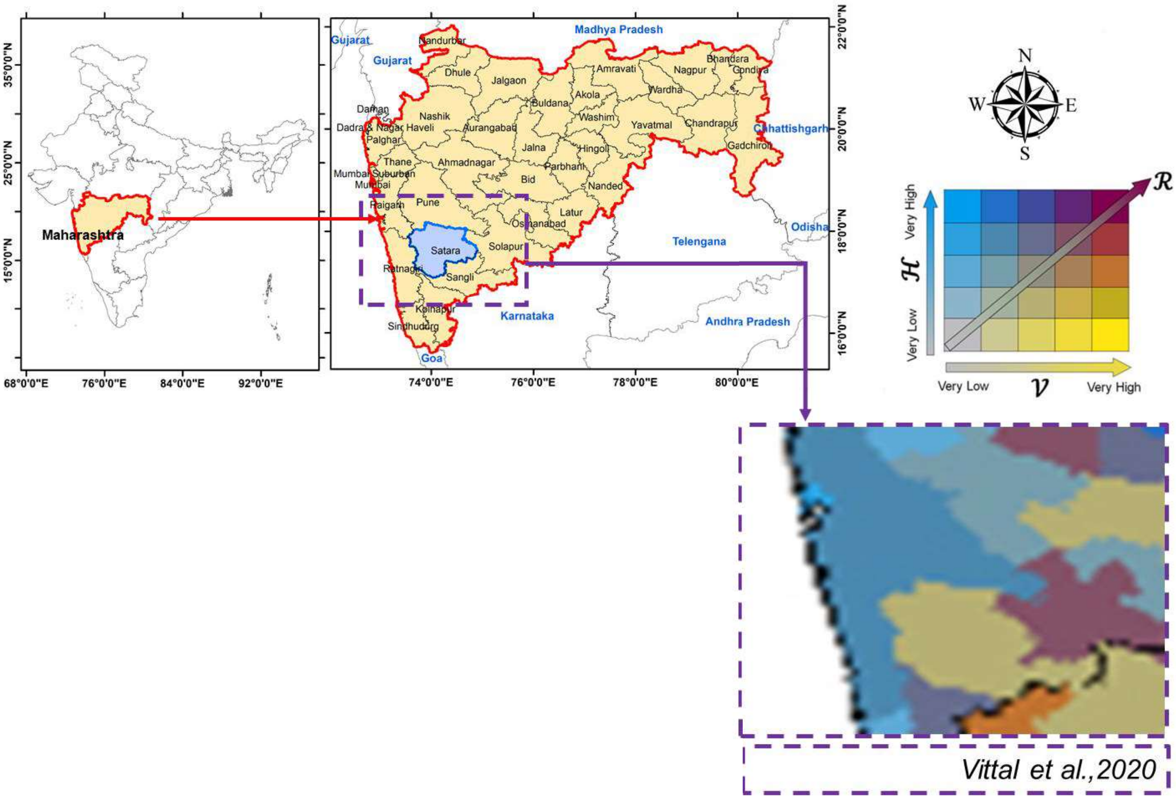

Fig 18: Hazard and Vulnerability Framework for Climate Risk

To assess and map agricultural risk and vulnerability under changing climate, simulated crop yield will be regressed with the simulated hydro-climatic variables (i.e., vulnerability indicators) within a Generalized Additive Model for Location, Scale, and Shape (GAMLSS) framework. An effort will be made to promote a more consistent and transparent application of the concept of climate risk following various assessment cycles of IPCC, i.e., Pre-AR5 (Cardona et al., 2012), AR5 (IPCC, 2014), and AR 6 (Simpson et al., 2021). The overall proposed outcome is a set of risk maps that will aid in identifying and prioritizing the regions more vulnerable to climate change by incorporating the effect of all possible influencing dimensions affecting crop production. This will assist in selecting optimal adaptation strategies to minimize agricultural risk and formulate a long-term adaptation plan for farmers to cope with adverse climate change impacts in the future. In summary, the following tasks will be performed to accomplish the two above mentioned goals:

a. Collection of high resolution socio-economic and agricultural data at high resolution administrative level – collection of socio-economic (and demographic) data from Census of India and field survey. Collection of ground-based data on crop yield, area under crop production, and different management practices of crops over test region, the latter to be utilized particularly for calibration of the crop model
b. Projection of hydro-meteorological variables - statistical downscaling of selected GCMs (based on a comprehensive literature survey) and simulation of the calibrated hydrological model using multimodel ensemble climate projections
c. Development of *Hazard* maps for precipitation extremes, temperature extremes, and drought for observed and projected scenarios
d. Development of *Vulnerability* maps for different crops, considering a suite of socioeconomic, agricultural (including simulated crop yields), and hydro-meteorological indicators

e. Development of *Agricultural Risk* (aggregating *Hazard* and *Vulnerability* components) map for Satara district with univariate and bivariate representations
f. To develop a framework for agricultural and socio-economic intervention guidelines for reducing risk in future
g. New technology evaluations and their possible roles on risk reduction.

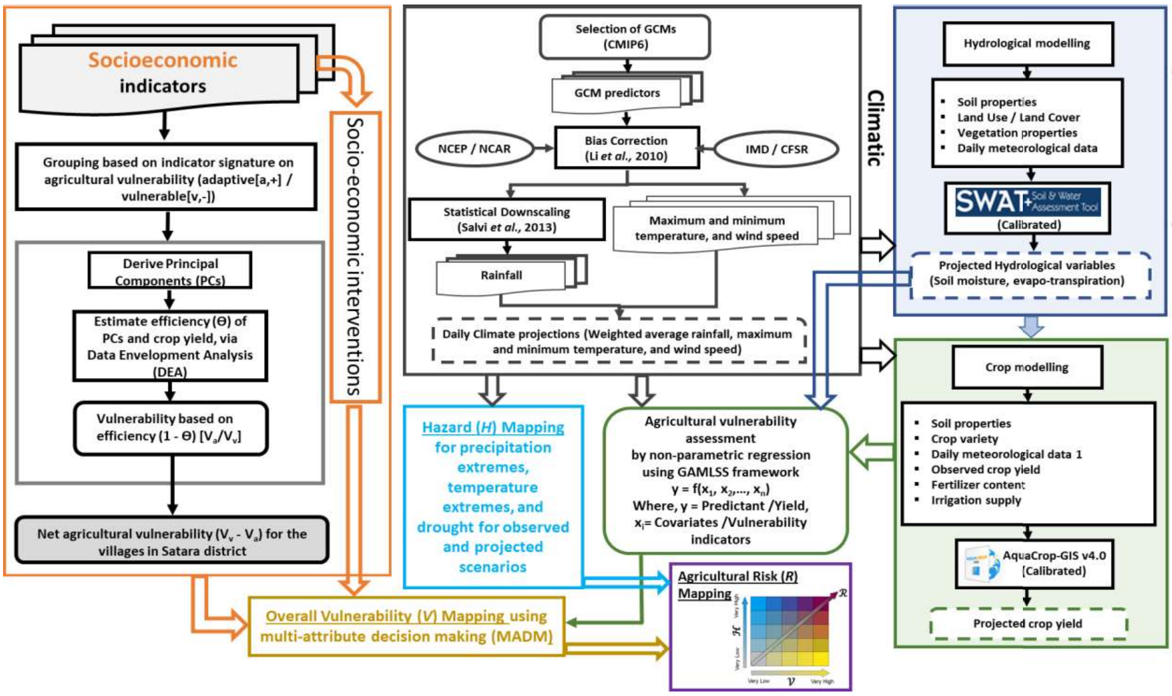

Fig 19: Risk Framework

To accomplish the objectives / goals of this study, we need to select the General Circulation Models (GCMs) from Coupled Model Inter-comparison Project phase 6 (CMIP6) that successfully captures the climate change signal over the entire India. Considering that statistical downscaling has the limitation of the assumption of stationarity, rainfall predictors of the GCMs will be selected such that the predictors essentially carry the climate change signal; hence, it can play a major role in addressing the projections in a nonstationary climate scenario (Salvi *et al*., 2016). The next step in statistical downscaling of rainfall will follow the bias correction of predictors using a quantile-based remapping technique (Li *et al*., 2010) with respect to National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR) reanalysis datasets. These bias-corrected predictors will then be used to regress the rainfall states derived from the India Meteorological Department (IMD) rainfall data using a robust non-parametric kernel regression technique (Salvi *et al*., 2013) to obtain high resolution daily rainfall projections for historical (1979-2021) and future (2027-2053 i.e. 2040's scenario) study periods. For the variables such as maximum and minimum temperature and wind speed, a single step statistical downscaling approach that applies the same quantile-based remapping technique will be used because of their less spatial variability as compared to rainfall; by using IMD maximum and minimum temperature data and Climate Forecast System Reanalysis (CFSR) wind speed data, respectively. Output of this comprehensive statistical downscaling approach will be a set of fine resolution daily scale climatic variables (rainfall, maximum and minimum temperature, and wind speed) for each selected GCM, which will be brought into a single frame by using super-ensemble or multimodel ensemble technique. This will be further considered as inputs for hazard mapping and also a major input to the hydrologic model (SWAT: Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change, https://swat.tamu.edu/). The output from the hydrologic model will be further considered in the crop model (AquaCrop-GIS 4.0: a crop growth model developed by FAO to address food security and assess the effect of the environment and management on crop production. It presents the results in a geographic information system, https://www.fao.org/aquacrop/software/aquacrop-gis/en/#c518674) to derive hydrological and agricultural projections over the study area.

For hydrological projections, a calibrated hydrological model SWAT+ installer 2.1.3 (released 5 July 2022) will be implemented, which has the advantage over other hydrological models of considering sub-grid variability in soil moisture storage and vegetation properties. Calibrated SWAT model will be used to derive hydrological variables such as soil moisture, evapo-transpiration, and runoff, which will be further utilized in different forms as indicators while mapping vulnerability as well as preparing input files for the crop model.

The crop model has the advantages of conveying user-defined management practices, such as fertilizer and irrigation supply, sowing date, etc. grid-wise inputs such as soil and vegetation properties will be used to calibrate the model with respect to area averaged observed yields. This calibrated crop model will be further used to simulate crop yield under the influence of future climate projections.

As already mentioned, the indicator-based vulnerability analysis (Sharma et al. 2020, Vittal et al. 2020) will consider multiple agricultural, hydro-meteorological, and socio-economic indicators. For example, a representative agricultural indicator could be crop cultivable area under different crops, crop type, simulated crop yield. Similarly, ground water level, soil moisture, crop-growth stage-wise temperature requirements, wet spell length, average wet spell length, maximum temperature warm spell length, etc. could be considered as hydro-meteorological indicators. On the other hand, presence of agricultural credit societies, power supply for agricultural use (hours/day), irrigated area by source, cultivator population, number of female and male agricultural laborers, marginal cultivators, marginal labourers are a few representative socio-economic indicators.

To derive agricultural vulnerability map under changing climate, a nexus of agriculture-meteorology-hydrology will be created by regressing the crop model simulated yield for the considered crops with the vulnerability indicators (i.e., agricultural, simulated hydro-climatic, and observed socio-economic indicators). For the purpose mentioned above, a cluster of 74 Generalized Additive Model for Location, Scale and Shape (GAMLSS)-based nonstationary models will be implemented. The GAMLSS provides a comprehensive platform to model nonstationarity, as compared to other additive models such as generalized linear models, generalized additive models, generalized linear mixed models, and generalized additive mixed models, as GAMLSS considers parameters of probability distributions both as linear or nonlinear function of time/covariates (Singh et al., 2016; 2020).

Understanding the interlinks between agricultural, climatic and socioeconomic aspects is important but also extremely challenging, considering that the projections of socioeconomic adaptation options are riddled with uncertainty. To tackle this challenge, recognizing the differences in the current and future status can enhance the knowledge on possible bottom-up approaches which in turn shall result in reduced adverse climate change impacts on future food security. Various socio-economic information in the form of sensitive indicators (cultivator population, number of female agricultural labourers, number of marginal cultivators) will be modified using a perturbation approach to generate a set of crop specific vulnerability maps, which will be further aggregated with projected hazard maps to derive the agricultural risk maps. An optimization exercise with multi-attribute decision making (MADM) approach will be undertaken thereafter to identify a set of optimal socio-economic interventions (say for example, increasing number of female agricultural labourers in a village or converting marginal agricultural labourers to main ones) which will ensure minimization of agricultural risk at village level.

A comprehensive flowchart illustrating the proposed methodology is provided in Fig. 19.

WP8: Future crop allocation to produce more food per drop
Ensuring sustainability of the agricultural sector in wake of climate change impacts is going to be extremely challenging. Here, the role of systematic agricultural planning, relying on scientific fundamentals as well as data-based tools, will be critical. Long term impacts such as changing rainfall patterns and temperatures must be accounted for in strategic planning. The effect of these changes on crop yield, nutrient content, water requirement, and other factors must drive the planning exercise.

The main objective of WP7 will be to develop systems approaches for agricultural planning so as to produce more food per drop and thereby address the food-energy-water nexus. We will be using optimization modeling as the basis for developing the framework. We will develop an optimization model at local/regional scale to recommend optimal agricultural planning so as to achieve certain objectives, such as maximizing productivity, minimizing irrigation water use, or maximizing the nutritional supply. While WP4 will look at short term planning specifically for irrigation, considering the time horizon of days, WP7 will consider factors relevant at longer time horizons for months, years, and decades. Figure 20 shows preliminary work done by use for the state of Maharashtra. In this work, we aim to balance the water consumption and farmer's profit in order to achieve a certain target production of fuel ethanol from agricultural residue. The focus of the proposed work, instead, will be mainly on food production. However, energy component is strongly woven into this issue and hence the problem eventually translates into a FEW nexus one.

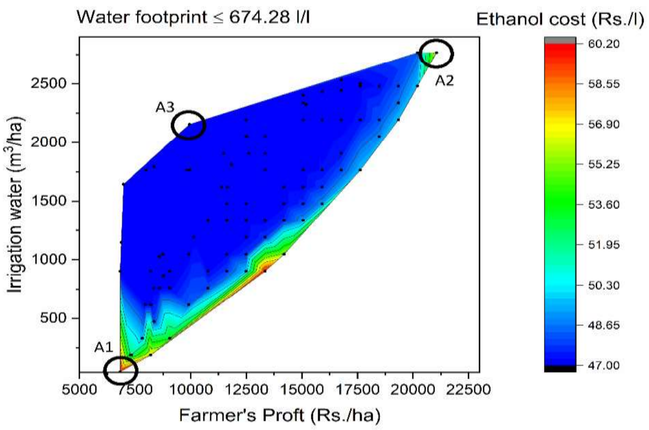

Figure 20: Trade-off between irrigation water consumption, farmers' profit and ethanol cost for a particular bound on water footprint of ethanol. This work has been done for the state of Maharashtra.

This work will build on the data collection and model development work proposed in WP3 and WP5. The important activities to be performed are described below (Figure 20).

1. Scoping of the problem statement: Based on the data collected through WP1, WP2, and WP3, as well as stakeholder engagement in WP5, we will define the detailed scope of the work. While we know that the issue of water availability and water utilization for agriculture is a key issue in the region, we will first understand the specific problems. Moreover, we will isolate problems specific to representative talukas of Satara district.
2. Identification of decision variables: The initial data collection and historical trends will also be used to identifying important decision variables that must be considered for the optimization model. This is very important since the decision variables must be those that can realistically be modified to achieve certain

objectives. This will ensure that the recommendations developed in the end are implementable and actionable.

3. Formulation of constraints, objective function, and deterministic optimization model: We will use climate and crop growth models formulate constraints. For Satara districts, we will use the crop specific water requirement and yield data for this purpose. For the district, we will also collect the socio-economic data such as population, per capita water demand, industrial water demand and so on. This will permit us to formulate the correct constraints for the overall food-water nexus model. Simultaneously, objectives such as farmer profit, irrigation water requirement, and water productivity will be identified. Once all these components are identified, the deterministic model will be developed. Although the model will be based on data collected for the specific region, it will be formulated in a generic manner so that it can be readily applied to other regions as well.
4. Assessment of uncertainties: Future is uncertain and cannot be predicted. Additionally, effects of climate change are expected further exacerbate unpredictability. Therefore, any decision making model for the future must account for these uncertainties. We will assess various uncertainties expected to impact decision making. Uncertainties can be static as well as dynamic in nature. Dynamic uncertainties, which are a function of time, will be relevant for the strategic decision-making model given its focus on long term planning. Dynamic uncertainties could be in the form of rainfall patterns evolving over time or probabilities of extreme events with time. We will use stochastic modelling tools such as wiener process, Ito process and so on to model them. The models will have to be developed based on the detailed climate models to be developed as part of other work packages. In each of these cases, we will first characterize the uncertainties, and the quantify those uncertainties in mathematical form.
5. Formulation of stochastic optimization model: The next stage of the work will focus on developing the stochastic optimization model as an extension of the deterministic model. A typical stochastic optimization problem can be described as:

$$Optimize \quad J = P_1[f(\theta, x, u)] such\ that P_2\big(g_1(\theta, x, u)\big) = 0 P_3(g_2(\theta, x, u) \leq 0) \geq \alpha$$

   a. where, $\theta$is a set of decision variables, x is a set of system parameters, $u$is a set of uncertain variables, and P_1, P_2 and P_3 are the probabilistic measures such as the expected value or variance. The uncertainty may affect the objective function and/or any of the constraints to make it a stochastic programming problem. The decision variables may also be continuous, integers or both. Moreover, the functions f, g_1, and g_2 may be linear or nonlinear.
6. Model simulation and recommendation: The final stage of the work will focus on solving the stochastic optimization problem to develop actionable recommendations. We will also compare the results with the deterministic optimization problem to understand the effect of uncertainties on decision making. The results will be used to determine the value of stochastic solution. The work will also include development of a software tool that can be used to stakeholders. The development of the tool will begin in the initial phases of the project. The tool will be connected to the deterministic problem developed in the initial phase of the project. This will be a useful development since it will allow us to get feedback on the feature as well as user friendliness of the tool. The tool will be refined with the developments in the modelling work (Fig 21). The methodology will also guide the policies for minimum support price of crops which are nutritious but less water intensive.

The specific deliverables of this work package are listed here.

1. **Identification of decision space:** It is likely that certain decisions will be much more critical than others in the context of the objectives, and such decision should be under focus. Using the information and data collected as part of other activities, we will identify important decisions to be considered for decision support tool.
2. **Optimization model for decision support:** The models proposed to be developed will be generic in nature and will be important deliverables of this work. We will focus on two different models at two different scales. The first model will focus on management and operational level decision making, while

the second model will focus on strategic decision making. The models will be developed in a user-friendly manner to aid future extension as decision support tools.

3. **Recommendations for the region under consideration:** The models developed will be implemented for the region under consideration to provide specific actionable recommendations. For the short-term decision making, these models will also be tested with actual data.

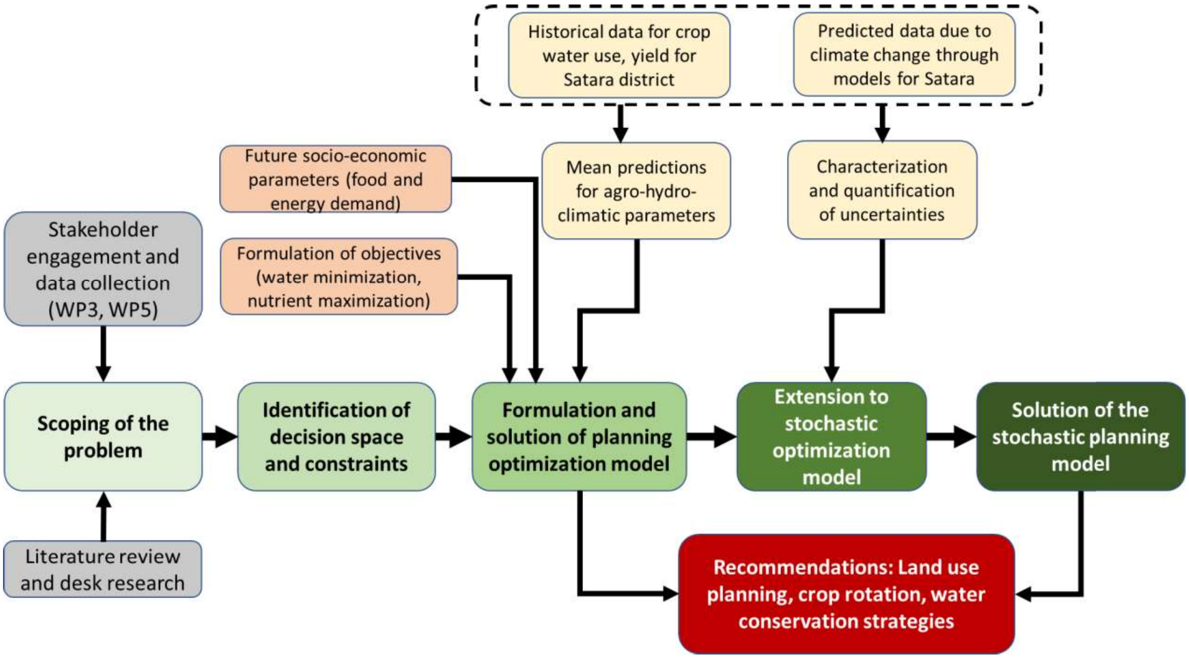

Figure 21: Flow chart of activities for work package 7. The green boxes show the important activities to be performed. The grey, yellow, and orange boxes show the supporting activities that will be connected to other work packages of the project.

WP9: Geospatial portal and app

The proposed activity under WP8 will involve the development of a cloud-based Geospatial web portal and Mobile application of "Climate Smart Agriculture Water Management".

The Proposed system will have the following spatial data layers

a) The Soil moisture, various agricultural data and maps generated during data collection activities under WP2 and WP3.

b) Output maps of Climate and Hydrological model at Hyper-resolution by building hyper blocks under WP4

c) Ecohydrological model outcome that demonstrate Farm level optimization of irrigation water requirement under WP5

d) Locations of key water storage structures Wells, Dams etc. with the information of the water quality, water levels, rainfall collected by means of participatory approach under WP5

e) Maps generated based on agricultural risk assessment under WP7

All the spatial information created from various activities from all the modules will be presented to the end users via a web interface and mobile app through a set of well-structured layers. The set of spatial information will be available at Taluka level and at each Lab parcel/farm level

The development of a mobile app is proposed for the dissipation of spatial and various other information to the users. The farmer can register with the system based on their credentials & details of farm/ land parcel number to

get access of their farm-wise detail of the assessment. The mobile app will also have facility to integrate with SMS gateway to send timely update and information to the farmer
The proposed system will also involve development of a dashboard to highlight key parameters such Soil moisture condition, water saved in irrigation, number of farmer registered.
The data in the back-end server will be updated at regular predefined time intervals in tune with the processing as per respective modules. This will include several raster layers as well as processed tabular information. The vector layer of farms will be superimposed on these layers to provide land parcel/farm wise information.
The proposed system will be developed based on GRAM++ GIS tool and will be hosted on cloud server with following technologies (Figure 22)

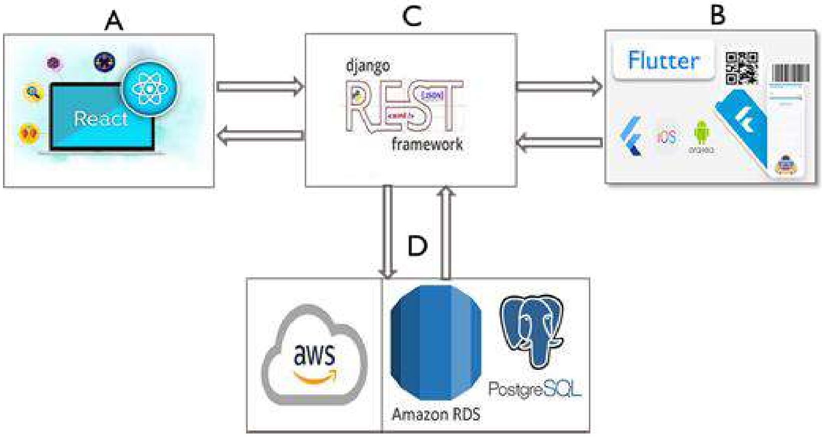

Figure22: Development Methodology

A) Web Application
   - The Web Application User Interfaces will be developed using standard and open-source technologies such as React JS, Node JS, HTML, CSS and Java Script.

B) Mobile Application
   - The cross platform mobile applications will be developed using open source Flutter Framework, and Dart Programming environment.

C) REST API
   - Different levels of Representational State Transfer (REST) APIs will be developed using python Django REST Framework.
   - These APIs will act as a carrier of the client requests and server responses both for Web and Mobile based timber Tracing Applications.

D) Database Server
   - The Database schema will be developed using open source PostgreSQL Relational database and will be hosted on cloud-based Database Service.
   - This schema will contain multiple relational tables associated with one other and will be used to store the operational data of both web and mobile applications.

B. Describe how the project /programme would promote new and innovative solutions to climate change adaptation, such as new approaches, technologies, and mechanisms.

Food energy and water scarcity in a changing climate is not only a problem for India, but a global problem for which solutions remain absent. IPCC AR6 WGII has stated that none of the adaptive approaches either resulted in highest yield or minimum water use. Hence, such a complex problem needs an innovative solution. The food-water tradeoff problem in the Indian context has not been addressed in a participatory framework specifically for vulnerable societies, and hence, innovative solutions are needed in every WPs. Here we list a few of them:

1. Introduction of new technologies like IoT and IoE in agriculture for climate resilience is not cost efficient at present. The sensors and drone-based measurements are expensive. Many farmers in the vulnerable regions of Maharashtra live below the poverty line and cannot afford such high-end technologies. One of the key objectives is to make such an approach cost-efficient with a minimal drone and sensor survey and use available and modeled data through data-driven merging techniques. The design of the whole system of measurement needs innovation.

2. Resolution mismatch is another challenge in converting large-scale coarse resolution forecasts/ predictions/ projections into impact specific fine resolution output. Such transformation can be done with regional modelling, but regional models are computationally expensive. The statistical models are computationally inexpensive and often work well. However, they are not grounded on physics and sometimes fail in a changing climate. There is a need for hybrid modelling where the data driven techniques will be guided by physics-based models. Such an approach is significantly dependent on the sector and the region. It requires novel ideas for the implementation. Time efficient downscaling is another area that needs innovation.

3. Converting climate services to actionable decisions is always challenging, considering the inaccuracies and uncertainties associated with forecasts. We propose to develop a stochastic optimization model-based tool that can be easily operated and consider farmers' feedback and input. The innovative framework will also use hyper resolution model output and merged monitored data. Such a framework is not available at present in literature and will be the first of its kind.

4. The other key challenge is involving stakeholders in the decision-making model or developing a participatory model for climate smart adaptation. This involves out-of-the-box techniques of combining multiple WPs in a unified way.

C. Describe how the project/programme aims to roll out successful innovative adaptation practices, tools, and technologies and/or describe how the project aims to scale up viable innovative adaptation practices, tools, and technologies.

Implementation Plan for the project

The proposed project is a multi-disciplinary multi-institution project. The work packages and the responsibilities of individual institutions are spelled out in Table 1. The connectivity between different WPs are shown in Fig. 23

Table1: Work Package and Participating Institutions

Activities/ Work Packages (WPs)	Institutes
Periodic Project Review by Setting up a Committee: • Periodic review and guidance	• Experts from other Institutes • NABARD • IITB • State/ District Officials (State Agricultural Department, District Administrative Office)
Project Steering Committee: • Project setting up • Project oversight	• NABARD • IITB

• Frequent Monitoring	• State/ District Officials (State Agricultural Department, District Administrative Office), representation from Krishi Vigyan Kendra, Borgaon, Mahatma Phule Krishi Vidyapeeth (MPKY), Rahuri, Satara District Disaster Management Officer (DDMO), Irrigation department officer
WP1: Stakeholders meeting and interactions • Stakeholders meeting • Stakeholders feedback • Implementation involving stakeholders	• SEVA • IITB • NABARD • State/ District Officials (State Agricultural Department, District Administrative Office)
WP2: Introducing new technologies and implementing IoT in extensive agricultural monitoring • Installation of Sensors • Drone based monitoring • IoT network for monitoring	• TIH • IITB • SEVA
WP3: Merging multi-source data for the generation of an agricultural map and soil moisture map • Satellite data retrieval • Merging multisource data • Generating soil moisture map	• IITB • TIH
WP4: Hyper-resolution climate and hydrological modelling • Downscaling • Statistical dynamical modelling • High resolution hydroclimate modelling	• IITB
WP4: Farm scale optimization for irrigation water management • Use of forecasts • Addressing uncertainty/ inaccuracy • Converting into irrigation decision model	• IITB
WP6: Participatory modelling and resolving field scale implementation challenges • Participatory model development • Community approach • Involving stakeholders	• IITB • SEVA
WP7:Agricultural risk assessment and risk minimization • Climate agricultural risk framework • Hazard • Vulnerability • Socioeconomic Interventions • Technology Evaluation on Risk	• IITB
WP8: Future crop allocation to produce more food per drop • Food & water management • Crop switching design • Optimization for multiple objectives • Water use minimization, maximizing nutrition	• IITB

WP9: Geospatial portal and app • Output and information dissemination • Geospatial portal • Apps for the farmers	• Bhugol GIS Pvt Ltd • IITB

The strong connections between the work package suggests that we propose a wholistic approach within continuous interactions between the sub-parts. The implementation has to be cohesive and hence, we propose participation of different institutions with different expertise. For a timely review and improvements of our contributions, we propose to have a project review committee with annual meetings. There will be half-yearly project steering committee meeting to make short term plans for the progress. Stakeholders will be invited to participate in these meetings for their feedback. In parallel the project team periodically meet the farmers for training, and feedback. A continuous training-feedback process bind the investigators and the stakeholders into a single team to make the agricultural practices of Man and Khatav sustainable.

Scaling Up

Scaling up any adaptation strategy is challenging task because of lack of generalization in a region-specific activity. However, in our proposed project, the development of models is generalized and easily applicable to any new area and new crop, whereas the implementation is regional. Our plan for the development of generalized model is to develop a common framework for all. We plan to cover a few villages, which is already scaled up to some extent and is not concentrated for just a few farms. Regarding implementation of the IoT and IoE in agriculture, there is no standard or guidelines available in India; though this is the need of the hour to make the agricultural system of the country climate-smart. Our technical experiences will be recorded following preparation of research article / white paper, which will most likely serve as a guideline/ standard for scaled up implementations.

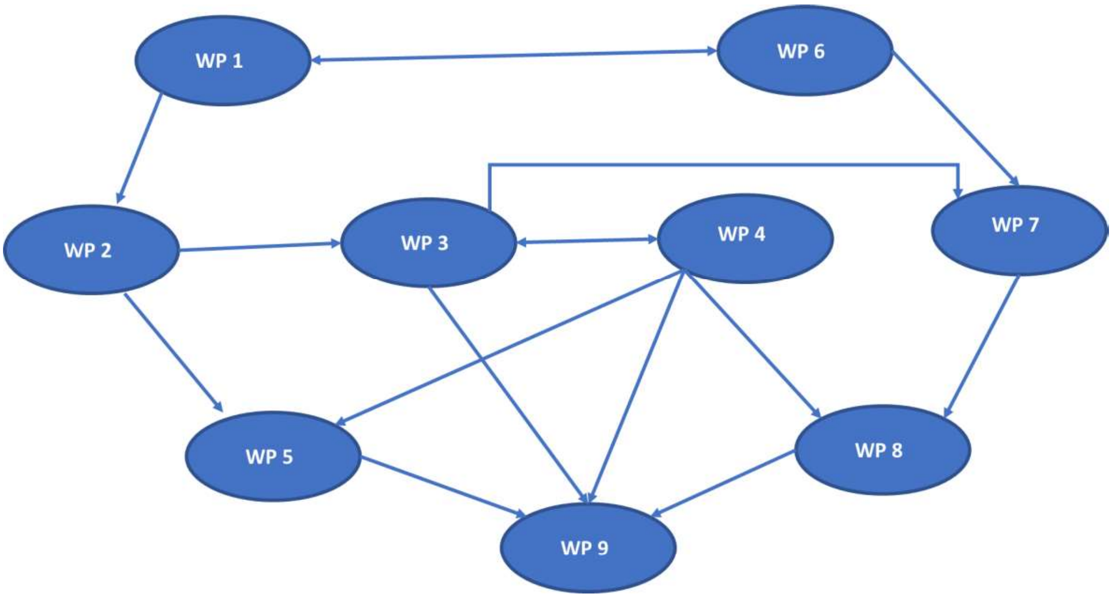

Fig 23: Connectivity between Work Packages

D. Describe how the project / programme would provide economic, social, and environmental benefits, with particular reference to the most vulnerable communities, and vulnerable groups within communities, including gender considerations. Describe how the project / programme would avoid or mitigate negative impacts, in compliance with the Environmental and Social Policy and Gender Policy of the Adaptation Fund.

The proposed project aims for the development and implementation of new technologies for irrigation management that have the co-benefits of reducing the climate vulnerability by improving the economic scenarios and by helping the vulnerable community. We aim to the 2 driest Taluka, Man and Khatav, where almost 50% farmers live below poverty line, the male population reduced due to migration making the region highly vulnerable. We propose to implement our technology for 5-10 villages from these Talukas.

Small and Marginal Farmers

We propose to implement the sensors and drone surveys targeting the small and marginal farmers having the land holding of 1-2 ha, who are vulnerable to climate change, suffers significantly from a single monsoon deficit and cannot recover easily. These are the farmers, who do not have any access to new technologies and newer services coming out from the IMD. There is an existing framework of weather based agromet advisory, but farmers do not use them because of resolution mismatch. The purpose here is to not just reducing water use but also improving the yield through avoiding water stress and hence, improving their profits. These farmers do not have to invest anything for implementation of the proposed technology, as we will take care of the entire implementation. After the successful development and implement, the technology will be transferred to India Meteorological Department, so that such efforts will be continued under the Government weather services and upscales in many other regions. We will also test the hypothesis through field investigation that introducing technology reduces the socio-economic vulnerability in a region as a co-benefit, in turn reducing the climate risk.

Women headed Agricultural Activities

Man and Khatav are the talukas, from where the major male agricultural workforce have migrated to the nearby cities Mumbai and Pune. Hence, both the agricultural activities and households are women led. The women of these regions also have to take care of other household responsibilities, which generates significant physical and mental stress. The monsoon uncertainty is an added significant stress which affects them the most. The technologies developed will be implemented in such regions. We also plan to develop training modules for the women and vulnerable community over these regions on how to use our technology products through apps. Automated decisions add relief from the stress related to monsoon uncertainty and non-water availability. The women population also care a lot for their next generation and it will be easier to make them understand the need for groundwater use minimization and savings. It is noteworthy that because of topographic character, the other water saving structure such as check dam etc. are difficult to implement over this region.

Awareness among unprivileged caste

The unprivileged people mostly from Schedule caste and tribe community often do not have the awareness about climate change. Working with them will have a co-benefit of making them aware of this serious global problem affecting all of us.

E. Describe or provide an analysis of the cost-effectiveness of the proposed project / programme and explain how the regional approach would support cost-effectiveness.

The implementation of IoT and IoE based monitoring, coupled them with modelling and forecasting and converting them to agricultural decisions over large regions (multiple villages) as proposed here is the first of its kind in India. Hence, a detailed past cost benefit analysis from past projects is absent for the same. This is probably true for any new project that involves newer innovations.

One of the key challenges in implementing IoT and IoE for agriculture is the high cost. There is a glaring need for innovation for low cost implementation of IoT/ IoE in agriculture specifically for small & marginal farmers. Here, we propose to add hyper-resolution modelling, and satellite products to the sensors and drones so that with minimum number of instruments, maximum coverage is possible. Such rationalization of instruments will reduce the cost of existing IoT system drastically and making such technology accessible, if not by individual farmers, but by village/ taluka administration. The approach will also help those small farmers, who do not have sensors in their own farm, but based on information from neighbouring farms, satellite and models. We propose to use weather component along with monitored data to convert into decisions to be taken at different stages which will reduce the water stress with improvements in the yield. The yield improvement will further improve the income. In the long run, the crop switching will also involve farmers'' profit as one of the objectives to improve the financial conditions of farmers below poverty line.

Implementation of technology will give us the basis of performing the cost benefit analysis of any project for large scale implementation of IoT and IoE. At present, there is lack of implementation of IoT and IOE over large region due to high cost. We envision that our approach will convert this into a scenario, when large regions will be preferred for cost-effective implementation.

F. Describe how the project / programme is consistent with national or sub-national sustainable development strategies, including, where appropriate, national or sub-national development plans, poverty reduction strategies, national communications, or national adaptation programs of action, or other relevant instruments, where they exist. If applicable, please refer to relevant regional plans and strategies where they exist.

The proposed project is aligned with the following national and sub-national sustainable development strategies (Table 2):

Table 2: Consistency with National/ Sub-national Programs

National/ Subnational Missions	Overview of the Mission	Connections with the Proposal
1. National Action Plan on Climate Change		
1.1 National Water Mission	Water resources development, improving water use efficiency minimizing losses, making water practices sustainable	The proposal aims to reduce water losses in irrigation and improving water use efficiency.
1.2 National Mission for Sustainable Agriculture	Agricultural risk management, improving yield.	The proposal aims to reduce the climate risk on agriculture and making

		it climate smart for higher yield (more nutrition) with low irrigation.
1.3 National Mission on Strategic Knowledge on Climate Change	Network of academic institutions for improving knowledge in Climate Science and Adaptation	The newly developed tools and technologies will add to the knowledge mission. IITB has already contributed in a significant way to this knowledge mission through centre of excellence on climate studies.
2. National Policy on Agriculture	To attain "more crop per drop" by sustainable agricultural practices. To achieve more yield with optimum use of resources	The project aims to maximize yield through optimum use of natural water resources.
3. National Disaster Mitigation Policy	Timely dissemination of disaster related information Preparing for Disaster Management	The project has a strong component on dissemination of weather alerts.
4. National Environmental Policy	Emphasized on integration of environment in economic and social development sectors	The project focuses on natural resources (groundwater) management with co-benefits of societal development by reducing vulnerability.
5. National Rural Livelihood Mission	To reduce poverty by enabling the poor households to access gainful self-employment and skilled wage employment opportunities	The project aims to improve the farmers' profits and promote climate-smart agricultural activities as self-employment opportunity.
6. Digital India	To transform India into a digitally empowered society and knowledge economy	The project aims to provide digital services to the farmers from monitoring to management for improving profit.
7. State Knowledge Management Centre on Climate Change (Maharashtra)	To improve state specific climate knowledge	The project will directly contribute with all its outcome.

G. Describe how the project / programme meets relevant national technical standards, where applicable, such as standards for environmental assessment, building codes, etc., and complies with the Environmental and Social Policy of the Adaptation Fund.

The project will follow all the existing regulations set up by the Government. At present there is no Indian standards available on implementation of IoT and IoE in agriculture over large regions. This will be the first of its kind, which will probably help in developing such standard. The project does not involve any new construction; hence, building codes are not really applicable to this project. The project will be implemented with close association with NABARD, State Agriculture Department, District Administration, and hence all the activities will comply with Environmental and Social policies. Periodic reviews will also ascertain the same.

H. Describe if there is duplication of project / programme with other funding sources, if any.

There is no duplication of existing project/ programme with other funding sources.

I. Describe the learning and knowledge management component to capture and disseminate lessons learned.

Since the proposal does not end at innovation and has a strong component on implementation, the dissemination is major component of the project. We propose to have the dissemination at the following stages:

Initial project stage

In the initial stage of project, the available knowledge on Climate Change and its possible impacts on water and agriculture needs to be disseminated. This will make the stakeholders understand the importance of projects on climate smart agriculture. We propose to arrange pre-project stakeholders meeting, where we will understand the farmers' problem and at the same time, we will explain our existing knowledge through different medium. We will also explain the depletion of natural resources due to uncontrolled human interventions. Such a dissemination will also help the community to participate in this project.

Installation stage

We propose to have the second stage of dissemination of knowledge with the participating farmers, the details of the installation. Our previous interactions revealed that farmers often are scared of installing sensors thinking it is for monitoring their activities. We will create simple training materials/ pamphlet/ videos to help the farmers understand that this if for their own benefit. We also explain the working principle and usefulness in a simple language so that they will not only allow us to install, but also take proper care of the instruments.

Product / Information Dissemination

When we will make our products and information ready, we will develop simple geospatial portal and apps for farm scale information dissemination. The details are explained in Part-II, Section A, WP9. Videos/ pamphlets will be created and tutorials will be arranged show the farmers can make use of the disseminated information to take correct decisions.

Knowledge Dissemination

The knowledge gained through the project will be disseminated in two stages during the end phage

Stage 1

At the first stage during the end phase, the benefits gained through installation will be demonstrated to the villages, where the technology is not implemented. This will make other farmers (who did not participate) understand the benefits. If the Government of India plans to upscale our approach after the successful implementation, these villages will participate.

Stage 2

The stage 2 dissemination is about the knowledge sharing. The knowledge gained will be converted into scientific articles, simple videos, training programs etc. That will result into a widespread communication of science. Further to this, as mentioned earlier, there is no standards available for IoT and IoE implementation over large region. The strategic knowledge developed through the proposed implementation will contribute to such standards. Finally, Climate Studies, IIT Bombay has been contributing significantly to the strategic knowledge on Climate Change maintained by the Ministry of Science and Technology. The outcome of the proposed project will also be communicated following the same pathway for other districts/ states to follow.

J. Describe the consultative process, including the list of stakeholders consulted, undertaken during project / programme preparation, with particular reference to vulnerable groups, including gender considerations, in compliance with the Environmental and Social Policy of the Adaptation Fund.

The consultation processes with the farmers of Maharashtra by Climate Studies started in 2019, where the faculty and students met the farmers of Nashik district, understood their problem and developed technologies for small scale irrigation water management, where cost efficiency was not the priority. The consultation helped us to know that framers need to make decisions at three stages, the first one is related to crop choices; while the second and third are related to water arrangements and water applications. The previous experiences helped us to formulate the present proposal on these three decision models. We selected an arid and vulnerable region to test the low-cost development, application, and implementation strategies.

During the proposal writing process, the team had a detailed interaction with the following officials:

1. A panel discussion was arranged to understand the implementation challenges of climate adaptation strategies with stakeholder participation. The panellists were Ms. Sujata Saunik, Additional Chief Secretary, Government of Maharashtra and Ms. Lipi Mehta, from Paani Foundation, extensively working in Man and Khatva (Fig. 24). Following the panel discussions, we also had separate meetings with them to identify the case study region.
2. Our identified partner SEVA is working with people from villages in Satara at a micro level. Presently they are working with 200 villages in Satara. Their key focus is on agriculture and natural resource management, women's development and gender issues, which are aligned with our proposal and adaptation fund. They work at the field in Satara district for improved water management (Figure 25). From the field work of SEVA, we have understood that surface water irrigation options through check dams are not very feasible in Man due to topography and groundwater irrigation remains as the only options for the farmers. Hence, improving irrigation efficiency is the key for sustainable agricultural activity
3. We also are interacting with the State agricultural department of Government of Maharashtra, the Regional office of NABARD, and the District collector of Satara for reconnaissance survey of the region.
4. The TIH, IITB also had TIH with following stakeholders from Maharashtra and rest of India
    - Farmers (Onion Growers) – Mr. Sachin Pawar and Mritunjay Kumar, Maharashtra
    - Agriculture Scientists (ICAR – DOGR) - Indian Council for Agriculture Research – Directorate of Onion and Garlic Research, Pune (very close to Satara)
    - Agriculture Scientists (ICAR – CICR) – Indian Council for Agriculture Research Central Institute of Cotton Research, Nagpur, Maharashtra
    - Agriculture Scientists (ICAR – NRCG) - National Research Centre for Grapes, Pune
    - Industry – General Aeronautics Pvt. Ltd. Bangalore
    - Industry – Proximal Soilsens Technologies Private Limited, Pune

5. IITB Climate Studies is in close touch with India Meteorological Department (IMD) and had several meetings to make planning for the proposed project. Recently on 2nd May, 2022, IITB Climate Studies and IMD have signed an agreement for data sharing for the development of climate services together (Fig. 26)

Fig. 24. Panel Discussion on Climate Adaptation Issues held on 6th July 2022 at IIT Bombay

Fig 25: Field visit at Satara District by SEVA

Fig 26: Signing of Agreement between IMD and IITB for development of climate services together

6. SEVA, the team member of the proposed project team has been working in SATARA for more than a decade, specifically with the women and unprivileged population. The details are provided below:

Sr. No	Name of Project	Project Year	Department	Project Objectives	Total number of NRM work Villages	Project Location	Project area (ha.)	Total no of Farmers Covered		Cast Category			Knowledge obtained which helpful for our project
								Male	Female	SC	NT/ VJNT	OBC/ General	
1	MWSIP Project (Maharashtra Water Sector Improvement Project) World bank funded.	2009 - 2012	"Jalsandharan Dept." Maharashtra Water Sector Improvement Project	Decentralize the irrigation system to farmers. Formation of Farmers Water Users Association.	21	Phaltan, Maan, Khatav Dist. Satara	11000 ha.	423	97	130	182	111	Participatory irrigation facility management
2	NRDWP (CNB works) National Rural Drinking Water Programme.	2012 - 2014	GSDA, Satara	To provide the water Security to Strengthen Water Source.	05	Satara District (Koregaon &Satara Block)	5 CNB	157	63	44	112	64	Source Strengthening work
4	IWMP Project (PMKSY) Integrated Watershed Management Programme.	2017 - 2020	Vasundhara Watershed Development Agency, Pune Maharashtra state.	To implement of Watershed and Livelihood based on Agriculture	06	Khatav block district Satara.	5521.39	8343	7981	3140	6280	7065	Natural resource management / Compartment bunding work on farmers land
			Total		**32**		**16521 ha.**	**8987**	**8141**	**3314**	**6574**	**7240**	

IIT Bombay has also successfully worked with the farmers of district Nashik on irrigation water management advisory development, but for a completely different socio-economic scenarios. The vast experiences of the team will be useful in creating upscaling guidelines.

K. Describe how the project/programme draws on multiple perspectives on innovation from e.g., communities that are vulnerable to climate change, research organizations, or other partners in the innovation space, in the context in which the project/programme would take place.

The proposed project is a truly an interdisciplinary work with a blend of laboratory, instrumentation, computational and field work. The project is bringing different perspectives through different expertise of the investigators of IITB and different partners. They are listed below.

Prof. Subimal Ghosh is leading from IIT Bombay. He is currently serving as the Convener of Interdisciplinary Program in Climate Studies and a Professor in the Department of Civil Engineering, IIT Bombay. His research interest includes hydro-climatology, regional climate modelling, understanding of Indian Monsoon and its variability, mesoscale hydrological modelling, water resources systems and simulating land surface feedbacks to climate. He has more than 100 journal publications, including Nature Climate Change, Nature Communications, Science Advances, Geophysical Research Letters, Water Resources Research etc. He is the fellow of the American Geophysical Union and the recipient of the AGU D L Memorial Medal, Shanti Swarup Bhatnagar Prize (highest award in Science and Technology in India), Swarnajayanti Fellowship, PRL Award, Dr. A P J Abdul Kalam Cray HPC Award, and many more. He is also the lead author of IPCC, Assessment Report-6, Working Group 1.

Prof. Arpita Sinha has been a faculty in Systems and Control Engineering at IIT Bombay since 2009. Before that, she was a postdoctoral fellow at Cranfield University, UK, for a year. Her research interest lies at the intersection of robotics and control systems. The broad areas of her work include guidance and control of autonomous vehicles, multiple vehicle coordination, and distributed decision-making. She is currently working on trajectory planning for autonomous on-road driving, multi-copter control for precision agriculture, and coordination of multiple mobile manipulators.

Prof. Subhankar Karmakar is currently a Professor & Head at the Environmental Science and Engineering Department (ESED), and associated faculty member in the DST-Centre of Excellence in Climate Studies, and the Centre for Urban Science and Engineering at Indian Institute of Technology Bombay. He obtained his PhD from the Indian Institute of Science, Bangalore, India. He worked as a Post-Doctoral Fellow at the University of Western Ontario, Ontario, Canada. Further, he received a BOYSCAST Fellowship from the Government of India to pursue research at Duke University, North Carolina, USA. His primary research interests are in Environmental Systems Analysis, Uncertainty Modelling, and Risk-Vulnerability Analysis to Climate-induced Natural Hazards. Some of his recent research contributions include mapping disaster-vulnerability for densely populated coastal urban areas, and mapping agricultural vulnerability at a national-scale. He has published over 90 international journal papers, 7 book chapters and several international conference proceedings. He received Professor S P Sukhatme Excellence in Teaching Award and Research Excellence Award at IIT Bombay in 2019 and 2020, respectively. He is the Principal Investigator for DST funded Centre of Excellence in Climate Studies at IIT Bombay.

Prof. PennanChinnasamy is currently an Assistant Professor with Indian Institute of Technology, Bombay - India, under the Centre for Technology Alternatives for Rural Areas (CTARA) department, where his work primarily focuses on natural resources assessment, monitoring and management in rural regions. He leads the Rural Data Research and Analysis (RuDRA) lab which establishes a database for better understanding rural issues, holistically. Over the past decade, Pennan has experience working in NGOs, national and regional government agencies and academic institutions, focusing on sustainable surface and groundwater management plans, climate change impacts, large data analysis and hydrological simulation models.

Prof. Karthikeyan Lanka is working as an Assistant Professor in Centre of Studies in Resources Engineering (CSRE), IIT Bombay since 2019. He is also an associate faculty member of Interdisciplinary Program in Climate Studies (IDPCS), IIT Bombay. Dr. Karthikeyan works in the areas of remote sensing of soil moisture and vegetation, land-atmosphere interactions, hydrological modelling, and monitoring soil moisture droughts. He is currently supervising 3 PhDs in IIT Bombay. He has authored 13 peer-reviewed journal publications.

Prof. Vishal Dixit is an Assistant Professor in the Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay, Powai Mumbai. His research focuses on different aspects of tropical climate dynamics with a special fascination for Monsoon dynamics. He uses satellite and ground based observations to learn about new features of monsoons and then uses an army of models (starting from Climate Models to Cloud Resolving Models) to replicate these feature with an aim to ultimately understand the underlying processes. He also teaches a course on Climate Systems and Climate Modelling at IIT Bombay. He has authored 12 peer reviewed publications.

Prof. Yogendra Shastri is Professor in the Department of Chemical Engineering, Indian Institute of Technology Bombay, Powai Mumbai. He is also associated with the Interdisciplinary Program in Climate Studies. His research focuses on developing and applying systems theory based tools for sustainable development. Specific areas of interest include biomass to energy systems, food-energy-water nexus, life cycle assessment, supply chain design, and system dynamics for sustainable energy transition. He also teaches a course on sustainable engineering at IIT Bombay. He has over 80 publications in peer reviewed journals, five book chapters, and on edited book to his credit.

Technology Innovation Hub (TIH): A section 8 company set up at IIT Bombay with support from the Department of Science and Technology. TIH will be involved in innovating and implementing new technologies related to sensors and drones for agricultural monitoring.

BHUGOL GIS Pvt Ltd: Bhugol GIS Pvt. Ltd. is an enterprise built on decades of research experience. Founded and Incubated at Society for Innovation and Entrepreneurship (SINE) at the Indian Institute of Technology Bombay (IITB). BHUGOL GIS is a technology and analytics firm with its own proprietary tool, GRAM++. GRAM is an acronym for Geo-Referenced Area Management, featuring robust Mapping, Data Analytics and Image Processing capabilities. BHUGOL will be developing the geospatial portals and apps.

Society for Empowerment of Villages & Agriculture (SEVA): SEVA is the leading NGO in the field of Agriculture, Water, Watershed, Sanitation, Environment, and Livelihood. SEVA works with people residing in villages at a micro level, and facilitates participation of rural people in the process of development of rural India. SEVA has an outreach of about 200 villages in the Satara District of the Western region in Maharashtra.

The interdisciplinary team will work with the stakeholders directly through SEVA, NABARD and Government organizations. The team is unique in terms of varying expertise and has the potential to bring innovation in the service of farmers for climate adaptation.

L. Provide justification for funding requested, focusing on the full cost of adaptation reasoning.

Sl No.	Budget heads	Justification	Link to Adaptation
1	Equipment	WP 3, WP 4, WP 5, WP 7 and WP 8 require data intensive parallel computation. High Performance Computing (HPC) and data storage facility will be established. WP2 involves ground based and airborne soil moisture sensing. High quality sensors (L Band Radar and Hyper spectral) are planned to be procured.	The adaptation tools needs high-resolution modelling at farm scale that should be running in the background. Without HPC, such simulations are impossible. It will also generate big data that needs storage. The adaptation framework needs monitoring of agriculture, which involves installation of sensors, drone survey, etc. Farmers in India cannot afford them, hence, through the project we are installing them. For upscaling the Government may be interested in doing the same for other regions, seeing the success of the present one.
2	Human resource (Salary)	This project involves innovation at several stages. A large cohort (28+) of Post-doctoral research scientists, Research Scholars, Technical and field assistants and administrative staff will be hired for successful implementation of the project.	It has two purpose, first we need staffs to work for large scale implementation. Further, it will generate skilled human resources, who will help the Government in the future in upscaling.
3	Travel	Frequent field visits over significantly longer monitoring period will be required to install and operate the equipment and stakeholder engagements.	Travel is needed to visit the site very frequently. Adaptation needs frequent field visits to the site.
4	Consumable	Project will require procuring and storing of tera- bytes of satellite and model data and climate modelling software.	Needed for the monitoring to be used for adaptation.
5	Contingency	Scientific reporting, logistic support for periodic project review meetings, troubleshooting and any other unforeseen costs.	For meeting with stakeholders, who are the key players of adaptation.

M. Describe how the sustainability of the project / programme outcomes has been taken into account when designing the project / programme.

Any innovation project needs evaluation before upscaling. Here, in this project, we propose to develop new technologies for climate-smart irrigation water management with its validation for some of the driest regions of Maharashtra, India. The project offers technology development with proof of concept after application in some of the most challenging regions. The investigators are aware that the call for proposal is on "large-scale innovation," which is different from the standard call of "adaptation" by the UNFCC. Hence, the proposal has distinct three components, innovation, application, and implementation. Successful completion of the project will lead to generating strategic knowledge for large-scale cost-optimized irrigation management planning. This is the first and foremost necessary information required for upscaling. The team working on the proposed project has taken the following measures for the sustainability of the project and possible future upscaling.

1. The technology developed through this project and the monitoring system will be shared with IMD and the Agricultural Department, Maharashtra (with data access to the project team). The transfer of the system will ensure that the activities will be upscaled and transferred to other regions.
2. The project is the first of its kind. The knowledge generated will be shared with the government leading to the development of standards for IoT and IoE in agriculture. Such standards will be followed for upscaling the system in other regions, if not the entire country/ state but for the arid regions.
3. A significant component of the project is community-led. After observing the benefits and co-benefits of the project, the community may take special care of the sustainability of the system.
4. The Ministry of Earth Sciences (MoES) has taken multiple initiatives for extensive earth system monitoring. Sharing all the details with IMD (part of MoES) will help them upscale the system for sustainable agricultural system.
5. The Department of Science and Technology and MoES has come together recently for India-specific climate science and adaptation. They are in process of developing a consortium for India. IITB has a DST supported Centre of Excellence in Climate Studies that contributes to the strategic knowledge mission on climate change. The project outcome shared with the strategic knowledge mission will help to sustain the efforts and upscale over a large region.

In summary, we will propose the mechanism through which the efforts not only be sustained but also upscaled over a large region. The team will be happy to support any such endeavours in this direction around the country. We also would like to highlight that previously we have developed technologies for climate services, such as India's first real time urban flood forecasting system and transferred the technology to MoES. MoES is now using the same for day to day applications. We follow the same here for this project.

N. Provide an overview of the environmental and social impacts and risks identified as being relevant to the project / programme.

Table 2: Environmental and Social Impacts and Risks

Checklist of environmental and social principles	No further assessment required for compliance	Potential impacts and risks – further assessment and management required for compliance
Compliance with the Law	There is no activities against legal framework	None
Access and Equity	The project will provide equal access of services to all the farms.	None

Marginalized and Vulnerable Groups	Priorities will be given to installing instruments for the vulnerable communities to help them and to reduce the risk. Hence the project supports the marginalized and vulnerable groups more	None
Human Rights	The project does not affect the life and liberty of any individual or group.	None
Gender Equity and Women's Empowerment	Priorities will be given to installing instruments at the women-led farms to help them and reduce the risk. Hence the project supports women's empowerment.	None
Core Labour Rights	Not applicable to this work.	None
Indigenous Peoples	Not applicable to this work	None
Involuntary Resettlement	Not applicable to this work	None
Protection of Natural Habitats	The project will not disturb the natural habitat.	None
Conservation of Biological Diversity	The project will not disturb the biological diversity.	None
Climate Change	The project will help farmers adapt to climate change.	None
Pollution Prevention and Resource Efficiency	Not applicable	None
Public Health	Not applicable	None
Physical and Cultural Heritage	Not applicable	None
Lands and Soil Conservation	The project improves water use efficiency, which may not have connections with land and soil conservations.	None

PART III: IMPLEMENTATION ARRANGEMENTS

A. Describe the arrangements for project / programme management at the regional and national level, including coordination arrangements within countries and among them. Describe how the potential to partner with national institutions, and when possible, national implementing entities (NIEs), has been considered, and included in the management arrangements.

The proposed project will be executed by the Indian Institute of Technology Bombay, an Institute of Eminence in India with the partners as Technology Innovation Hub, IITB, Bhugol GIS Pvt Ltd and Society for Empowerment of Villages and Agriculture. The following committes are proposed for overlooking and periodic overview of the project:

1. Project Review Committee: A project review committee will set up, which will meet for the review of progress once a year. The committee will consist of (1) representative of Ministry of Environemnt Forest and Climate Change; (2) representative of NABARD; (3) representative of IMD; (4) representative of state agricultural department; (5) representative from district collector's office; (6) Gram Panchayat members; (9) academic experts; (10) industry experts. The committee will be formed in consulation with the NBARD regional office. The committee will also meet the farmers/ stakeholders for their feedback.
2. Project Steering Committee: A project steering committee will be set up with officials from (1) NABARD, (2) IITB, (3) State Agricultural Department, (4) District administrative official; (5) IMD (6) Krishi Vigyan Kendras (Agricultural organizations). The project steering committee will meet more frequently as and when required (but minimum once in 6 months) to understand project management and project execution.
3. Project Management Committee: A project management committee will be set up with representative from (1) IITB; (2) NABARD; (3) SEVA; (4) TIH; (5) BHUGOL. They will be responsible for the overall management of the project. The committee will update the steering committee periodically about the management plan, work progress, success/ failure of every step.
4. Work Package Leads: Each of the work package will be led by project investigator. WP1 will be led by SEVA, WP2 will be led by TIH, WP3 will be led by Prof. Karthikeyan Lanka of IIT Bombay, WP4 will be led by Prof. Vishal Dixit (IIT Bombay), WP5 will be led by Prof. Subimal Ghosh (IITB), WP6 will be led by Prof. Pennan Chinnasamy (IIT Bombay), WP7 will be led by Prof. Subhankar Karmakar, WP8 will be led by Prof. Yogendra Shastri, WP9 will be led by BHUGOL. The WP leads will periodically inform the updates from their WPs to the steering committee for suggestions and management decisions.
5. The connections and collaborative work plans under each WPs are explained in details in Part II, Sections A, C and K.

   The detailed strcuture of project management is presented in Fig. 27.

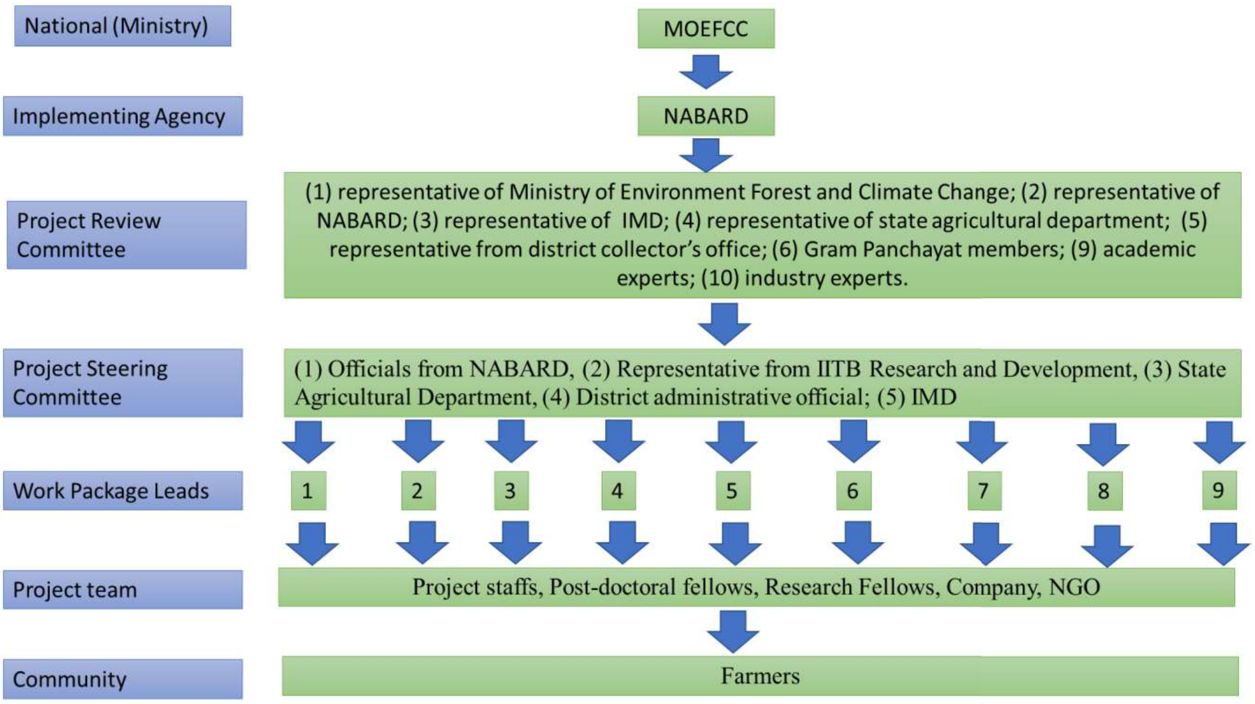

Fig. 27: Project Management (The Krishi Vigyan Kendra Representatives will also be involved in the implementation and community interactions)

B. Describe the measures for financial and project / programme risk management

Risk Class/Category	Level	Mitigation
Operational/Administrative: Coordination of activities with other agencies; large timeliness of technical inputs and their proper scheduling number of on-going projects/programme Issues related to planned intervention in desired outcome due to unavailability of timely inputs	Low	• NABARD will be involved closely with coordination and administration. • Both Bhugol and TIH are housed in the vicinity of IITB, this will help in coordinating activities without delay. • Both the agencies will have a dedicated team while IITB will employ both scientific and administrative staff for successful implementation and execution of the project.
Financial: Cost escalation leading to increased costs for goods and services	Low	• Procurement of major equipment are planned in the first year itself • If the cost of sensors increases the number of sensors will be adjusted accordingly.
Environmental: Natural Hazards (flood, drought, storm surges, and storms) may hamper project implementation.	Low	The peak observation period will be designed considering the weather forecast. Special care will be taken to guard sensors and other field equipment in case of unforeseen natural hazards.
Participation of stakeholders and required cooperation from government, private and technical institutes.	Low	Several Govt bodies have shown strong support and partner NGO has some prior experience of working with the stakeholders of the study area.

C. Describe the measures for environmental and social risk management, in line with the Environmental and Social Policy of the Adaptation Fund.

The environmental and social risk components in line with adaptation fund are not applicable to the proposed project. Kindly refer to Sectio II, Part-N

D. Describe the monitoring and evaluation arrangements and provide a budgeted M&E plan.

The monitoring and evaluations schedule are mentioned in the following table:

Evaluation/ Monitoring/ Meeting	Tentative Timeline	Activity
Pre-project stakeholder meeting	September2022/ January 2023	Interaction with farmers to understand their problems, and explaining them Climate Change
Project Steering committee	January 2022	Evaluating Project plan and initiation of work
Stakeholder meeting	March 2023	Installation plan
Project Steering Committee meeting	June 2023	Evaluation of ongoing installation/ progress review
Stakeholder meeting	September 2023	Feedback from farmers about Kharif crop season
Project review Committee meeting	December 2023	Progress evaluation and guidance
Stakeholder meeting + Steering committee meeting (on-site)	March 2024	Evaluation of ongoing installation/ progress review, getting feedback from farmers, training program for farmers
Stakeholder meeting	September 2024	Feedback from farmers about Kharif crop season, Training Program
Steering Committee Meeting + Project review Committee meeting	October 2024	Discussion and review on modelling and tool development, Review on installation, Guidance
Midterm Review	December 2024	Progress evaluation and guidance
Stakeholder meeting + Steering committee meeting (on-site)	March 2025	Evaluation of progress, review, getting feedback from farmers, training program for farmers on how to use advisories
Stakeholder meeting	September 2025	Feedback from farmers about Kharif crop season, Training Program
Steering Committee Meeting	October 2025	Discussion and review on modelling and tool development, Review on installation, Guidance
Project Review Committee Meeting (onsite)	December 2025	Project review and committee interactions with farmers
Stakeholder meeting + Steering committee meeting (on-site)	March 2026	Evaluation of application of technology, getting feedback from farmers, planning for incorporation of farmers feedback
Stakeholder meeting	September 2026	Detailed meeting to resolve all the issues, inviting non-participating villages for upscaling
Steering Committee Meeting + Project review Committee meeting+ Final Review, Terminal Evaluation (onsite)	October 2026	Final evaluation by the Steering committee, Evaluation on the project and planning for generation of standards for IOT/ IOE applications in agriculture

Periodic report submission: Periodic updates will be submitted in every 6 months, June and December in every year. The final report will be submitted in March 2027

The M&E cost has already been absorbed in the IITB budget. No more extra budget is needed.

E. Include a results framework for the project / programme proposal, including milestones, targets, and indicators.

Milestone	Indicator	Target
Installation of Sensors	No of villages covered and no of plots covered within a village	Minimum 5 villages, and within village plots of different soil types. Networking and dissemination.
Drone Survey	No of villages covered and no of plots covered within a village	Minimum 2 villages, 1 from each tehsil supplementing the sensor network
Merging soil moisture	Generating plot level soil moisture for the entire village	Retrieval of multi-source information and generation of plots for at least 5 villages at farm scale
Hyper resolution Hydroclimate Modelling	Regional downscaling product and hydrological forecast/ projections	The scale consistent with observation network
Farm Scale Optimization	Percentage of farms covered within villages	Irrigation scheduling for farms with water savings without losing yield (target improving yield)
Agricultural risk map	Risk map for the entire district	Hazard, and vulnerability map generation for different crops, technology evaluations, and designing socio-economic interventions
Crop switching	Crop switch planning for entire district	Improving nutrition production, and farmers'' profit with minimization of water use
Stakeholder and participatory Modelling	Involving % of framers in the exercise	At least 50% farmers involved / got trained/ interacted (feedback) during the entire exercise.

F. Demonstrate how the project / programme aligns with the Results Framework of the Adaptation Fund

The budget here excluding overhead and implementing institute cost

Project Objective(s)[2]	Project Objective Indicator (s)	Fund Outcome	Fund Outcome Indicator	Grant Amount (USD)
To make the agricultural practices climate smart and climate resilient with an upliftment of rural wellbeing in vulnerable arid regions of South Asia	% of villages and farmers participated in the project	Installation of IoT and IoE in the villages	Number of villages and the area covered	1865566
		Providing Irrigation advisory to the farmers	Number of farmers using advisory and giving feedback	
	% reduction in irrigation water use	Agricultural risk map	Granularity of risk map (resolution)	285136

[2] The AF utilized OECD/DAC terminology for its results framework. Project proponents may use different terminology but the overall principle should still apply

	% improvements in the crop yield	Crop switching policy	% of improvements in water use and yield, field level feasibility study	
Project Outcome(s)	**Project Outcome Indicator(s)**	**Fund Output**	**Fund Output Indicator**	**Grant Amount (USD)**
More crop per drop: improving crop yield with optimum use of water at farm scale	Farmers response on the quantification of improvement	Farmers participating in climate smart agricultural practices	Fraction of farmers switching to climate smart irrigation decisions	1865566
Minimization of climate agricultural risk	Future optimum crop choices reducing yield Evaluation of new technology Identification of socio-economic interventions	Improvements in yield Reduction in water use Improvements in farmers' profit	All the quantities in %	285136

G. Include a detailed budget with budget notes, broken down by country as applicable, a budget on the Implementing Entity management fee use, and an explanation and a breakdown of the execution costs

Detailed Budget of IIT Bombay (in USD): T1

Budget Head	Year 1	Year 2	Year 3	Year 4	Total Amount in USD
Equipment					
HPC with Data Storage	252000				252000
PCs and laptops	12600				12600
Salary					
Sr. Project Manager (1 Nos)	12374	13724	15074	16424	57596
Post Doctoral Research Fellow (6 Nos)	74245	82345	90444	98544	345578
Sr. Project technical Assistant (1 Nos)	6075	6750	7425	8099	28348
Sr. Project Software Engg (1 Nos)	8999	10124	11249	12374	42747
JRF/SRF (2 Nos)	11624	11624	13124	13124	49497

Project attendant (1Nos)	2268	2570	2873	3175	10886
Stakeholder meeting + discussions	6300	6300	6300	6300	25200
Travel	6300	6300	6300	6300	25200
Contingency	12600	12600	12600	12600	50400
Consumables	12600	12600	12600	12600	50400
TOTAL (T1)	417986	164937	177989	189541	**950453**

Budget for IOT Installation (IITB identified Technology Innovation Hub, IITB) (in USD): T2

Budget Head	**Year I**	**Year II**	**Year III**	**Year IV**	**Total Amount in USD**
Equipment					
Laptop/Desktop/Printer/Scanner/ Other computer accessories	1890				1890
Storage Device (100TB storage)	1260	1260	1260	1260	5040
Sensors - L band radiometer	63000				63000
Sensor – thermal	630				630
Sensors-Hyperspectral	88200				88200
Ground station	3780				3780
Field/lab equipment/autonomous drones	22680				22680
Other equipment (Field Generator)	1890				1890
Soil Moisture Sensor system for 100 sensors	25200				25200
Consumables					
Battery packs		5292	5292	5292	15876
Other consumable items	1260	1260	1260	1260	5040
Salary					
1. JRF/SRF/Project Engineer (1 Nos)	10584	11642	12807	14087	49120
2. Research Associates (2 Nos)	36288	39917	87817		164022
3. Technical Assistant/Field Assistant/Pilots (4 Nos)	30240	33264	36590	40249	140344
Travel					
1. Conference/seminars/workshop	630	630	630	630	2520
2. Field/other visits	25200	25200	25200	25200	100800
Contingencies	1890	1890	1890	1890	7560
TIH Service charges					
2% of the Total	62924				62924

TOTAL (T2)	377546	120355	172746	89869	**760516**

Budget for GIS portal and apps (IITB identified Bhugol GIS Pvt Ltd) (in USD): T3

Budget Head	**Year I**	**Year II**	**Year III**	**Year IV**	**Total Amount in USD**
Manpower and Development Cost	44100	31828	25460	19908	121296
Hosting Charges	6300	8820	10080	12600	37800
Total	50400	40648	35540	32508	159096
GST@18%	9072	7317	6397	5851	28637
FINAL CHARGABLE AMOUNT (T3)	**59472**	**47964**	**41937**	**38359**	**187733**

Stakeholder meeting, connecting farmers, and dissemination (IITB identified SEVA (Society for Empowerment of Villages & Agriculture)) (in USD): T4

Budget Head	**Year I**	**Year II**	**Year III**	**Year IV**	**Total Amount in USD**
Stakeholders meeting and continuous interactions/ feedback with farmers	126000		126000		252000
TOTAL (T4)					**252000**

Budget Summary

Project Cost (T1+T2+T3+T4) (in USD)	**2150702.253**
Execution cost @ 9.5% of Project cost	**204317**
Total Project Cost	**2355019**
Project/Programme Cycle Management Fee charged by the Implementing Entity (NABARD) @ 8.5% of Total Project Cost	**200177**
GRAND TOTAL (Amount of Financing requested)	**2555196** **(2.56 million USD)**

***For detailed budget notes please refer to Section II L.**

H. Include a disbursement schedule with time-bound milestones.

Project Fund Disbursement Schedule						
Sl. NO	Particulars	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**
	Scheduled Date	**January'23**	**January'24**	**January'25**	**January'26**	
TO EXECUTING AGENCY						
1	Project Cost	981004	333257	518672	317769	2150702
2	Execution Cost	93195	31659	49274	30188	204317
3	Total Project Cost	1074200	364916	567946	347957	2355019
TO NATIONAL IMPLEMENTING ENTITY						
	Project Management Cost	50044.25	50044.25	50044.25	50044.25	200177
TOTAL AMOUNT REQUESTED		**1124244**	**414960**	**617991**	**398001**	**2555196 (2.56 million USD)**

Milestones

Activities	Time (Months)							
	0m -6m	6m-12m	12m-18m	18m-24m	24m-30m	30m-36m	36m-42m	42m-48m
WP1: Stakeholders meeting, interactions, feedback								
WP2: Installation of Sensors								
WP2: Drone Survey								
WP2: Maiantaining IoT								
WP3: Algorithm development for merging								
WP3: Improving algorithms through feedback								
WP4: Regional climate modeling								
WP4: Regional hydrological modeling								
WP5: Irrigation model development								
WP5: Optimization								
WP5: Improving decision model based on feedback								
WP6: Participatory modeling								
WP7: Risk Map Generation								
WP7: Socio-economic interventions design								
WP7: Technology evaluation for risk reduction								
WP8: Food energy water study								
WP8: Crop switching optimization								
WP8: Feasibility Study								
WP9: Portal development, app development and maintenance								

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PART IV: ENDORSEMENT BY GOVERNMENT AND CERTIFICATION BY THE IMPLEMENTING ENTITY

A. Record of endorsement on behalf of the government Provide the name and position of the government official and indicate date of endorsement. If this is a regional project/programme, list the endorsing officials all the participating countries. The endorsement letter(s) should be attached as an annex to the project/programme Proposal/PCN. Please attach the endorsement letter(s) with this template; add as many participating governments if a regional project/programme:

Mr. Neelesh Kumar Sah, Joint Secretary Ministry of Environment, Forest & Climate Change Government of India	Date: 26 December 2022

B. Implementing Entity Certification Provide the name and signature of the Implementing Entity Coordinator and the date of signature. Provide also the project/programme contact person's name, telephone number and email address

I certify that this Proposal/PCN has been prepared in accordance with guidelines provided by the Adaptation Fund Board, and prevailing National Development and Adaptation Plans (National Action Plan on Climate Change) and subject to the approval by the Adaptation Fund Board, commit to implementing the project/programme in compliance with the Environmental and Social Policy and the Gender Policy of the Adaptation Fund and on the understanding that the Implementing Entity will be fully (legally and financially) responsible for the implementation of this project/programme.	
(CSR Murthy) Chief General Manager NABARD, Head Office, Mumbai (Implementing Entity Coordinator)	मुंबई Mumbai
Date: October 11, 2022	Tel. and email: +91 22 2653 0040, +91 98675 65192 csr.murthy@nabard.org
Project Contact Person: Sukanta Kumar Sahoo, Deputy General Manager, NABARD, Head Office, Mumbai	
Tel. and Email: +91 22 2653 9331, +91 94140 29140 climate.change@nabard.org sukanta.sahoo@nabard.org	

नाबार्ड

Ref No NB.HO.FSDD/CC/997/2022-23

26 December 2022

To,
Adaptation Fund Board Secretariat
c/o Global Environment Facility
Mail stop: N 7-700
1818 H Street NW
Washington DC 20433
Email: afbsec@adaptation-fund.org

Dear Madam/ Sir,

Submission of Concept Notes to Adaptation Fund under Large Innovation Project

In the capacity of NABARD's role as National Implementation Entity (NIE) for Adaptation Fund of UNFCCC, we submit herewith following Concept Note (CN) along with Letter of Endorsement (LoE) from NDA (MoEF&CC, Govt.of India) for your kind perusal:

i. Large Innovation project titled "**Climate Smart Agricultural Water Management in Man and Khatav Taluka of Satara District, Maharashtra State, India**".

   The CN has been prepared in accordance with the Government's National priorities in implementing adaptation activities to reduce adverse impacts of, and risks, posed by climate change in India. The Executing Entity of the CN is Indian Institute of Technology, Bombay (IITB) a premier technical Institute in India.

We request you to consider the above CN in AF's next Board Meeting (B.40) scheduled to be held in March 2023. We shall be glad to provide any additional information/ clarifications in this regard.

Kindly acknowledge the receipt of the above concept note.

Thanking You,

Yours faithfully,

(C S R Murthy)
Chief General Manager

Encl.: As above

राष्ट्रीय कृषि और ग्रामीण विकास बैंक
National Bank for Agriculture and Rural Development
कृषि क्षेत्र विकास विभाग
प्लॉट नं. सी-24, 'जी' ब्लॉक, बांद्रा - कुर्ला कॉम्प्लेक्स, बांद्रा (पूर्व), मुंबई - 400 051. • टेलि.: +91 22 2653 0094 • फैक्स : +91 22 2653 0009 • ई-मेल : fsdd@nabard.org
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नीलेश कुमार साह
संयुक्त सचिव
NEELESH KUMAR SAH
JOINT SECRETARY

सत्यमेव जयते

पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
भारत सरकार
Ministry of Environment, Forest and Climate Change
Government of India

D.NO .CC-13008/327/2022

26-12-2022

To

The Adaptation Fund Board
c/o Adaptation Fund Board Secretariat
Email: Secretariat@Adaptation-Fund.org
Fax: 202 522 3240/5

Subject: Endorsement for the Project Concept Note (PCN) on "Climate Smart Agricultural Water Management in Man and KhatavTaluka of Satara, Maharashtra, India"

In my capacity as designated authority for the Adaptation Fund in India, I confirm that the above National PCN is in accordance with the Government's National priorities in implementing adaptation activities to reduce adverse impacts of, and risks, posed by climate change in India.

Accordingly, I am pleased to endorse the above PCN with support from the Adaptation Fund. If approved, the project will be implemented by National Bank for Agriculture and Rural Development (NABARD) and executed by Indian Institute of TechnologyBombay (IITB), India.

Sincerely,

Neelesh Kumar Sah
Joint Secretary
Ministry of Environment, Forests& Climate Change
Government of India

प्रकृतिः रक्षति रक्षिता
Nature Protects if She is Protected

अग्नि विंग, इंदिरा पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली–110 003, फोनः (011) 24695130 ई–मेलः sahnk@cag.gov.in
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