Multidisciplinary Project Cotton Water

Baseline study of designing sustainable instruments for smallholders in Maharashtra, India

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Challenge the future

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by

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in partial fulfilment of the requirements for the degree of Master of Science
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Supervisors:	Dr. Saket Pande,	TU Delft
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TU Delft

Preface

Delft, 2019

During the spring, summer and fall of 2019 we got the unique opportunity to investigate possible ways to improve the livelihood of smallholders in Vidarbha and Marathwada, India. During the project we had the chance to implement the skills we have learned in becoming Civil Engineers throughout our education for a real cause. Over the past month we have learned an incredible amount about water related issues in India, the challenges of smallholders in the area, developmental work and its challenges, working in a diverse group and much more. The project has opened our eyes in many ways. It is a rare opportunity to experience from up close what hard work goes into the cotton we consume in the western world. For personal stories, pictures and movies we refer you to our Facebook page, www.facebook.com/projectcottonwater, where we regularly posted updates.

We are very grateful to have worked together with Solidaridad, an organisation that has proven their willingness to truly improve the situation of the farmers. All their associates we met were highly involved in and knowledgeable of the situation. During our field visit we felt very welcomed into their country. All of this would not have been possible without Saket Pande. He is a passionate mentor that truly cares about the project and the process that lead to the results presented in the report. He got us all involved in the project and kept track of the process at very regular intervals.

We hope that our results will be used to improve the livelihood of the hardworking cotton farmers. To those reading this who will continue the project where we left off, we are more than willing to explain our process beyond what is written in the report and share all necessary data clearly organized in an online drive with you to facilitate your progress. Besides, we hope that through this project we have already started to create more awareness amongst friends, family and everybody who is willing to listen to better understand where our raw material comes from. We hope for a future where cotton is grown in fair circumstances without the severe stress a major part of farmers currently experience.

Abstract

This report represents the baseline study of the multiyear project cotton water, a collaboration between Solidaridad Asia and TU Delft to improve the livelihood of cotton farmers in the Vidarbha and Marathwada regions of Maharashtra, India.

This baseline study was divided in three main steps: a desktop study, where high resolution maps of precipitation, potential evaporation, soil type and landuse were used in conjunction with a smallholder socio-hydrological model to identify 'hotspots' where farmers' capital falls below poverty lines; a field survey, in which farmers were extensively questioned on their financial situation and farming practices as well as their perception of water scarcity and irrigation schemes; and a final synthesis where interventions are analysed with the smallholder socio-hydrological model and a psycho-social analysis of farmer behaviour is delivered.

The main results found are that the proposed water harvesting and recharge intervention slightly increases and stabilizes yield, but the overall effect on capital remains marginal. Other factors that don't impact water availability including fertilizer and labour were found to have notable impacts and should be well understood to accurately improve farmers' situations. Financial aspects including cotton sale prices and loan interest rates had strong impacts on farmers' capital development as well, particularly with high interest rates punishing some farmers.

An analysis of good- and poor-performing farmers demonstrated that irrigation and micro-irrigation did improve probability of good farmer performance as did increased yields. Older men also showed higher rates of profit, demonstrating that the impact of experience may increase profit margins, even if it necessarily doesn't increase likelihood to adopt interventions.

What was found to increase probability of adopting irrigation and irrigation technology was low promotion exposure. It is hypothesized that increased promotion may influence many farmers negatively, fostering an attitude of despair rather than informing them of opportunity. The psycho-social evaluation also found that solutions that are reasonably expensive but not too costly have higher chances of being adopted.

Four main recommendations were made to help improve farmer welfare with respect to the scope specified. It was recommended to: limit promotion and to be more selective and positive with the message; focus on localized water storage interventions to increase farmers' access to water; regulate cotton prices through government intervention or contracts with clothing companies to decrease vulnerability to price changes; and improve access to loans from the government and reduce the role of money lenders who often are the ones charging the greatest interest rates.

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1 Introduction

1.1. Problem outline

Cotton, an important cash crop grown in India, plays a vital role in the economy of the country's agriculture and the global textile industry. According to the National Food Security Mission (NFSM), about 6 million farmers are employed in the cultivation of cotton and the cotton textile industry of the country employs another 40-50 million people.

In this context it becomes extremely important to consider the cotton growing regions of the country which are Punjab, Haryana and Rajasthan in the North zone, Madhya Pradesh, Gujarat and Maharashtra in the central zone and Andhra Pradesh, Telangana, Karnataka and Tamil Nadu in the Southern zone.

The region has been drawing attention due to the rising number of farmer suicides that it has witnessed over the decades. According to the Vidarbha Jan Andolan Samiti, about 95 percent of the farmers in Vidarbha are in debt [4]. According to the National Crime Record Bureau (NCRB), the number of farmer suicides in Maharashtra between 2015 to 2018 is over 9000 farmers. The fact that these numbers do not seem to show significant decreases in spite of loan waivers, indicate that a long term sustainable solution is required. The study area is confined to the most critical regions: Amravati, Wardha, rural Nagpur and Yavatmal, see figure 1.1.

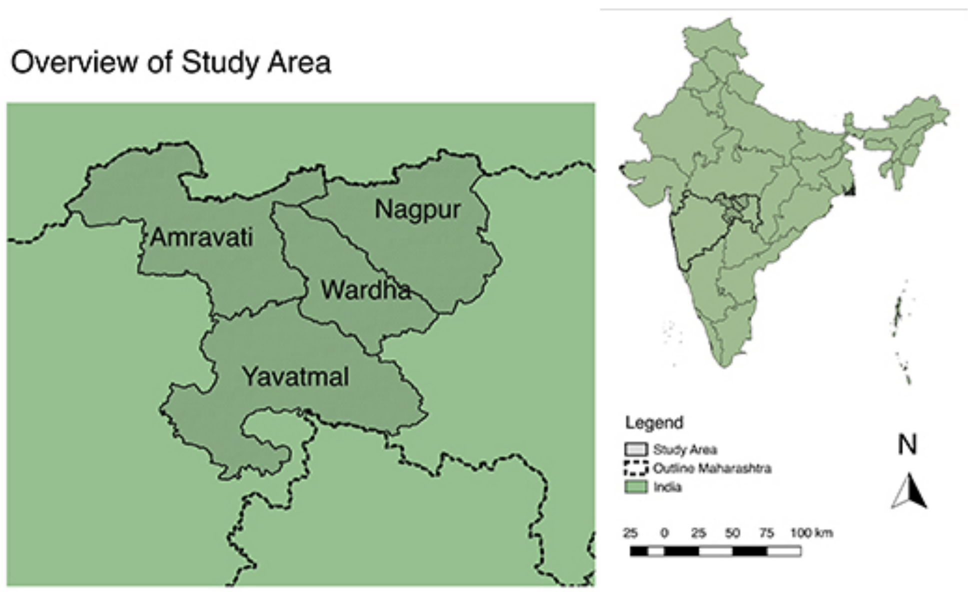

Figure 1.1: Our study area within Maharasthra: Amravati, Nagpur, Wardha and Yavatmal

The causes of these massive number of deaths have been primarily attributed to erratic rainfall, the attack of the pink bollworm [5], lack of protective gear while spraying pesticides and the non standard prices of cotton during selling [6]. Some have even blamed Bt cotton for the rises in indebtedness which leads to increased suicides while other claim that the practice of using Bt cotton has been poorly managed, leading to deteriorating environmental health and growing resistance to the pink bollworm [7]. Bt cotton has led to the decreased use of pesticides but still there is an increased health risk with the application practice and likely mismanagement leading to resistance [8, 9]. Meanwhile the region is drought-prone and water sensitivity is high. The high dependence on rainfall where nearly 65 percent of the farmers have no support from other sources of water infrastructure, make them highly vulnerable to changes in the Indian monsoon [10]. The cotton crop is highly prone to pests and diseases, and to safeguard them from infestation, farmers are resigned to increase their costs of investment. Wide fluctuations in the cotton demand prices, and inadequate market infrastructure add to farmer woes. Critical interventions are therefore required to provide farmers safety nets against these variable forces.

The causes of these rising suicides are hydrological as well as social. The objective of the baseline study is to therefore address the issue of improving the water use efficiency of small-holders in a multidimensional form. This can be done by incorporating a data driven analysis of the hydrological resources as well as the socio-economic conditions for the purpose of suggesting physical interventions in the form of community farm ponds.

While trying to address these objectives, it is indeed interesting to take note of success stories of irrigation interventions in other village communities across India. As an example is the Alwar district in Rajasthan which by the mid 1980s had run dry after years of deforestation and mining and was therefore largely barren with un-cultivable fields. Constant use of bore-wells had driven the already depleting aquifers to become dry. Persistent work of building check dams, farm ponds and johads (local term for rainwater storage wetlands) has now resulted in the rise of ground water tables and has made agriculture more viable. Similar interventions of earthen check dams being built to harvest rainwater has proven to make agriculture more sustainable by improving ground water table levels in Gujarat and Madhya Pradesh as well. In the same state of Maharashtra, as that of our current study, two villages Ralegaon Siddhi and Hiware Bazar of Ahmednagar district, stand out as exemplary cases of what effective water management can do to combat even the most severe of droughts. Persistent effort directed towards recharging the groundwater through about 40,000 trenches and check dams accompanied by water budgeting and growing crops according to the amount of rainfall, has safeguarded the villages against droughts. Farmers who had migrated to the cities in the earlier decades started to return after these interventions. [11]

1.2. Cotton Growing

Globally, cotton production is responsible for 2.6 per cent of all water use. The amount of water required to produce 1 kg of cotton is 10,000 liters on average for the world's production [12]. This amount of water varies by region due to climatic and biophysical factors that influence the water requirements of the plant and also due to processing and farming practices. In India, the amount of water required to grow the same 1 kg of cotton is 22,500 liters, more than twice the global average. In India, the field level crop water requirement (the natural amount of water demanded by cotton plants for the given environment) is 810 mm/year compared with 516 mm/year for the USA, 718 mm/year for China, and 850 mm/year for Pakistan. The total consumptive use (the actual amount of water used by the cotton plants in the region through irrigation and rainfall) of field level cotton production in India is 538 mm/year; in the USA it is 419 mm/year, in China, 638 mm/year, and in Pakistan, 850 mm/year [13]. Globally, around 33 million hectares are planted with cotton, out of which 12 million hectares are in India. The crop water requirement is a useful metric indicating the favorability of climatic conditions from a water resources perspective: the lower the crop water requirement, the lower the evaporative demand and the less irrigation is needed allowing for a higher water-use efficiency in growing cotton.

Water use also may be increased through different farming or processing practices. Irrigation methods like furrow and sprinklers have a lower efficiency than drip irrigation, meaning less of the water is able to effectively get into the root zone for the plant to use. As an example, a study on the water footprint of cotton production in India found that irrigation consumption was on average 382 m^3/ha for drip irrigation and 427 m^3/ha for furrow irrigation [13, 14]. Also, when considering use of fertilizers and pesticides, overuse or misuse of certain chemicals can necessitate the use of a lot more water that is needed to dilute the polluted land and waterways. Use of minimal fertilizers or pesticides can be more water efficient in this way. Meanwhile, there is a trade-off in yield seeing as conventional fields typically produce nearly twice the production as organic fields. Despite this trade-off, the amount of water needed as a result of pesticide and fertilizer use for conventional fields is sometimes exponentially more than that used for organic fields, ultimately meaning that organic is more water efficient. For instance, in a study of Maharashtra cotton production the water needed for dilution of conventional fields was 88,698 m^3/ha while for organic fields it was only 384 m^3/ha, 230 times less than for conventional.

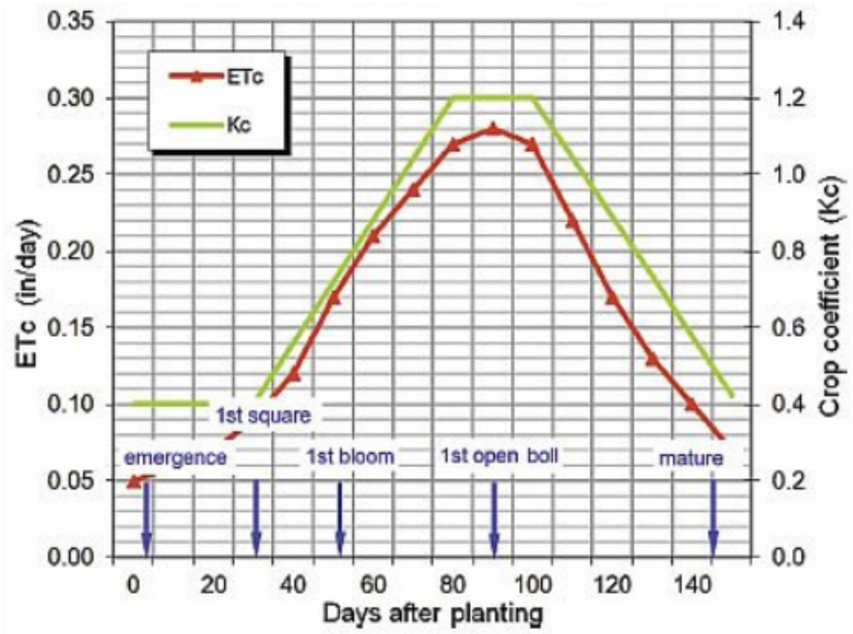

Figure 1.2: Water use and crop coefficient function for cotton [1]

While the overall water use of cotton production at the field level has been discussed, a crucial element of the water demand of any plant is the timing of the water application. This timing is critical especially to those farmers who are dependent on the whims of the rain. Cotton's water use increases gradually from the initial stage to the developmental stage and then finally peaking in the mid-season stage, afterwards dropping once the plant is mature. While the initial stage of germination may not require a lot of water comparatively, it is vital that there is enough water at this stage and if there is not, then the yield may drop dramatically or the plant may need to be re-sowed entirely [1, 15]. Other critical stages for cotton water use are from peak flowering to peak boll development (see 1.2).

1.3. Stakeholders

This report is part of a five year project 'Cotton Water' initiated by Solidaridad Asia. Solidaridad Asia is an organization that has been working to increase the sustainability of cotton practices since 2011. The organization has been active in India since 2004 and started two organic cotton and water programs in India's Maharashtra state in 2018, aiming to reach 30,000 farmers [16]. Solidaridad is active in the nine major cotton producing states by promoting the use of organic cotton. Besides Solidaridad many organisations are active in the area with the interest to increase the livelihood of small holders. These organisations include Welspun, Pani Foundation, Biocare+ in cooperation with the Better Cotton Initiative and the C&A foundation. Both the local and national government have multiple schemes designed to enhance the cotton production cycle, subsidizing elements such as seeds and fertilizer. Other major players also include seed, pesticide, and fertilizer chains, irrigation system companies, the textile industry and the end consumer.

2

Introduction into the study area: Geology and Hydrology

In the next sections, we will introduce the geohydrology, climate and farming practices of our study area further. In addition, we will mention alongside what remote sensing and ancillary data is used as an input for the hydrological model that is in turn used to identify critical hotspots.

2.1. Geology

Most area of the state Maharashtra is characterized by the hard basalts of the Deccan Traps. The Deccan Traps were formed about 65 million years ago by a hotspot that resulted in large volcanic eruptions. The Deccan Traps shape the geography of the area. Our study area is located on the eastern flank of the Deccan Traps having a slight slope towards the east. Figure 2.1 shows that most of Maharashtra is covered by these hard basalts. This strongly influences the hydrology of the area. Bedrock can only contain water in fractured spaces, whereas regolith has 20 to 50 times the water storing capacity of the bedrock [3], see figure 2.2.

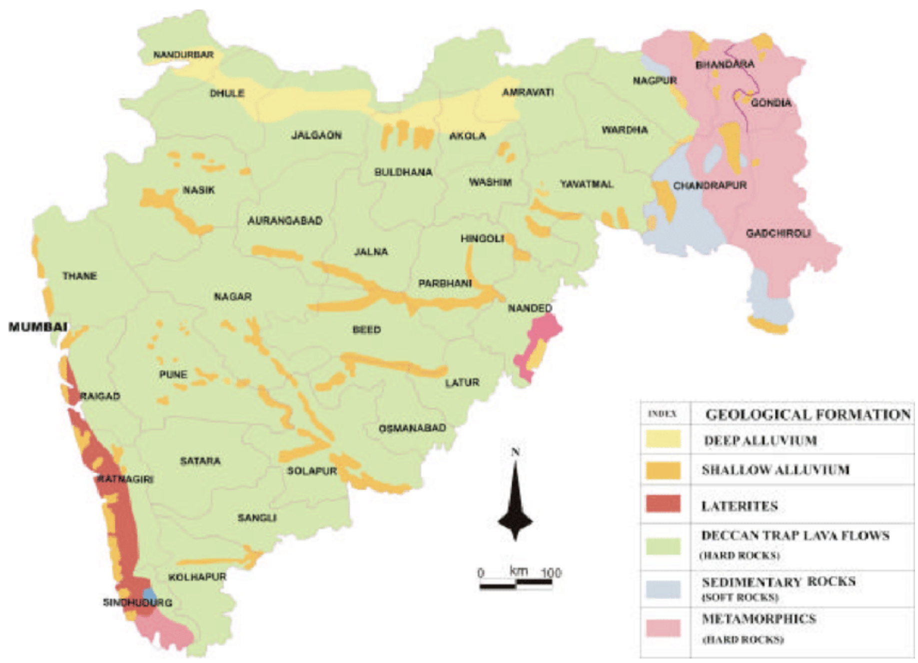

Figure 2.1: Geological Map of Maharashtra. From the Geological Survey of India, 1997 [2]

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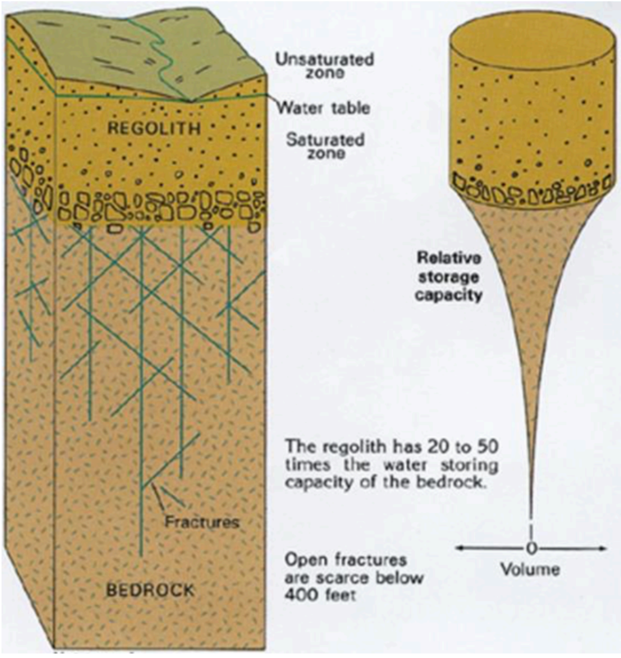

Figure 2.2: Soil storage capacity of regolith versus bedrock [3]

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2.2. Elevation

The geology on the area puts a significant stamp on the geography and hydrology of the area. A Digital Elevation Map (DEM) for our study area is shown in figure 2.3. This data is taken from the ISRO's free accessible Bhuvan Portal. The product is derived from Cartosat-1 with vertical accuracy of 8m at 90 percent confidence and with a spatial resolution of 1". Note that due to the geology the elevation in Yavatmal is higher than the other districts and might correlate with performance. This DEM is used in a later stage for stream flow mapping and intervention design.

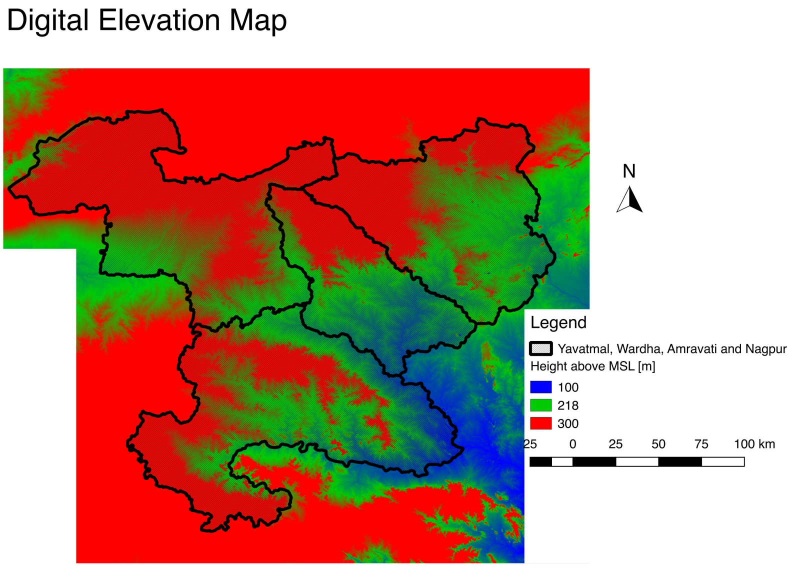

Figure 2.3: DEM

2.3. Soil Characteristics

Soil characteristics play an important factor in determining plant growth, water availability an maintaining carbon stocks and are used as an input product for the hydrological model. These characteristics include soil depth, defined as the depth to a (para)lithic contact (USDA Soil Survey Manual), and soil texture. The latter describes the relative content of particles of various sizes and indicate the fraction of sand, silt and clay particles in a soil. Texture influences the ease at which a soil can be worked, the amount of water it can hold and the rate at which the water enters and leaves the soil. Data on these soil characteristics was taken from the Bhuvan portal. This platform provided data at a 5 km grid as percentages. The mapping was done using visual interpretation of satellite products and regional soil mapping projects of soil profiles.

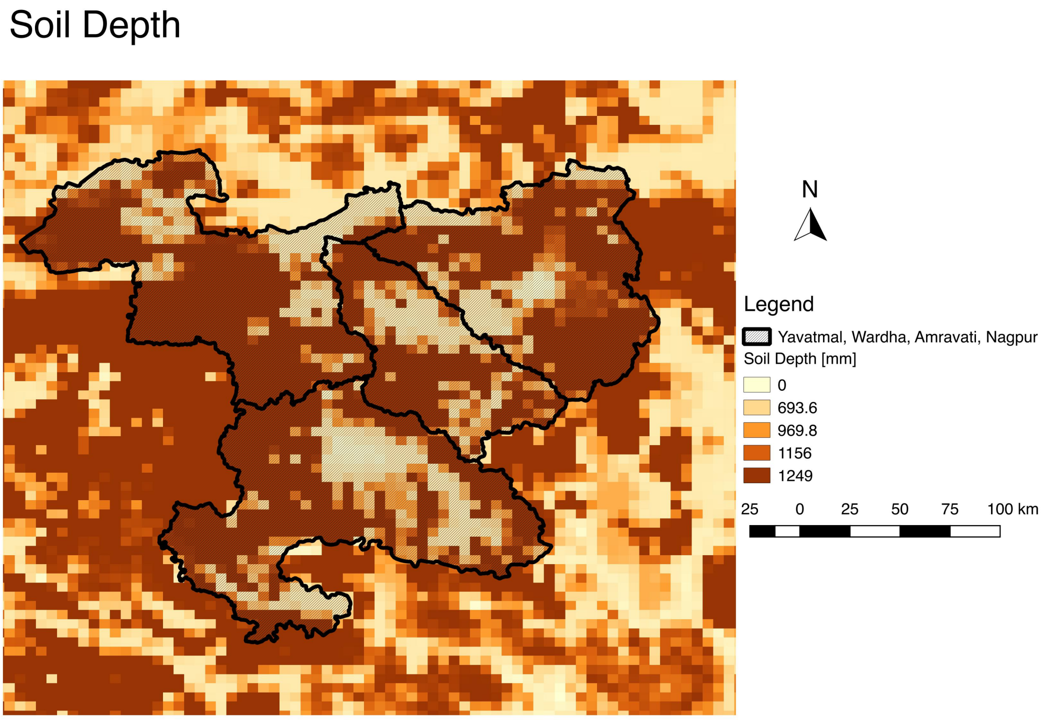

Figure 2.4: Soil Depth

Various soil maps gave the grid wise fraction area of a depth and texture class, and thus some reworking had to be done to get an average texture and soil depth value for every pixel. To calculate porosity we used soil diagrams and average porosity values for various texture classes. The results are shown in figure 2.4 and 2.5. Most of the soil in our study area is black cotton soil belonging to the textural classes clay loam, clay and sandy loam. Clay loam occurs mostly on higher altitudes, clay spread throughout the area and sandy loam mainly at the foot hill areas.

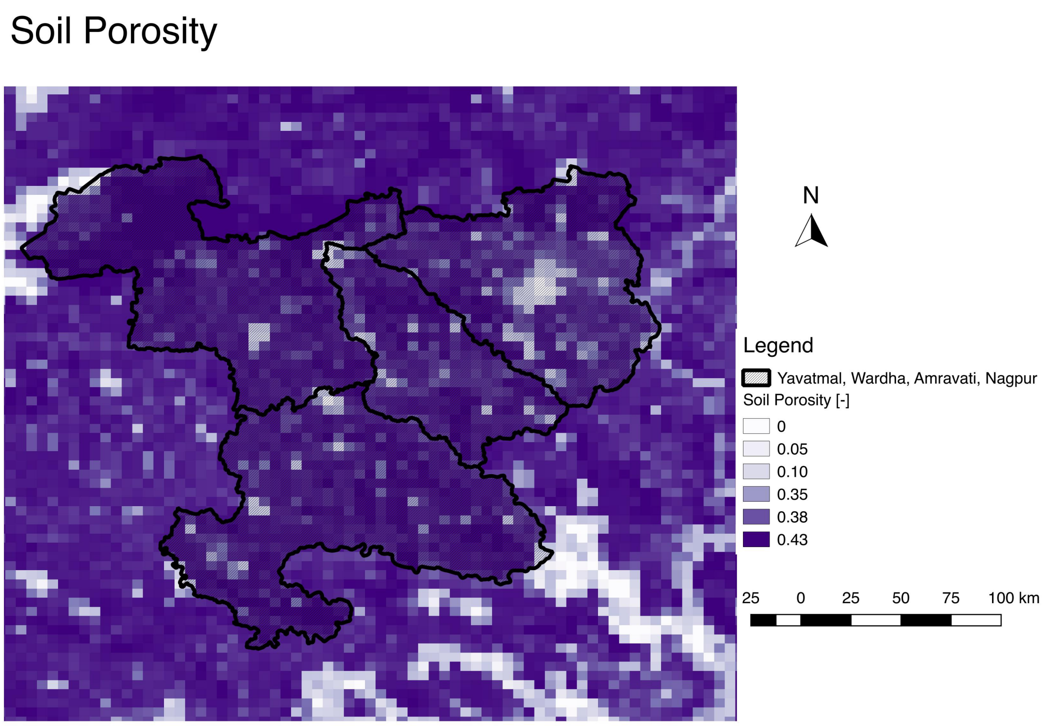

Figure 2.5: Computed soil porosity

2.4. Hydrology

Due to the hard rock geology of the area the occurrence of groundwater is mainly confined to secondary permeable structures. These include fractured and weather horizons and in upper unconsolidated materials. A small part of major rivers in the area is covered by alluvial deposits. Therefore, the geomorphological set-up of the area has great relevance to groundwater studies and subsurface aquifer characteristics due to impact of surface-groundwater interaction through the alluvium and fractures.

Of the major rivers that span the Deccan plateau, four major rivers run through Maharashtra of which Narmada and Tapti run west, while Godavari and Krishna run east, all of which are monsoonal rivers. A key indicator of a farmer's agricultural yield per acre of his farm land is dependent on the amount of irrigation that is available to him. This means that in addition to the local geology of the area, for irrigation to be supplemented to farms through canals, the proximity of the farm land to a stream also plays a very important role. Vidharbha's main rivers are Wainganga and Wardha which join together to form the Pranahita river and constitute a part of the Godavari basin [17]. The proximity of the different districts and taluks within the districts to some of the main streams of Maharashtra are shown in the map in Figure 2.6 which is made from the digital elevation map.

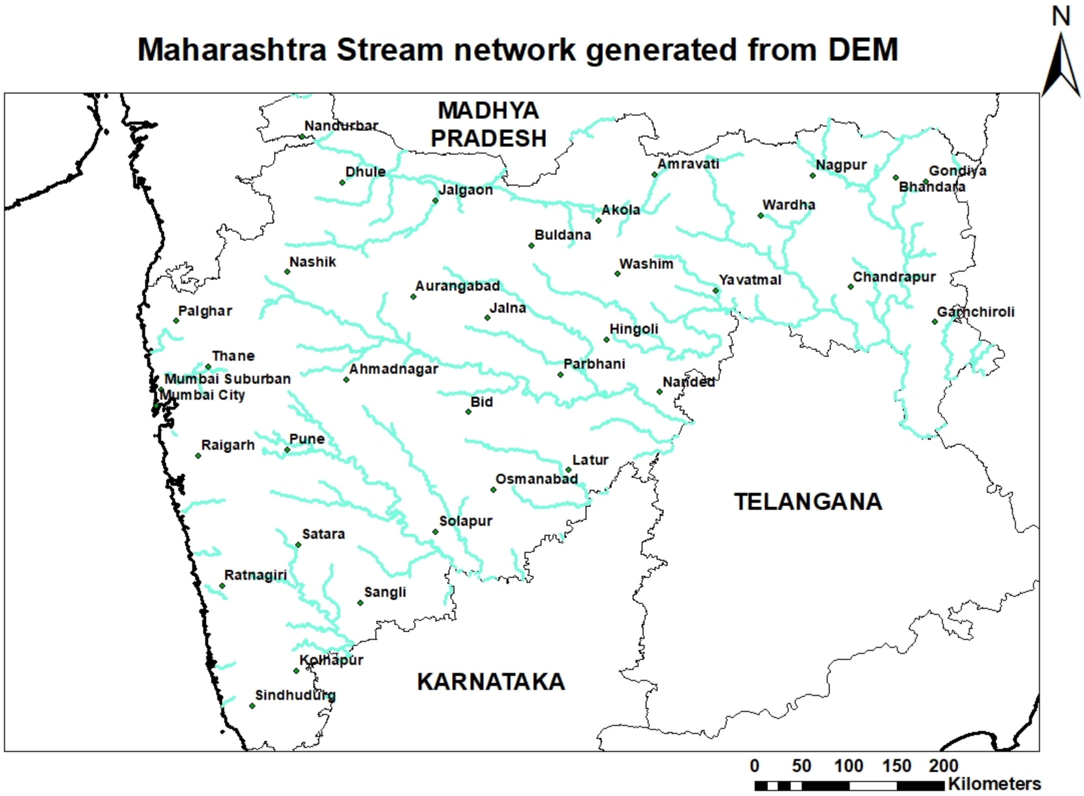

Figure 2.6: Stream flow network generated from DEM

3

Introduction into the study area: Climate

The climate of the study area is ruled by the tropical monsoon. The Western Ghats block winds coming from the Arabian Sea and cause rainfall. The monsoon starts around early June and lasts 3-4 months. The rainfall averages around 800 mm per year though can vary between 400 and 6000 mm locally. March, April and May are usually very dry months with high temperatures. The temperature averages around 25-27 degrees Celsius annually though can vary strongly locally. See figure 3.1 for a climate chart of Amravati.

Multiple studies of the Intergovernmental Panel on Climate Change (IPCC) report that under the business-as-usual climate change rate scenario (between RCP6.0 and RCP8.5) warming in India is between 1.7 to 2 degrees Celsius by 2030 and 3.3-4.8 degrees by 2080s relative to pre-industrial times. Precipitation under this scenario is projected to increase with 4 to 5 percent to 6 to 14 percent by the end of the century. In addition, over the decades the amount of extreme precipitation days (e.g. >40 mm/day) are expected to increase [18].

3.1. Precipitation

Precipitation data has been obtained from the Indian Meteorological Department (IMD) which is responsible for rainfall data collection through in situ rain gauge measurements. The resolution of this precipitation data is dependent on the station to station spacing from which measurements are recorded. The gridded spatial data used in this study has a resolution of 0.25° * 0.25° which also been used in several other studies [19]. The year of 2015 particularly stands out as a year with poor monsoon [10]. The maps below show the comparison of the mean rainfall in mm/day between the years 2015 and 2016. The scarcity of rainfall in the year 2015 is evident and is indicative of the year to year variability of the Indian monsoon on which the farmers are highly dependent.

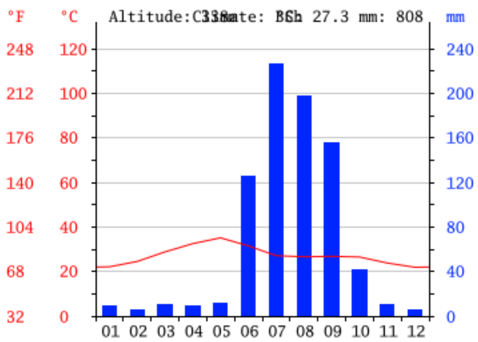

Figure 3.1: Climate of Amravati from ClimateData.org

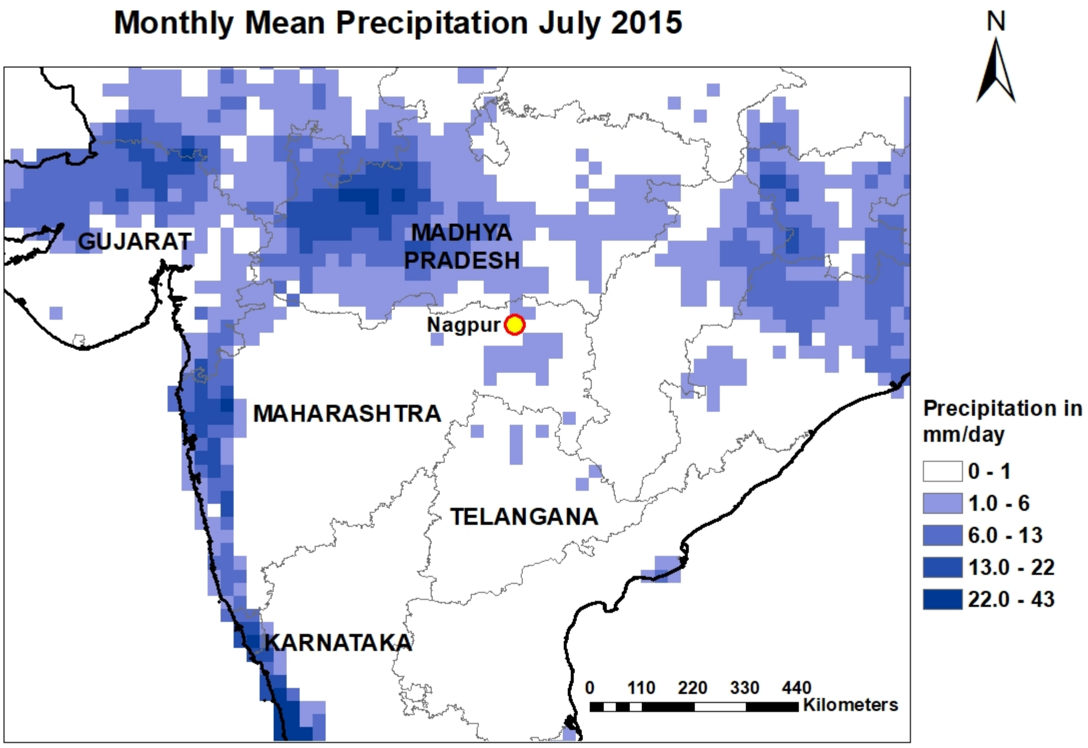

Figure 3.2: Mean Precipitation July 2015

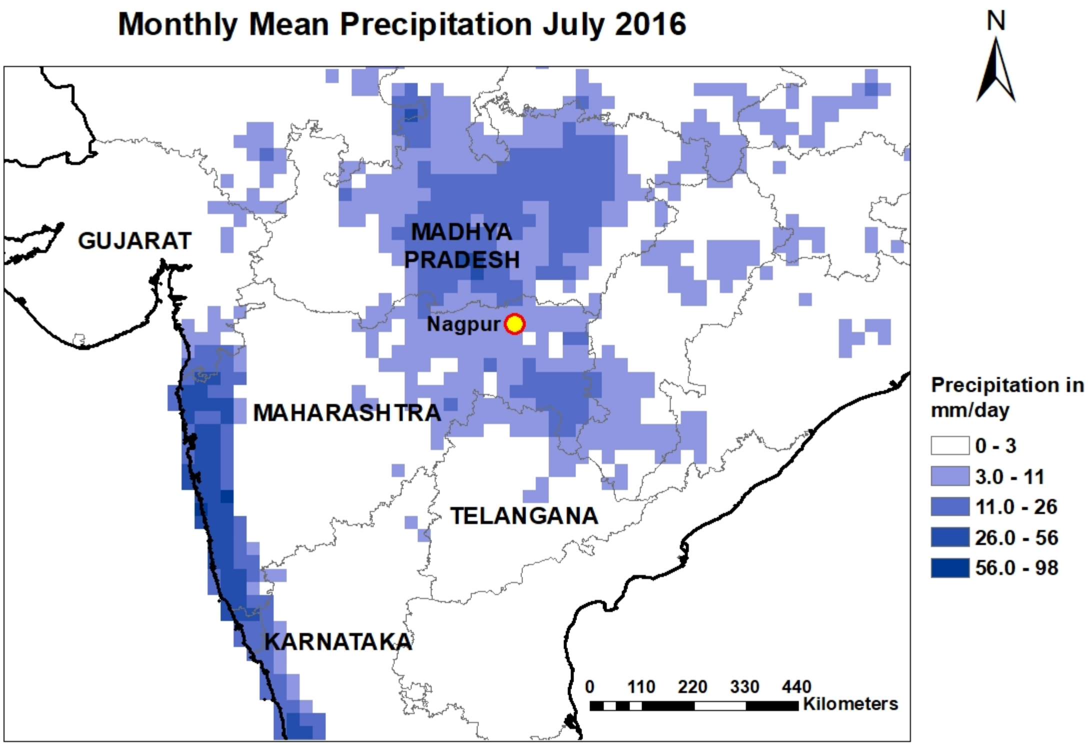

Figure 3.3: Mean Precipitation July 2016

3.2. Additional Climate Data

The hydrological model can be calibrated using various satellite products. These include soil moisture and climatic data such as evaporation. CCI, the Climate Change Intitiative of ESA, is one good example. The combined product of this project is based on both scatterometer and radiometer products and comprises global merged data sets at a daily resolution between 1978 and 2016 at a spatial resolution of 0.25° [20], see figure 3.4.
GLEAM (Global Land Evaporation Amsterdam Model) is another useful data source for the hydromodel. The source is a set of algorithms that estimate the components of land evaporation: transpiration, evaporation, interception loss, open-water evaporation and sublimation. The model also provides estimates on surface and root-zone soil moisture, potential evaporation and evaporative stress conditions. The data is derive from satellite products and comes at a resolution of 0.25° and at a daily temporal resolution [21] [22]. The daily data of potential evaporation was used as input for the socio-hydrological model.

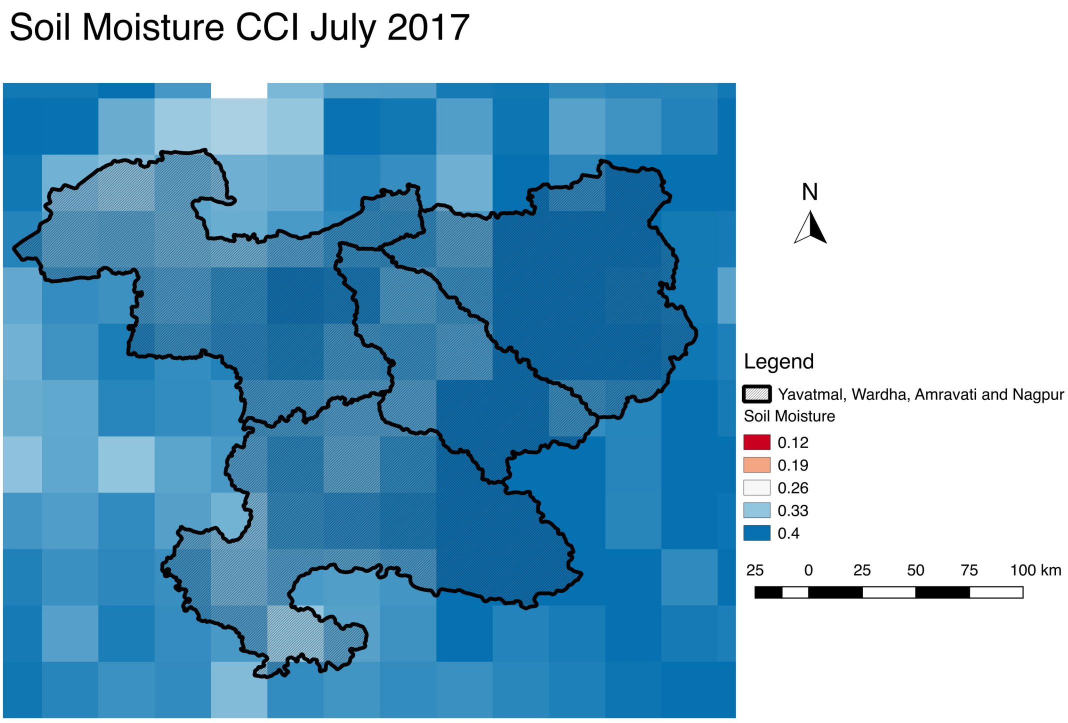

Figure 3.4: Soil Moisture as a volume-volume fraction

4

Introduction into the study area: Farming practices

As mentioned previously Vidarbha is one of the main cotton growing regions of India. In this chapter we discuss some social statistics of the area and general farming practices.

Cotton needs 700-1200 mm of water to meet its maximum water requirement, depending on climate and crop-growing period. In our study area the rainfall averages around 800 mm per year and varies between 400 and 6000 mm locally, therefore, many areas require irrigation [4]. The water requirement is low during the first 60-70 days after sowing, and is highest during flowering and boll development [4]. The most common methods in our study area for irrigation are flood and furrow irrigation [Cotton Cooperation India]. The latter is more effective and water saving. Drip irrigation is also increasing in prominence in the area. The frequency of irrigation depends on the water retention capacity of the soil. Sandy loam soils require 3-5 irrigations, whereas red soils with low water retention capacity benefit from 4-13 light irrigations [Cotton Cooperation India]. Besides flood, furrow and drip irrigation some farmers use sprinkler irrigation. This system can however only be used in the earlier stages of the crop cycle, as it will damage the flowers and is subject to interference by the plants. The ability to irrigate not only depends on the availability to irrigation resources, it also strongly depends on the accessibility to water resources, which the hydrological model will aim to take into account. Water is usually taken from the ground through open wells, and rarely borewells. Water sources are locally recharged through farm ponds and small reservoirs. In the area farm ponds are generally not used for water storage but more as recharge structures. Since they are unlined, they act as regions that allow for the percolation of rainwater into the ground. A typical farm pond is shown in the figure 4.1

4.1. Land Cover and Land Use

The geology, geography and soil type are closely related to the land use pattern. Figure 4.2 shows a map of land use in our study area at a 100m resolution for DAAC NASA. Note the correlation with the Digital Elevation Map of figure 2.3, most highly elevated areas are not suitable for farming practises. From this map we filtered out the agricultural areas and the model was only run for pixels were agriculture is significant.

4.2. Population

Figure 4.3 shows the population count of the districts of Maharashtra. According to the 2011 governmental census, the population of the districts is 2.7 million in Yavatmal, 2.9 million in Amravati, 4.6 million in Nagpur and 1.3 million in Wardha.

4.3. Social Data

From secondary sources we found data sets on cotton yield in the area. The data is provided by the government of Maharashtra, dept. of agriculture and contains yearly average yield data between 2011 and 2016. An average of these years is shown in figure 4.4. Note that this map already provides an

Figure 4.1: Farm pond in Wardha district

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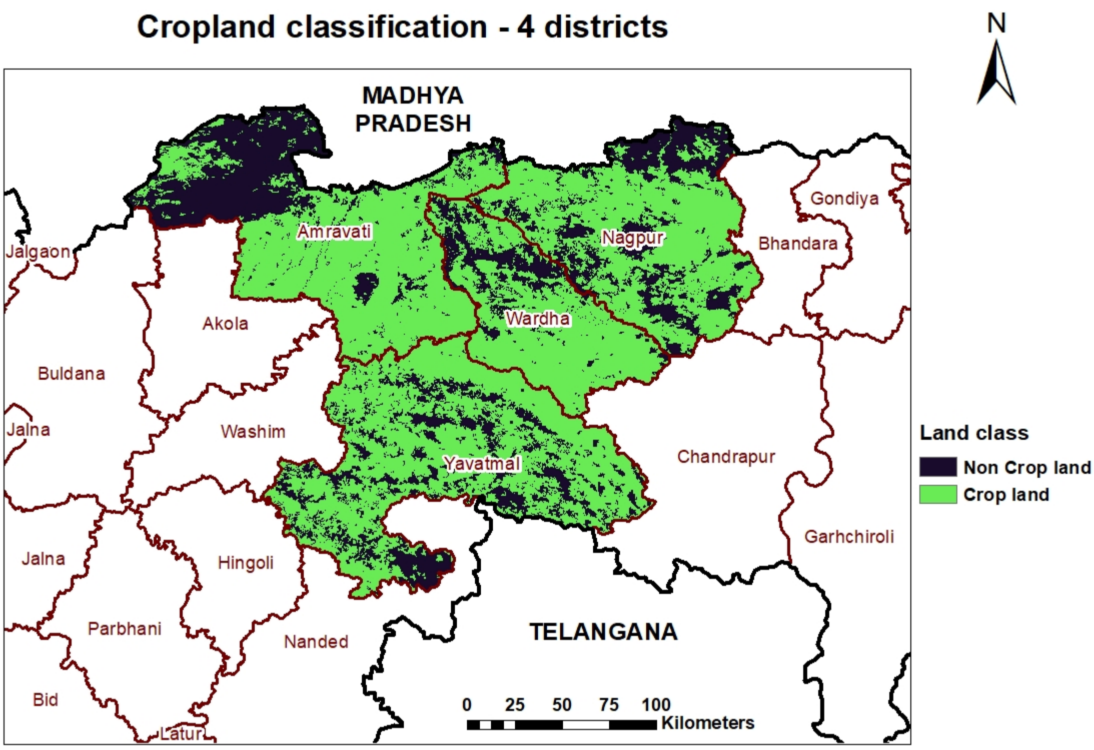

Figure 4.2: Land classification map 100m resolution (DAAC NASA)

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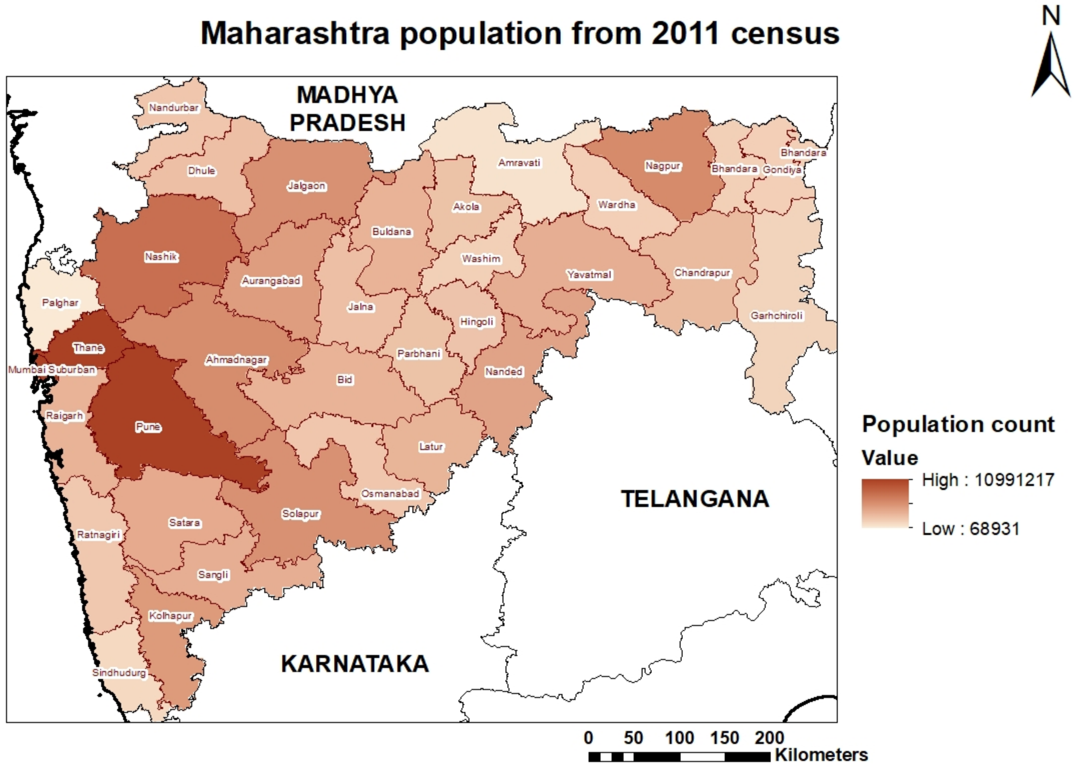

Figure 4.3: Population count (Indian government census 2011)

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indication of were the major hotspots are, that is, in what areas the average yield is lower. This map is later used as a validation with the outcome of the hydrological model.

4.4. Visual Data

In addition to the satellite products described before visual data can be a great aid for identifying farming practises. One could use it to see where cotton is grown and what plots are irrigated when. In addition, NDVI maps can be used to estimate the greenness of pixels. Visual spaceborn data, from for example the Sentinel mission is readily available from the Sentinel Hub. The issues include the ineffectiveness on cloudy days, a revisit time of approximately 10 days and a relatively low spatial resolution. Airborne data can be much more useful due to the higher resolution and potentially more frequent visit times. However, aerial data is scarcely available in the area. To show its potential figure 4.5 is shown. This data comes from Bing maps, unfortunately the exact data of the photographs is not given, which is a general problem with Bing maps. The image is include to show the power of the high resolution data: the cropping pattern of the plot is shown, wells can be identified and it is clearly visible what plots are and are not irrigated. Using remote sensing for identifying cotton grown and irrigated areas is however a whole new study and falls outside the scope of our study.

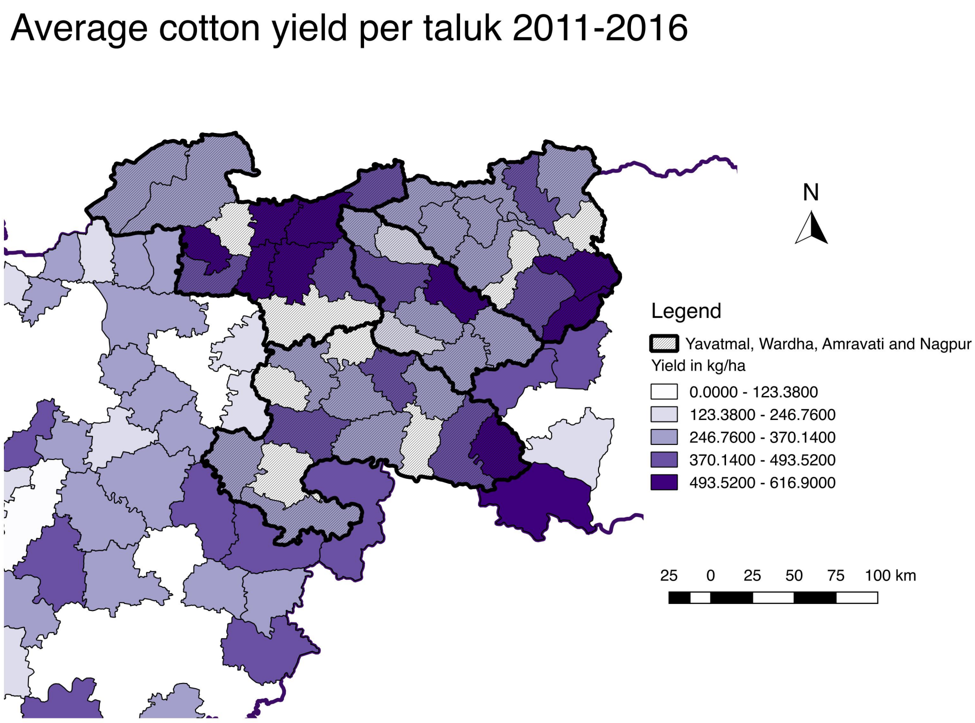

Figure 4.4: Cotton Yield from governmental data. Average yield in kg/ha between 2011 and 2016.

Figure 4.5: Bing aerial data from an unkown date. The figures show the potential of using aerial data to investigate farming practices: where farmers use irrigation and where farmers do not. The white spots on the plots show locations of open wells.

5

Methodology

The tools used to design appropriate interventions include remote sensing data, a socio-hydrological model and a survey. A detailed description of those tools can be found in later sections. How these tools interplay is shown in figure 5.1. Remote sensing data of the region was first collected. This data was used for the hydrological model. The hydrological model was used to estimate the areas which were distressed and needed interventions. The field survey supplied socioeconomic data for the socio-hydrological model and psycho-social data used for a behavioral analysis of the farmers decisions.

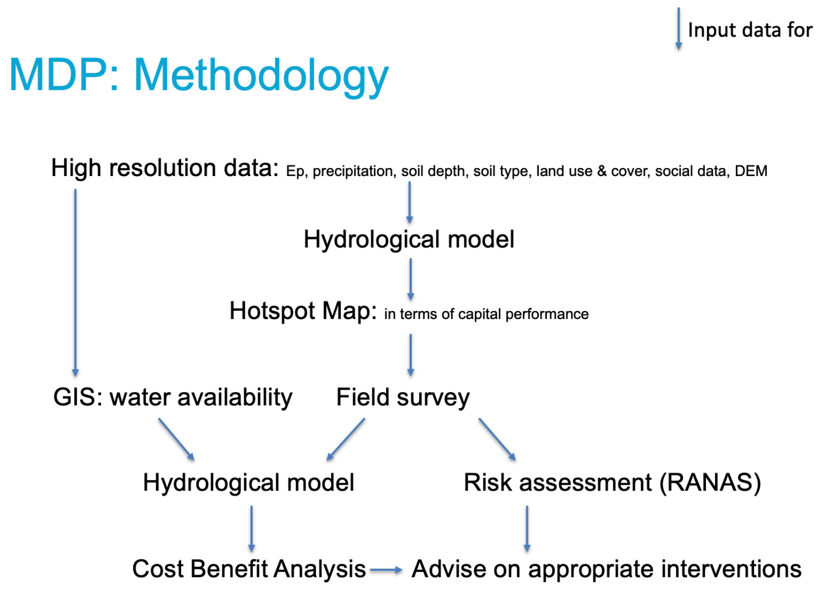

Figure 5.1: Overview of the various tools used for the study and how they interact

The outcome of the socio-hydrological model and the survey serve as the basis on which appropriate interventions for the farmers in the regions can be proposed.

5.1. Surveying Methodology

Interviews were conducted for a total of 345 households with the intention of understanding why some farmers are successful and why some are failing. Villages were selected through a combination of methods utilizing the socio-hydrological hotspot identification model to find regions of interest and also through the work of the Solidaridad's field coordinators who relied upon their relationships with village representatives and farmers in the area to organize interview sessions. Farmers were selected for interviews on a voluntary basis and on the prerequisite condition that they cultivated cotton. The goal of the survey was to learn of the different perspectives farmers have on the cultivation practices, irrigation methods, and the financial constraints that influence their capital. To do this, the survey was broken down into two main components: a farming practices component and a psycho-social evaluation.

Psycho-Social Evaluation
The psycho-social evaluation incorporates RANAS (Risk, Attitude, Norms, Ability, & Self-regulation) methods to understand the links between socio-economic indicators, psycho-social factors, and use of irrigation systems. The various factors represent the following:

- Risk factors indicate the interviewee's perception of risk of water scarcity as pertains to crop failure;
- Attitude factors indicate the interviewee's perception of the situation regarding their beliefs about the costs and benefits of the behavior in consideration (irrigation usage);
- Norms factors indicate the the perceived normality of the behavior;
- Ability factors represent the interviewee's perception of their own ability to execute the considered behavior;
- Self-Regulation factors indicate the interviewee's perceived ability to continue a behavior and maintain.

RANAS is a tool that works by first defining the relevant behavioral factors related to the specific behavior of concern. It continues with identifying the influencing socio-economic indicators of those behavioral factors. Finally it uses these to understand what are the most important behavioral factors and socio-economic indicators for this behavior in terms of influencing the ultimate behavior [23]. This identification of direct and indirect influencing factors is able to give insight into the relevant behavioral mechanisms that are of concern and may help policy makers best plan for communities. RANAS was first presented as a method to understand and influence WASH (Water, Sanitation, and Hygiene). Its increasing usage has shown its versatility beyond WASH applications and it is applied here to improve efficacy of interventions where technical, engineering solutions cannot explain it all [24]. The use of so many psycho-social parameters in analysis regarding irrigation and water supply infrastructure here is novel in its application. While other studies have focused on the impact of linking behavior factors with socioeconomic features to understand conservation practices, not many have attempted to understand as many behavioral factors in such a local context where interventions have had little to no success [25]. With the intention of the project focused on interventions to improve conditions that are anticipated to come in the form of irrigation systems, RANAS provides a tool that can be used to better understand why some may adopt irrigation technology and others may not, and also what are the limiting factors for households when it comes to using irrigation systems. This can then be used to optimize the efficacy of any interventions by helping decision-makers apply interventions to those who would receive it best.

Farming Practices
The general information study focused on asking simpler questions to understand the farmers' situation. It ranged from household information (e.g. family size, area of land cultivated) to social perspectives (e.g. who is responsible for your water). This part of the questionnaire is important because it is able to help fill in the gaps that are not explained by remote sensing data or other existing government records. The survey also has provisions to record the difficulties farmers face.

5.1.1. Field Methodology

During the field visit, 345 households were surveyed in total in the four districts of Yavatmal, Wardha, Nagpur and Amravati. Villages were selected from a combined approach of finding locations near hotspots (as identified by the socio-hydrological model) and through use of Solidaridad's field coordinators. During the process of conducting the survey at the field, farmers who cultivated cotton were interviewed. The target farmers were those that would give the best representation of farmers in the area, so farmers with smaller and larger plots of land were all accepted. Isolated one-on-one interviews were targeted although it was common for bystanders to be present at most interviews. Group interviews were also collected to help quickly gain a broad understanding of the area, however since they were more prone to biased responses, the priority was to conduct individual interviews.

The questionnaire was translated into the local language, Marathi, first through Google Translate and then revised by the field coordinators. The questionnaire was then back-translated to English for verification. There were sections related to 1. general demographics, 2. water usage, 3. financial circumstance and decisions, and 4. cultivation practices that were used to collect the data necessary for analysis. Some of this data collected would also serve as information for the socio-hydrological model.

Behavior-related questions used in the RANAS analysis were scored on a scale of one to five-item *Likert* scale; other questions accepted answers using a *nominal* scale or an open, numeric input. Open questions were limited in their use for data collection as their translation to statistical analysis is not good, but they were used with some farmers to expound upon their answers or to learn of their situation in more depth which helped tremendously with the edification of each interviewer. Most of these open responses were not collected systematically.

	Determinant Factor	Question	Mean	S.D.
Risk	Perceived Severity	How does the current water supply compare to the water you need for your crops?	3.74	0.94
	Perceived Vulnerability	How confident are you that you have enough water in the next 5 years?	3.98	0.97
	Perceived Severity	How severe is the impact on you when you do not have any water for your crops?	1.56	0.66
	Perceived Vulnerability	How responsible are you for your water source?	2.75	1.29
Attitude	Feelings	How much more effort do you believe using irrigation takes?	2.05	0.75
	Beliefs About Costs & Benefits	How much more crop production do you believe you could have if you used an irrigation system?	1.51	0.55
	Beliefs About Costs & Benefits	How willing are you to pay for irrigation systems?	2.96	1.02
Norms	Others' Behavior	What proportion of people in your village use irrigation systems?	2.39	1.19
	Others' Approval	People who are important to you, how much do they approve of using irrigation?	1.18	0.46
	Personal Importance	How important is it to you that you use water as efficiently as possible?	1.44	0.59
Ability	Confidence in Performance	How confident are you that you could operate an irrigation system?	1.30	0.58
	Confidence in Continuation	How much more time do you believe using irrigation takes?	2.41	0.88
	Confidence in Recovering	Has it become more or less difficult for you to get water in the last 10 years?	1.68	0.67
Self-Regulation	Barrier Planning	To what limit could you withstand water shortage?	3.60	0.99

5.1.2. Data Analysis

RANAS Psycho-Social Factors Out of the total 345 households surveyed, 264 were eligible for psycho-social analysis based on necessary congruent questions used for RANAS. The method by Daniel [26] was followed to analyze the RANAS data through the use of PCA (Principle Component Analysis) and a BBN (Bayesian Belief Network). RANAS psycho-social factors were collected at the sub-factor level requiring the need of PCA to simplify the BBN structure. Data was analyzed using SPSS software. The first component resulting from the PCA was used to represent each behavioral factor. The components were then divided into three classifications: low, moderate, and high. This division was done by splitting the range into equal thirds. These classified factors were then used in the BBN analysis. The behavioral factor, Self-Regulation, did not use PCA as it had only one question that was used for its representation. A classification of Self-Regulation was used that separated scores greater than 3 as high, lower than 3 as low, and equal to 3 as moderate.

Bayesian Belief Network Model BBN's have been tested for resource management in environmental applications and proved an accurate method while also visually descriptive and easy to use [27]. A BBN model was constructed to analyze the relationships between the different factors and how they may influence the relevant behavior. Two behaviors were tested: the use of micro-irrigation (inclusive of sprinkler and drip systems) and the use of irrigation, in general. When designing the model and the links between various factors, a chi-squared test was used to determine statistical significance which can be used as a proxy for what links should be made. To reduce model complexity and validate links, model performance was checked for each node by altering the state of the probability and noting the change in outcome on the behavior. If there was no change in the outcome, then the node is insignificant, and it, or the specific link tested, can be removed from the model. Socio-economic characteristics were also only indirectly linked to the behavior through psycho-social factors as it is assumed that socio-economic indicators rarely directly influence a behavior; this decision also simplified the model which improves the result. Therefore, there is a hierarchy of nodes trending from socio-economic characteristics to psycho-social factors to behaviors.

GeNIe Modeler 2.4 was used to build the BBN as it provides a simple and intuitive GUI with sufficient algorithmic performance [28]. The BBN is tested through use of LOO (Leave Only One) validation [1]. The ROC (Receiver Operating Characteristics) curve was also used as a performance evaluation metric for the model with the AUC (Area Under the Curve) numerically representing the model's accuracy [29].

The influence of each node was tested with a sensitivity analysis by altering the state of each node to 100% for the various states and observing the change in behavior (For example, the probability of the Age node can be updated to 100% 'Older than 50' and then the change in Irrigation or Micro-Irrigation can be checked to see the role that Age plays on this behavior, at least indirectly). This analysis gives an assessment of the influence that each node has and helps the inference of what are the most important factors that are influencing behavior in this case.

Socio-Economic Characteristics Seven socio-economic characteristics were identified as relevant for this study: 1. Age, 2. Education, 3. Water Source, 4. Number of Dependents, 5. Number of Family Members that help with Farming, 6. Wealth level, and 7. Promotion. Wealth level and promotion were also collected at a subfactor level so PCA was performed to create a single factor to represent the characteristic. A wealth index was created using PCA of area owned, total annual income, and number of livestock owned. The impact of obtaining income information strengthened the wealth index and area was a good fit as it is often tied directly to wealth with the ability to grow more crops. Material data was collected on roof and home construction material, but the uncertainty around assets as a good metric for a wealth index combined with the low variability in responses from the farmers led to these measurements being excluded from the PCA [30]. A promotional index was created from questions regarding frequency of promotional influence, helpfulness of promotional material, and source of promotional material.

Each of the characteristics were classified also into three groups, with the exception being water source since there were more than three categories recorded and it could not be simplified. Number of Family Members that help and Number of Dependents was broken down into low ($N<2$), medium ($1<N<4$) and high ($N>3$); Education was divided into none or primary, secondary, or graduate or above; Age was divided into less than 35, between 35 and 50, and greater than 50.

Winners and Losers An analysis was made of good-performing farmers and poor-performing farmers. Since identification of these specific households could not be done prior, good-performing and poor-performing are based off of reported incomes. This was scaled into an income-per-area factor that represents the profits farmers are earning from each acre of land so that farmers with large plots of land do not dominate income where they may not be as productive for each unit area. The analysis to determine if there are any features that relate with success was performed using a Bayesian-Belief Network (BBN) model to observe relationships between low, medium, and high income-per-area with different characteristics such as irrigation, irrigation technology used, age, yield, cotton price, education, and area of land owned.

Organic Cotton Analysis Organic cotton generally leads to lower yields when compared with conventional and Bt cotton [15, 31]. They may range anywhere from 50% to 95% of Bt yields, at least in the first few years. Although when compared with conventional cotton cultivation, organic practice may produce comparable yields after several years with diligent farming and improvement in environmental health over time, it still generally lags behind Bt cotton in widespread application [32, 33]. However, these lesser yields require less capital investment in the way of fertilizer and pesticides. Therefore, it was analyzed how profitable organic cotton farming may be with a lower yield but lower input costs per acre by discounting the relevant expenses from the net income formulation and decreasing the yield. Irrigation costs and seed costs were not adjusted as there is not a decisive difference between organic and Bt practices.

[1] LOO validation works as an extreme case of K-fold validation which divides the data-set into K parts of equal size where K for LOO is equal to n. The model is trained on *n-1* times and tested on the remaining data point. LOO validation is recommended as the most efficient evaluation method.

5.2. Socio-Hydrological Model Methodology

5.2.1. Problem outline

The overall goal of the problem is to improve farmer welfare and well-being. Problems related to water resources play a large role in this case, but to tackle such a socio-economic problem from a purely geophysical and climatological point of view would leave important aspects out. Another challenge is the scale of the project. The three districts of Yavatmal, Wardha and Amravati where surveys were conducted and which are the focus areas of the project, have a combined population of almost 7 million people, most of which are completely or partially dependent on cotton production. Additionally, the network of cotton growers in the area is poorly mapped and assumptions regarding where the situation is most critical have to be made.

5.2.2. Model Description

For the mapping of the socio-economic situation of the farmers, the socio-hydrological modelling framework by Pande [34] is followed.

The socio-hydrological model follows the interaction between five basic model parameters. These are: household capital, water storage, livestock, soil fertility, and biomass fodder. These parameters interact with each other through a series of feedback mechanisms on an annual basis. There is one exception to this which is the water storage which is evaluated on a daily basis. Water storage then interacts with the other parameters on an annual basis. The main parameter that this report will focus on, is household capital. As for this study, the role of soil fertility is not considered.

5.2.3. Hotspot Identification

For the purpose of determining areas that need specific interventions, focus has to be made on identifying locations that face water crunches or where the local physical environment renders it difficult to cultivate cotton. From here on, these regions are called 'Hotspots'. Input parameters for identifying these hotspots include hydrological data like time series of precipitation in the districts of Nagpur, Wardha, Amaravati and Yavatmal in addition to geological data like soil depth in the aforementioned districts.The parameter of soil depth is crucial since it forms the basis on which soil water holding capacity is estimated. Other input data includes commodity price indices for cotton and urea fertilizer, which was taken from the world bank[35]. The four districts were divided into a total of 5127 pixels. For all these pixels, a simulation was run to identify how the individual pixels performed with regard to being identified as hotspots. The input parameters for the simulations was taken as a time series of data ranging from 2002 to 2016. The model assumes an arbitrary initial capital of Rs 50000 for every farmer. The simulations over the time duration yielded a capital for the year 2016 and this change in capital over the years, served as the metric that determined the pixel's performance in the hotspot analysis. Some specific details which are noteworthy at this point (where further field level information is unavailable) are that most of the other input parameters remain constant in space. These parameters include initial livestock (2 milk animal equivalents), farming area (2 hectares for cotton and hectares for grazing) and fertilizer use (66kg N per ha). To account for farmers taking loans, a constant crop loan interest of 12% on a 25000 Rs crop loan was considered.

5.2.4. Implementing survey data

From the survey several parameters were collected to be used in the model for a post-fieldwork analysis:

- GPS Coordinates
- Number of dependents and number that farm
- Total farming area
- Total cotton cultivated area
- Number of livestock
- Loan debt and interest rate
- Additional income

- Price of seeds in Rs per unit area
- Selling price of cotton
- Irrigation applied [yes/no]
- Irrigation tech
- Fertilizer applied
- Fertilizer costs per unit mass
- Pesticide cost per unit area

This data from the survey provides a more accurate look into realistic situations and allows for comparison of interventions to be made. Using the following procedures, the model produces an output as a product of the surveyed inputs. Spatial datasets of precipitation and soil depth by virtue of having location information, were readily used and tied to farmer surveyed locations. The number of farming dependents is used for estimating the total available labour to the household. Cotton farming area is taken as a direct input for cotton farmland area. This is deducted from total farm area and an estimation for income from other crops is made by multiplying a constant scalar to the amount of area used for other crops (and not dedicated to cotton). Grass area, which is used for livestock to graze from, is calculated as the maximum of either 0.24ha/livestock * livestock or as 20% of farmland but, this is not subtracted from the farmland area. The number of livestock is taken directly as an initial constant.
Loan debt and interest rate are used to determine the annual interest payment of a farmer. The model assumes that this loan debt cannot increase or decrease.
Additional income is added onto the farmers total annual income.
Prices of seeds, fertilizers, and pesticides are used as the main components to calculate agricultural expenses.
Selling price of cotton is used as their selling price in the most recent year. The selling price of all other years is then scaled according to the world bank data[35] to include price fluctuations. The formula for this is:

$$P_i = \frac{W_i}{W_n} * P_n \tag{5.1}$$

where W represents the world bank price index and P indicates the farmer selling price.

Irrigation is applied up to a percentage of maximum soil moisture capacity. This percentage is defined by how wet/dry the previous year was, depending on the amount of annual precipitation. The precipitation time series is ranked by annual amounts. The percentage is determined by sorting and ranking the precipitation time series by the annual sum. The year with the least precipitation is given the rank 1 and the year with the most precipitation is given rank n. All the ranks are then divided by the total number of years n and this corresponds to the percentage of total porosity to which the soil moisture can be replenished. If the soil moisture storage drops below this percentage of maximum storage the soil is then irrigated up to this amount.
The irrigation coefficient then corresponds to the method used which is 0.6 for furrow or flood irrigation, 0.7 for sprinklers and 0.9 for drip irrigation [36]

The amount of fertilizer applied is taken as an input to the model. The fertilizer yield coefficient is a scalar between 0 and 1 applied to the maximum cotton yield that is used to determine the actual cotton yield. It is calculated as follows:

$$\eta_F = b + min(\frac{F_{app}}{F_{max}}, 1.) * (1 - b) \tag{5.2}$$

in which b is the minimum yield factor if no fertilizer is applied. This depends on the soil fertility, but because this is disconnected from the model, b is set as a constant zero. This does have the implication that applied fertilizer has a rather large impact on yield. F_{max} is assumed and set at 156 kg N/ha.[37] F_{app} is taken as the amount of kg fertilizer applied by the farmer * 0.5 as the fertilizer nitrogen content factor. Additionally the nitrogen from cow manure is added to the applied fertilizer.
The price of fertilizer is determined by the survey details from the farmer and then historically scaled to the pink sheet data[35] of urea similar to how the cotton selling price is scaled. Pesticide and seed costs are not scaled this way however and just taken as constant.

5.3. GIS Methodology for interventions

To explore the potential of water harvesting projects and the amount of extra water available for irrigation we performed an analysis using QGIS. All surveyed villages were included in the analysis and organized into groups depending on location, as closely located villages are expected to benefit from the same water harvesting project. The entire catchment was divided into small sub basins depending on their areas and distances to each group of villages. Six sub-basins were determined, corresponding to six-groups of villages.

A Digital Elevation Model (DEM) and a SWAT (Soil and Water Assessment Tool) model were used to determine the area that generates runoff. This data is the same as was used for the hydrological model. To examine the up-stream boundaries for each sub-basin, different thresholds were tested, starting from 5 km2 up to 200 km2. Finally, the rational method was used to calculate the discharge water for each sub-basin.

Land-use and land-cover maps were used to determine the area of non crop-land within each sub-basin. The intersecting area is considered as barren area where runoff is generated and groundwater is replenished. There are limitations in this process, because the land-use land-cover map defines the area according to crop and non-crop land. Linking this assumption with the socio-hydrological model, precipitation that falls within the crop-land is either used by the crop or stored, hence no runoff is generated from those pixels. Therefore, in this approach only the intersected area between the sub-basins and the non-cropland is used in generating additional water supply. In order to find the annual average amount of water for each sub-basin, the resulting amount was divided by the total crop-land area within the sub-basin. The formula then reads as follows:

$$S_{add,annual} = P_{av,annual} * \frac{A_{basin} - A_{farm}}{A_{farm}} \tag{5.3}$$

in which S_{add} represents the additional mm's of water the farmer can apply to his farm. He will do this after applying his regular irrigation. If the farmer possesses an irrigation system, then that irrigation coefficient is used. Otherwise it is assumed that the farmer will use furrow irrigation.

6
Analysis and Results

The results from the socio-hydrological model, the fieldwork survey and the interventions from the supplementary irrigation are presented here.

6.1. Socio-hydrological Model

The results from socio-hydrological model forms the basis on which the hotspots have been decided, capital of farmers have been compared and yields have been analysed.

6.1.1. Hotspot identification

The results of the hotspot identification process can be seen in figure 6.1. ’Hotspots’ within the scope of this research, can be defined as those places where farmers go bankrupt over the time for which the simulation has been run i.e, from 2002-2016. In the figure this has been expressed with four classification categories: ’very poor’, ’poor’, ’medium’, and ’reasonably good’. In the figure, the locations that are not classified as farmland are marked black since they are not of interest to the analysis. ’Very poor’ farmers are those who have capital below zero and are therefore seen as bankrupt. ’Poor’ are those who have less in 2016 compared to 2002, but are not bankrupt. ’Medium’ are those who have a slight increase of capital and ’reasonably good’ have at least doubled their capital over the period. The most poorly performing district from this analysis is Yavatmal and the best is Wardha. This matches field experiences and validates the survey results where a similar trend was observed.

A comparison has been made here to evaluate the extent to which a correlation can be drawn between the records of cotton yield data from the government and the hotspot map, where the latter is an indication of farmer distress.

6.1.2. Capital development

For the analysis of the results of the socio-hydrological model, it is important to analyse how the capital of the farmers develop over time. Factors of key interest include farmers who are performing poorly which is indicated by their bankruptcy status and those whose capital shows an increase over time. In particular, the bankruptcy status of the farmers reflects whether or not they are bankrupt in the year 2016, not necessarily those who have gone bankrupt in any past year. Therefore ’good’ farmers are considered to be those who are not bankrupt in 2016. In other words, their final capital is greater than zero.

Figure 6.3 shows the details of the development of farmer capital over the years without any intervention. The first thing to note is that right from the start, the spread is considerable and there are many outliers. This is an expected consequence of the variability in the reported incomes. Secondly, it has to be noted that there is a gradual increase in capital over time. This increase is accelerated significantly after 2009. It can also be observed that the decrease of the wealth of many bankrupt farmers decelerates or even stagnates. This is a surprising result since in practice, it is expected that many farmers may tend to fall into a vicious cycle whenever they go into debt. It can also be observed that there is an increase in farmer capital after 2009. It is therefore possible that the events that have caused this increase, may have also caused the stagnation of the rate at which the bankrupt farmers were further

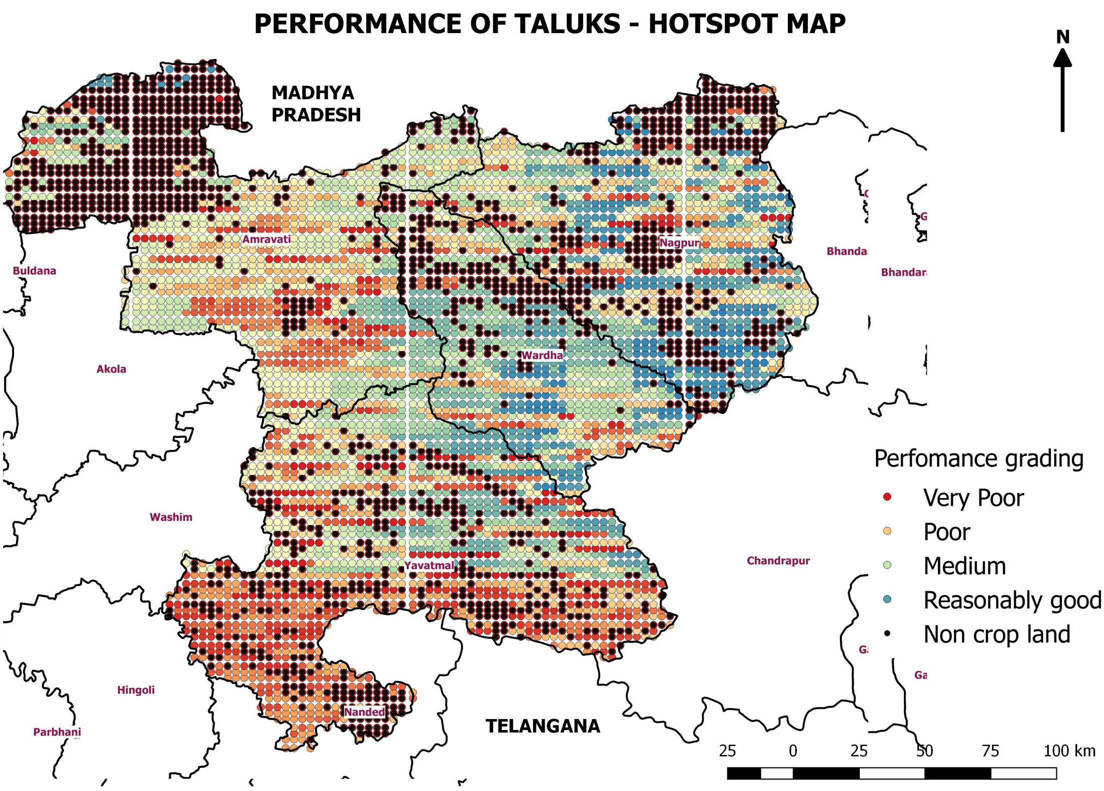

Figure 6.1: Hotspot map. Defined by relative capital in 2016 to 2002.

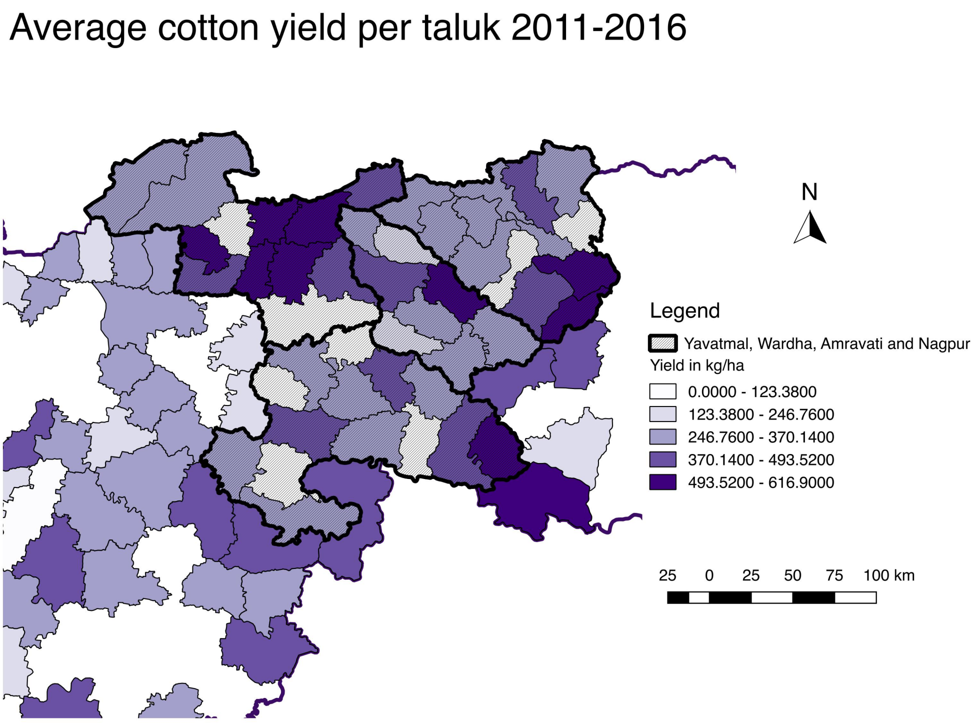

Figure 6.2: Yield of cotton (Government of India data)

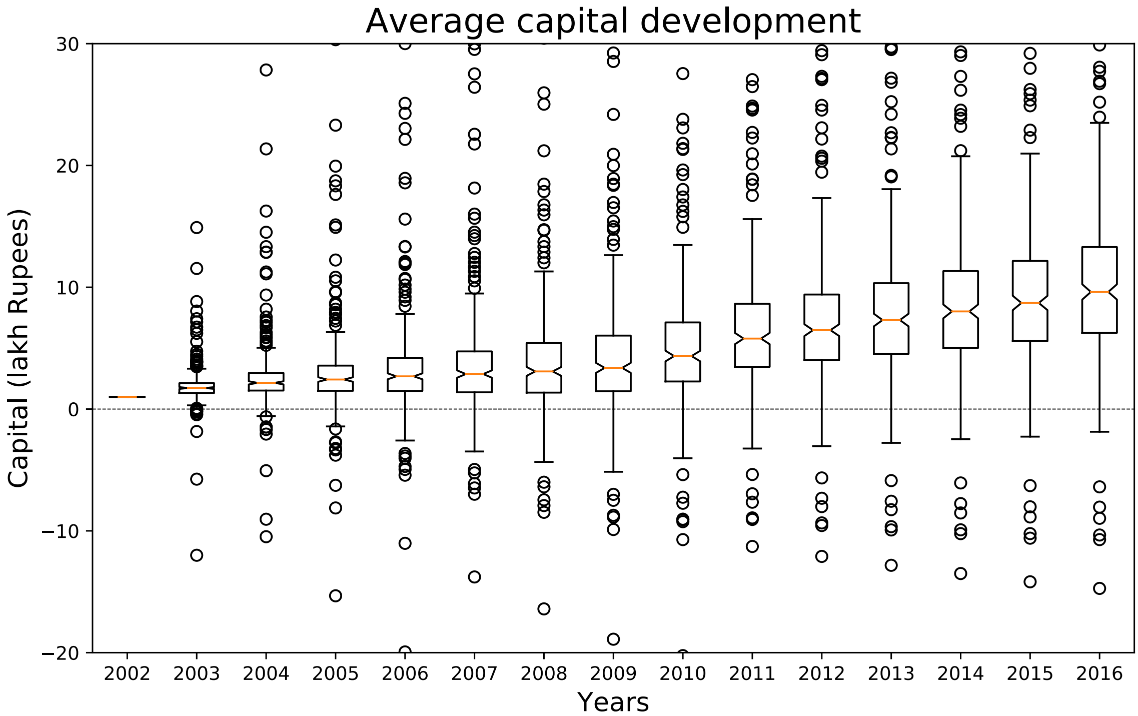

Figure 6.3: Capital of all farmers year by year. The window on the y-axis is limited, because outliers will diverge far from the mean in 2016.

losing income. Figure 6.4 shows the effect of supplementary irrigation on whether farmers go bankrupt or not.

As shown in the figure, about 5% of all farmers go bankrupt in 2016. Out of the 17 farmers who would be bankrupt without any intervention, 16 of them would still remain so even after applying intervention. The orange bars represent the percentage of farmers who would be bankrupt in spite of having access to irrigation interventions and the red bars represent the percentage of farmers who do not. It can be seen that the yearly trend in both cases is similar.

In figure 6.5 the average capital of both good and poorly-performing farmers is shown. Both show a significant runaway effect in either a positive or negative direction indicative of the capital increasing or decreasing rapidly. Also, contrary to the results from both 6.3 and 6.4 where bankrupt farmers show indications of improvement, figure 6.5 indicates that the capital of the bankrupt farmers plunges further down. This can be attributed to outliers that impose a heavy weight on the trend of the capital decrease. Since figure 6.5 does not show the effect of the spread in the data–but rather the magnitude of the capital alone–it conveys a message that is contrary to figure 6.3 and figure 6.4. However, it is worth noting that some farmers who were bankrupt in 2009 were no longer bankrupt in 2016 and this inference can be independently drawn from all the figures, 6.4, 6.5 and 6.3. From these two figures (6.4 and 6.3), it can be seen that both the percentage of farmers who are bankrupt and the median capital of bankrupt farmers indicate a stagnating trend after 2009, that demonstrates that the situation is at least not worsening. The cotton price indices of the respective years reveal that they have played a major role in alleviating the plight of these farmers from the year 2009 onward. This is further discussed in section 7.2.2.

6.1.3. Spatial variability

Figures 6.6 and 6.7 show the spatial distribution of capital among the surveyed farmers. Figure 6.6 depicts wealth by color and the sample size is represented by the size of the dots. In figure 6.7 average capital is depicted identically by color, but the size of the dot now stands for the standard deviation. From a first glance it can be seen that Wardha district performs slightly better than Yavatmal district and Amravati district. The worst performing villages surprisingly are not in Yavatmal district, but rather north of Dhamangaon in Amravati district. Internal differences here are higher than in the Ghatanji block of

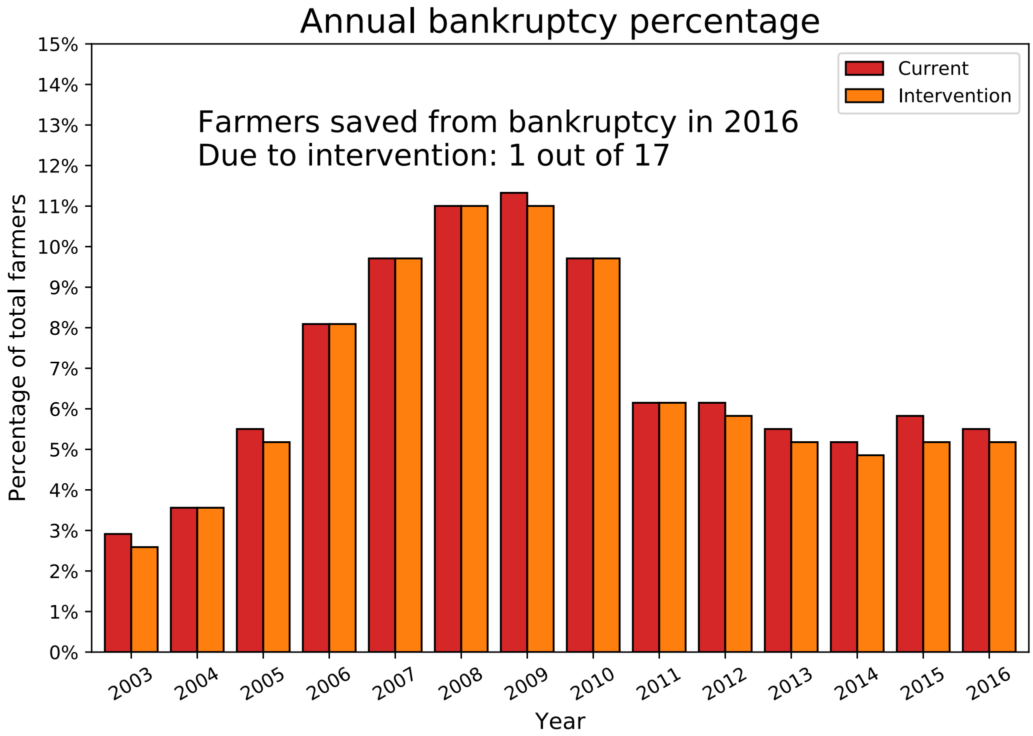

Figure 6.4: Bankruptcy percentage by year.

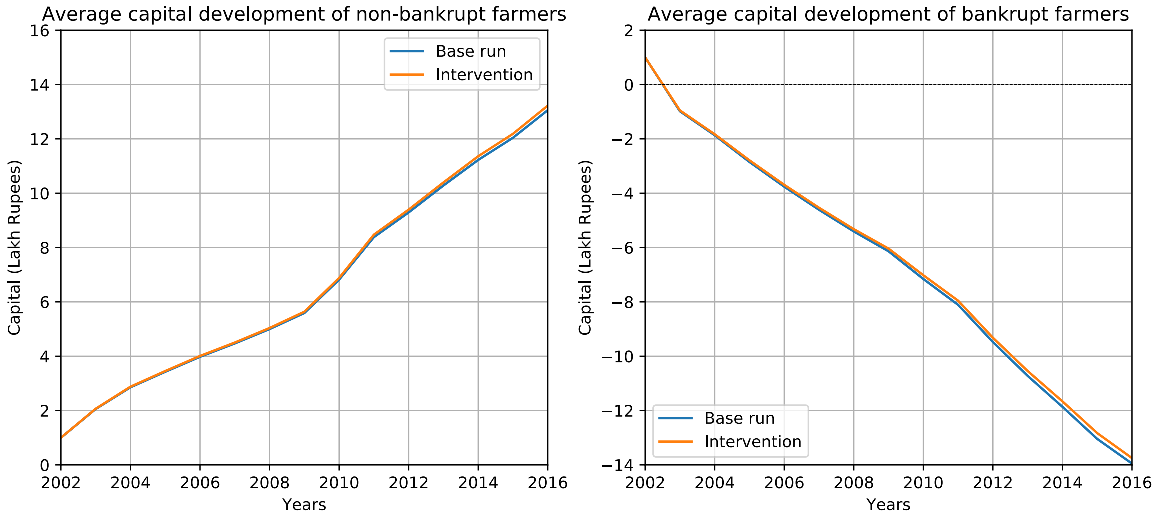

Figure 6.5: Effect of intervention on non-bankrupted and bankrupted farmers.

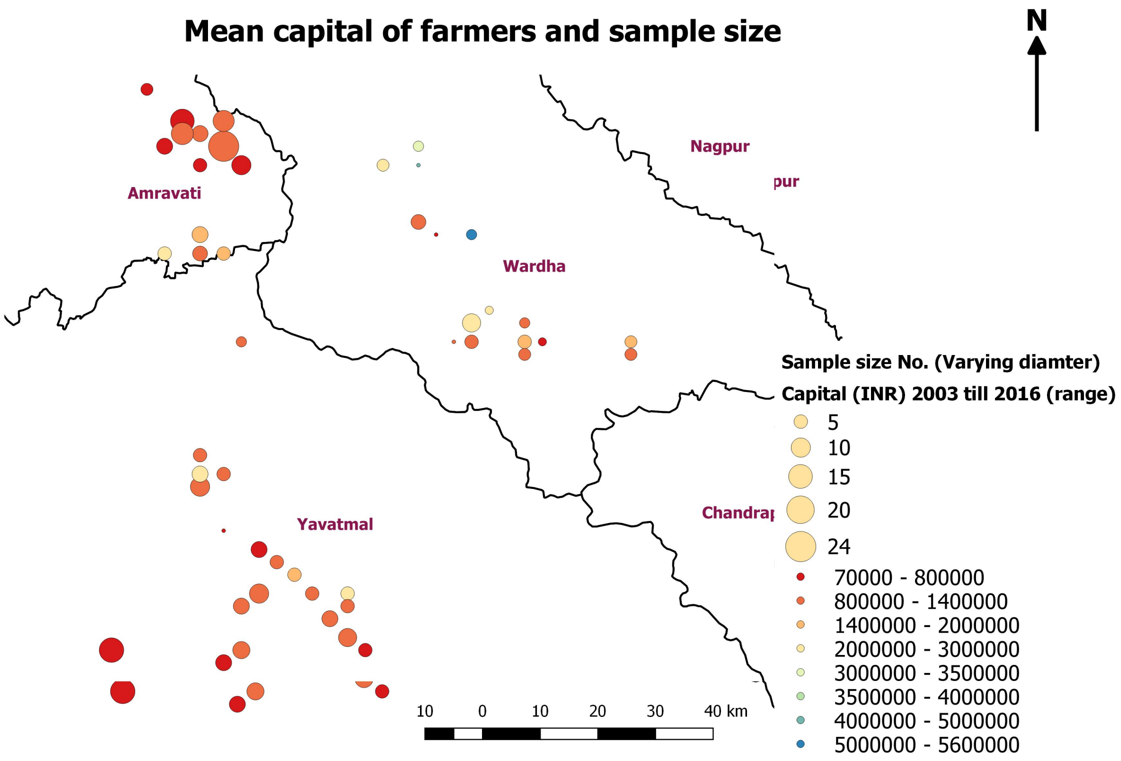

Figure 6.6: Spatial variation in capital.

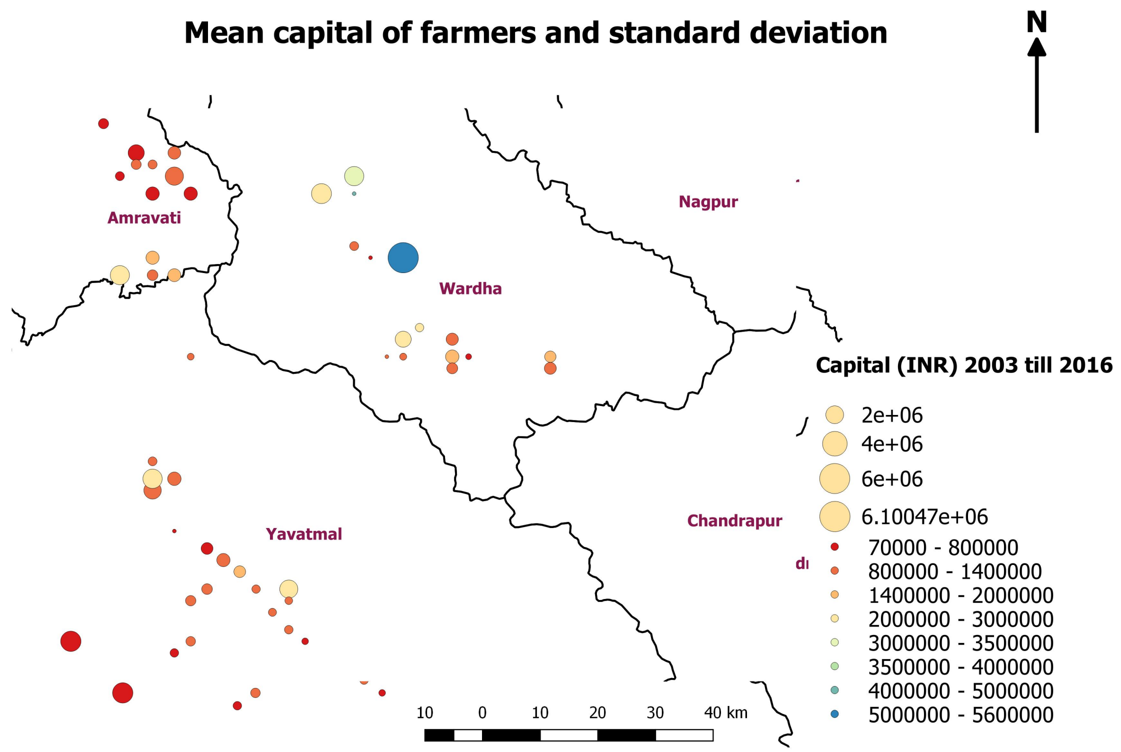

Figure 6.7: Spatial variation in capital.

the Yavatmal district where the spread is poor and richer farmers is very slim. Wardha in this regard seems to be the most irregular district.

6.1.4. Yield

Figure 6.8 shows the development of the yield of cotton over time with the effect of interventions. The huge dip in yield between the start of the simulation and 2010 is evident. This is due to the selling price of cotton which interacts with a labour mechanic in the model and which is explained in the section 7.2.2 Figure 6.9 shows a zoomed image of the yield after 2010. This part of the figure is likely more similar to the real situation. This validates that poor performing farmers have a lower cotton yields than good farmers. The yield of good farmers show much more fluctuations than the poor performing farmers. The latter category of farmers have a nearly constant yield after 2010.

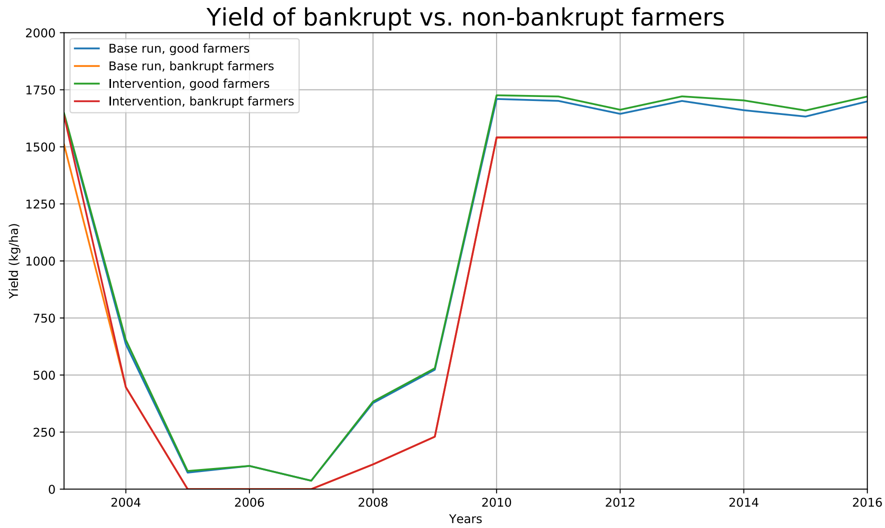

Figure 6.8: Yield of farmers with and without intervening.

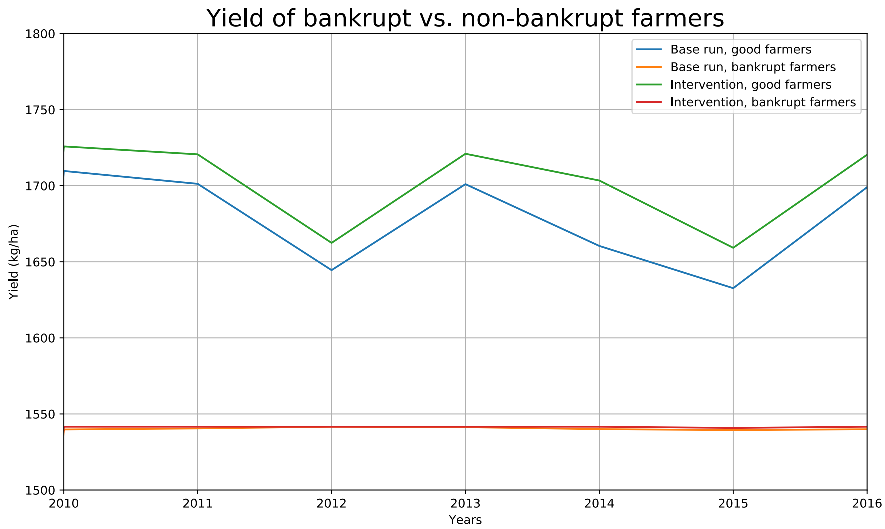

Figure 6.9: Yield of farmers with and without intervening between 2010 and 2016.

Furthermore, the calculated yield was compared with the yield reported by the farmers and can be seen in figure 6.10. The calculated yield is shown on the y-axis and the claimed yield is shown on the x-axis. The reported yields from the survey were mostly stated as integer values representing the number of quintals per acre. These typically ranged between 4 and 12 (D.2). The width of the boxplot indicates the spread of the reported yield. The reported yield has been converted to the unit of

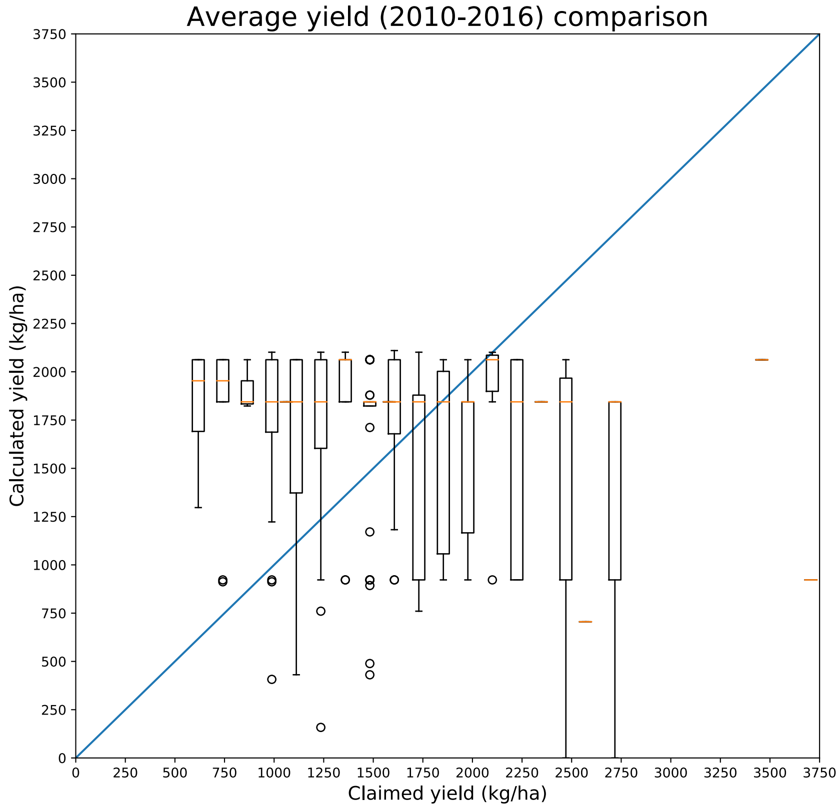

Figure 6.10: Yield farmers claimed to have in the survey versus model calculated yield.

kilograms per hectare to maintain consistency. The boxplots have varying sample sizes. On comparing both yields, it can be seen that there is no clear correlation. However, the average reported yield is similar to the average calculated yield between the years 2010 to 2016 - the years for which there is higher certainty in the price indices of the cotton crop. (Figure 6.8).

6.1.5. Livestock

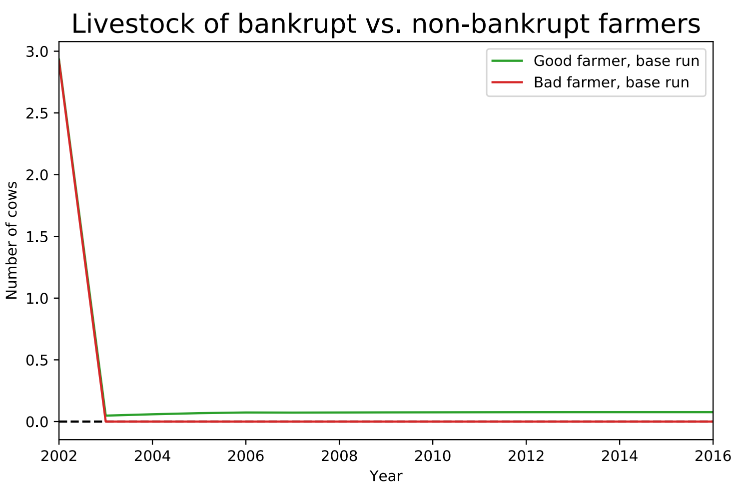

Figure 6.11: Livestock separated, bankrupt farmers do not have money to buy any so will stay at 0.

Figure 6.11 displays the livestock development of the farmers over time. In the socio-hydrological model, most livestock die within the first year of the model run, which is due to the carrying capacity factor in the model being much lower than in reality. Good farmers will then have a bit of livestock and bad farmers have none. The model assumes that bankrupt farmers cannot buy new livestock.

6.2. Survey Results

Out of the 345 households interviewed, 98% of the respondents were male with an average age of 46 years. Most of the farmers interviewed were middle-aged or above with the oldest interviewed at 94 and the youngest at 19. The mean total area owned and used for farming was 7 acres and most farmers were below 10 acres. Out of this, an average of nearly 5 acres was used for cotton growing and an average of only 0.3 acres was dedicated to organic cotton cultivation. 96% of all farmers grew other crops besides cotton. Pulses were most common with 84% of all farmers interviewed growing it as it is a common staple crop and is used for self-sustenance. From crops alone, the average farmer reported earning more than 2.2 lakhs Rupees per year with total annual crop expenses of just over 1.5 lakhs Rupees. The mean additional income from other work and from other family members in the household added approximately another 33,000 Rupees to the total annual income. Only 118 farmers however reported actually earning a secondary income and only 63 indicated that someone else in their family also had an income. 84% of farmers also reported that they had taken out loans. Of those farmers, the average amount of debt taken on (oftentimes every year) was over 1 lakhs Rupees; this amount varied a lot by farmer and the max debt reported was 27.5 lakhs Rupees. The average interest rate of these loans was 11.6%. This interest rate also statistically varied quite a bit. From each institution, there wasn't much variability as standard contracts from the government banks were signed by most with fixed interest annual interest rates no higher than 16%. However, alternative sources such as money lenders may have charged monthly interest which compounded to give an APR as high as 80% which leads to overall discrepancies in the interest rates of all farmers.

The mean cotton yield surveyed was 6.3 quintals (100 kg's) per acre with a mean price of nearly 5,100 Rupees per quintal. The maximum yield recorded was 19 quintals per acre, about as high as what the highest good, or ideal, yield many farmers aspired after. Most even though that a good yield for them would be on average 11 quintals per acre. The main reason for crop failure was mostly attributed to a lack of water in general, but untimely rainfall also was listed as a main cause (6.12). Timely rainfall was by far the most cited reason for a successful crop season.

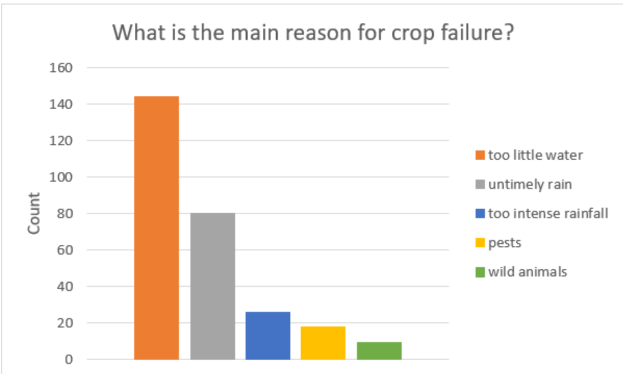

Figure 6.12: Main Reasons for Crop Failure

The breakdown of specific expenses for farming by irrigation, fertilizer, pesticides, and seeds informed the data that fertilizer was the most expensive cost input for farmers with seed costs being the lowest and least variable. Irrigation costs were highly variable with a large standard deviation; this is partially due to only 264 farmers who reported any costs for irrigation at all, and also the wide variety in irrigation possibilities from different technologies, different labor needs and expenses, different water sources, and more dependencies on other temporally sensitive cultivation decisions (figure 6.13). 254 farmers interviewed owned livestock of some sort, with the mean farmer owning more than 3 individuals. The livestock helped contribute to the third most popular (67%) fertilizer used by farmers). Urea (89%) was used the most followed by N:P:K (74%), a chemical fertilizer that serves specific ratios of Nitrogen: Potassium: Phosphorus. Most farmers used a blend of fertilizers which may lead to their higher expenses. The average amount of fertilizer applied per acre was 176 kgs with the maximum amount being 2000 kgs per acre and the least being 0 kgs. The vast majority of farmers bought their fertilizers from the local Agriculture Service Center (ASC, 95%) and about half also used their own livestock as a source of manure. The ASC also served as the predominant source of seeds (93%) with small fractions receiving seeds from the government or even Solidaridad, for organic cotton trials. Most (73%) cotton was sold at local open markets with some also utilizing sale directly to ginning centers (20%) and others opting to work with a broker (12%).

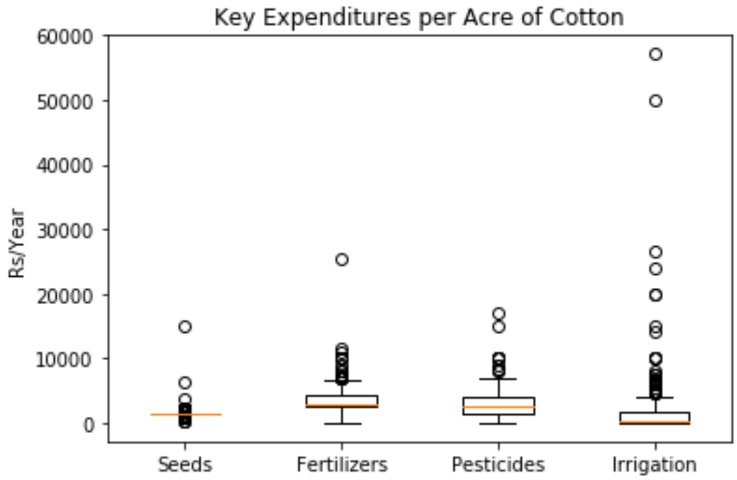

Figure 6.13: Boxplots of reported crop expenses

Most (63%) farmers had access to at least one open well and 13% even had access to more than one open well. 9% of farmers had access to a borewell and the same amount also had access to a farm pond. Nearly 10% reported having a river nearby enough that they could use for irrigation while 32% had at least a canal that they could use for water abstraction. Of course, farmers were still heavily dependent on rain despite whatever supplemental irrigation sources they had obtained and 48% of farmers saw rainfall as the most reliable water source, just ahead of open wells (41%). No other type of water source was recognized as most reliable by more than 5% of respondents.

Of farmers that did own at least one open well, the average depth of the well was 37 ft with the deepest open well reported being 65 ft deep and the shallowest, 15 ft. Over 40% of farmers interviewed also said that their primary water source had changed in the last ten years, meaning they had dug a new well, gained access to a new canal, or perhaps a previous source had dried up leaving them solely dependent on rainfall or whatever other source they could manage.

Many farmers bore responsibility for their own welfare with more than half saying themselves were the most responsible for problems related to their crops, water management, or farmer welfare. One third lay the responsibility on the local government and 10% placed it on the national government to solve their problems, largely due to their previous subsidy and loan forgiveness programs. At the same time, 57% of farmers say their overall capital has been in decline the last few years with 28% actually reporting an increase. 16% report no notable change in their household capital.

Organic Cotton Analysis The mean deducted expenses attributed to fertilizer and pesticides was 6,500 Rupees per acre. Using an average of 70% of the reported yield, the organic yield used for the analysis was 4.4 quintals per acre yielding a net income of 19,262 Rupees per acre compared with a Bt net income of 22,527 Rupees per acre. It is clear that from out analysis, the decreased cost does not make up for the likely loss in yield on its own. Organic cotton prices would have to be higher by about 600 Rupees per quintal if production is 70% of Bt. For context, the standard deviation of cotton prices reported was 418 Rupees per quintal.

Winners and Losers Analysis Figure 6.14 illustrates the BBN created to model the relationships between relevant factors and success, defined as income-per-area. Figure 6.15 then shows the optimal set of characteristics to maximize the amount of high-earning farmers. It can be seen that Improving irrigation and utilizing micro-irrigation does have a moderate impact on farmer success. This also should result in a higher yield which also validates the relationship expected with a higher income. However,

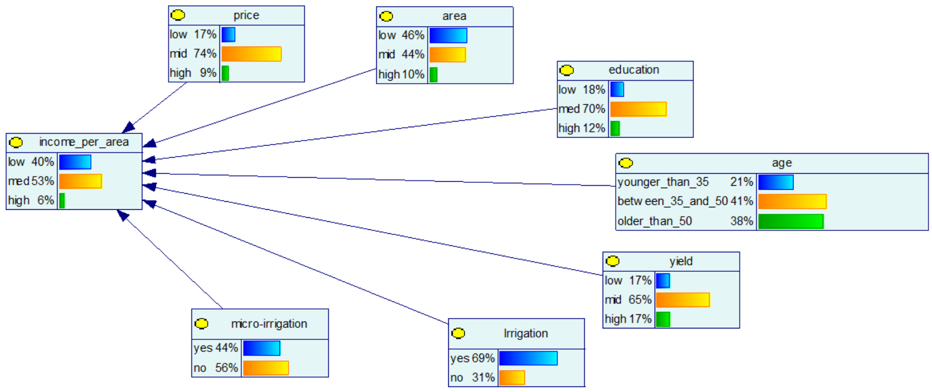

Figure 6.14: BBN mapping of the Good- and Poor-performing farmers with various related factors

price does not play a major role as higher prices do not lead to the highest income-per-area; this could be due to the low variance of prices meaning among farmers, although price is obviously important, increasing yield is more linked with success for current conditions than just a high price. Medium educated farmers (secondary school) and middle-aged to older farmers have the highest success likely due to experience and market knowledge. Higher education may not result in a better farmer and more time spent learning the practice may be more valuable for cotton farming. A medium amount of area (between 5 ad 8 acres) leads to the highest incomes as well likely due to labor and resource constraints with large areas and capital constraints on smaller farms.

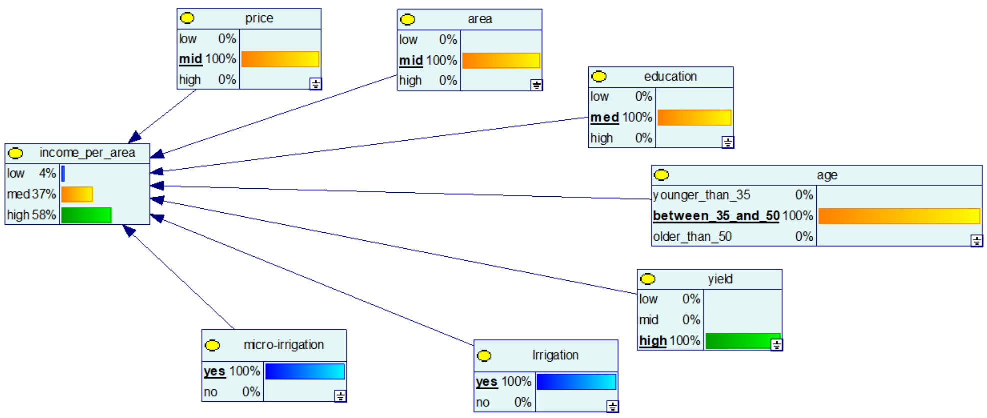

Figure 6.15: BBN mapping of the Good- and Poor-performing farmers with optimized farmers for maximized population with high income

6.2.1. RANAS

PCA Output The model output of the PCA was tested with two values: the Kaiser-Meyer-Olkin (KMO) test and the variance percentage (Var%) [38]. As a rule-of-thumb, the KMO value should be above 0.6

	KMO	**Var%**
Risk	0.639	39.7
Attitude	0.543	41.4
Norms	0.526	40.217
Ability	0.563	44.1
Self-Regulation	*N/A*	*N/A*
Wealth Index	0.612	54.5
Self-Regulation	0.635	69.6

Table 6.1: KMO value and variance percentage of PCA

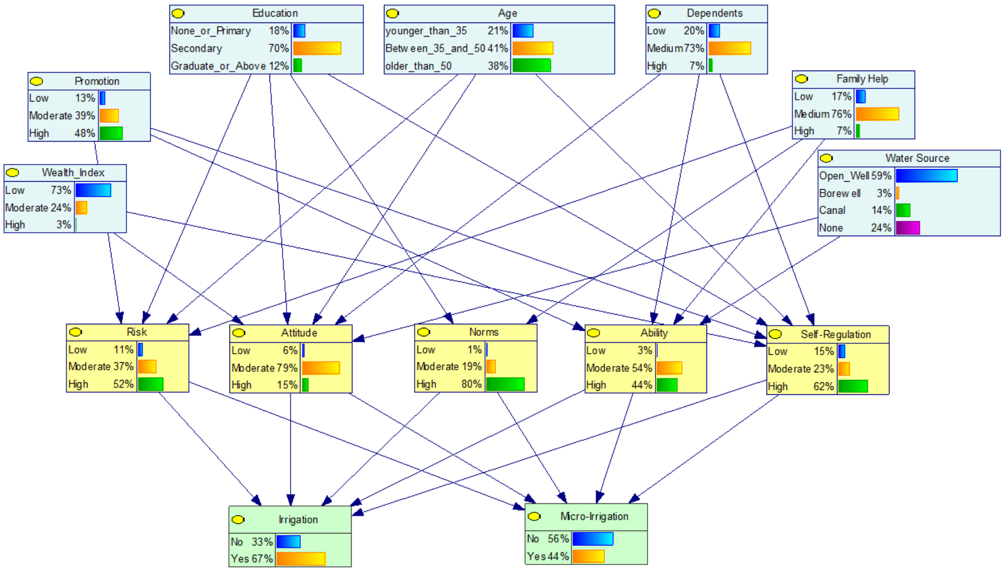

Figure 6.16: BBN mapping for recorded data from survey

and the variance percentage should be above 50%. These tests were not both passed for several of the psycho-social metrics but the socio-economic indicators–wealth index and promotion–hold up well (See 6.1).

BBN Validation LOO (Leave One Out) validation was performed on the BBN to test for its accuracy and ability to predict the correct state of the node. The overall model accuracy is 0.62 (accuracy of predicting the correct answer for either micro-irrigation or for irrigation, in general). The highest accuracy is for predicting a Yes for general irrigation (0.84, 152/182) and the lowest accuracy is for predicting a No for general irrigation (0.20, 16/81).

The ROC curve was determined for each node of irrigation and micro-irrigation. The AUC for irrigation and micro-irrigation was found to be 0.69 and 0.64, respectively [1].

BBN Mapping The BBN map (figure 6.16 shows the links between the different nodes and the current probabilities for each node. Links between nodes were drawn only for those with a significant enough chi-squared value. In this analysis, the Dependents characteristic node was deleted as it had no significance. Testing of the node within the model by setting the probabilities of states to 100 % validated that the number of Dependents seemed to have no bearing on the probability irrigation or micro-irrigation was used. The highest chi-squared values in descending order were between Water Source Attitude (15.8), Wealth Index Self-Regulation (14.4), and Promotion Risk (14.1).

Table 6.17 shows the relative isolated impact of altering each node's state to 100% probability for the various states of each node on the change in probability of either micro-irrigation or irrigation, in general.

[1] AUC ranges from 0 to 1 with the closer to 1 meaning a more accurate result. A score between 0.5 and 0.7 is considered less accurate[29]

Table 6.2: QGIS model outcomes

Sub-basin	Potential for supplemental irrigation [mm/year]
1	200
2	38
3	200
4	38
5	121
6	79
Average	113

Among socio-economic indicators, it can be seen than none of the characteristics influence the nodes very strongly with a max P of 4%. The highest for both instances comes from changing Promotion to low. Education and Age influence the final irrigation nodes the least when isolated. Among behavioral factors, Attitude and Risk influence the irrigation nodes the greatest, with a change in Attitude to 100% High translating to a 24% increase in irrigation, in general. Norms and Ability have the smallest isolated impact on change in probability of using irrigation or micro-irrigation.

Optimal Scenarios The optimal socioeconomic characteristics were found to be the group with 100% probability for each nodes that maximizes the probability of 'Yes' to irrigation and done as well for the question of micro-irrigation. It was found that the same combination of socio-economic characteristic states led to the optimal case for irrigation and micro-irrigation. **Highly educated** (graduate or above), **middle-aged** (between 35 and 50 years old), and **moderately wealthy** with **a lot of help** from family members and an **open well** as their primary water source, while receiving **low promotion** related to water scarcity and cultivation practices represents the optimized case. Setting these characteristics to 100% probability results in a probability of using irrigation and micro-irrigation of 83% and 71%, respectively.

Alteration of behavioral factors was also investigated. When all factors were set to 100% high, it is found that the proportion who irrigate and who use micro-irrigation is equally 100% (Figure 6.18). The factors Risk and Attitude were adjusted as well as they have the best fitting questions and are hypothesized to have the biggest impact. When all behavioral factors are 100% high except for Risk set to 100% low, the percentage of those who irrigate drops to 70% and those who use micro-irrigation drops to 59%. When the same test is applied to Attitude, the result is even more dramatic. When Attitude it set to 100% low, the proportion of people who do not use irrigation or micro-irrigation drops to 0%!

6.3. Supplementary irrigation

The results of the water harvesting potential as sources of supplementary irrigation from each sub basin, are illustrated in the table 6.2. The supplementary discharges from the sub basins have been estimated by taking into account the effective runoff from the precipitation that the sub basins receive. These discharges from the sub basins do not factor in the loss due to evaporation. The potential supplementary irrigation thus estimated, ranges from 3.8% to 20% of the annual average precipitation, which is a considerable amount. These results are fed into the socio-hydrological model for the purpose of estimating the amount of irrigation that is available to supplement the farmers. This is the amount of irrigation for which suitable irrigation infrastructures can be designed for.

Irrigation (yes)	67%				
	ΔP	**P_{max}**	**State[max]**	**P_{min}**	**State[min]**
Age	1	68	Young/Middle	67	Old
Education	2	69	Graduate	66	None/Low
Wealth Index	3	70	Moderate	67	Low
Family Help	3	70	High	67	Medium
Water Source	2	69	Open well	65	Canal
Promotion	4	71	Low	66	High
Risk	8	75	Low	61	High
Attitude	24	85	High	43	Low
Norms	5	72	Low	63	Moderate
Ability	4	71	Low	66	Moderate
Self-Regulation	6	73	Moderate	65	High

Micro Irrigation (yes)	44%				
	ΔP	**P_{max}**	**State[max]**	**P_{min}**	**State[min]**
Age	0	44		44	
Education	1	45	Graduate	44	
Wealth Index	2	46	Moderate	43	Low
Family Help	2	46	High	44	
Water Source	2	45	Open Well	42	Canal
Promotion	4	48	Low	42	High
Risk	12	56	Low	40	High
Attitude	15	53	High	29	Low
Norms	6	50	Low	41	Moderate
Ability	3	47	High	41	Low
Self-Regulation	8	52	Low	41	High

Figure 6.17: Sensitivity Analysis for Socioeconomic and Behavioral Factors

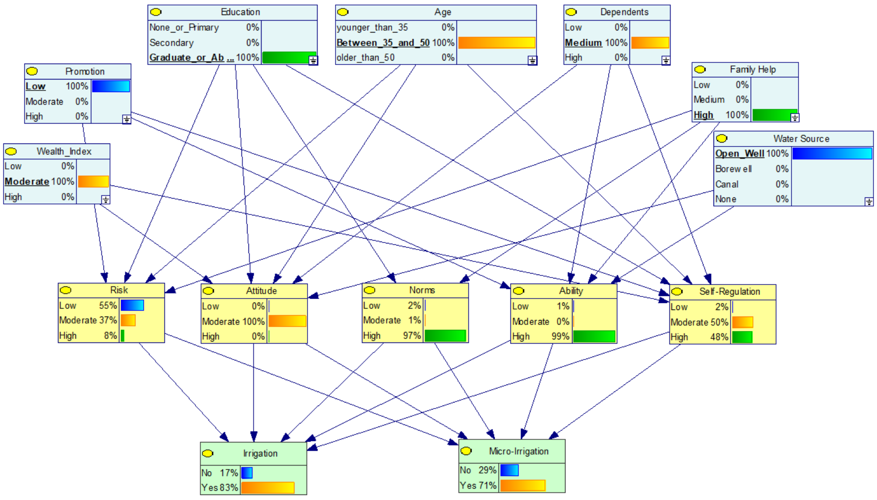

Figure 6.18: BBN Mapping for optimal set of socioeconomic characteristics

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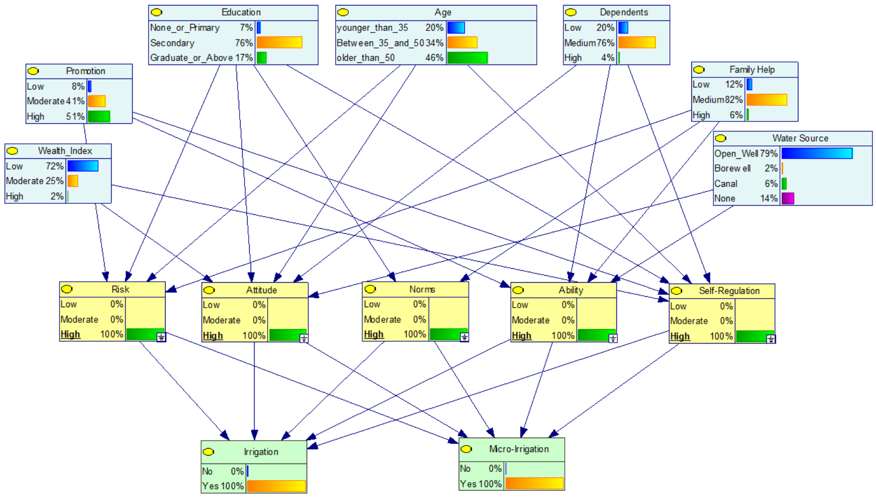

Figure 6.19: BBN Mapping for all RANAS factors set to 100% high

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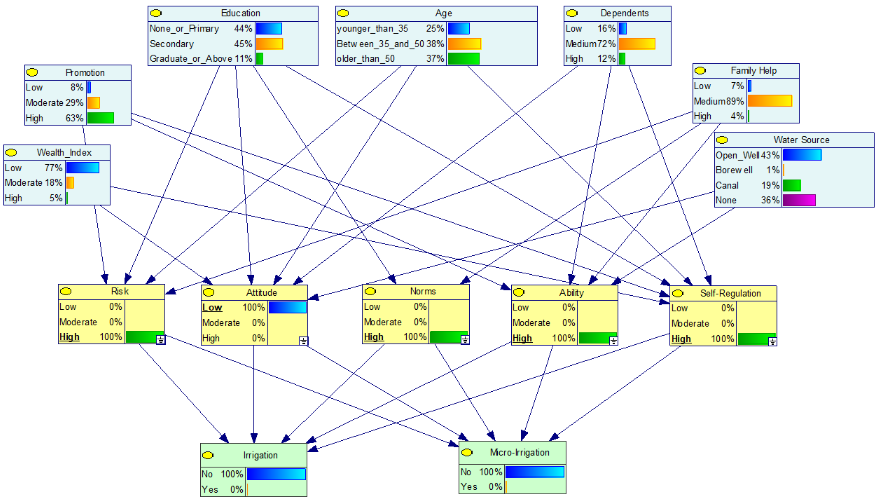

Figure 6.20: BBN Mapping for all RANAS factors set to 100% high with Attitude 100% low

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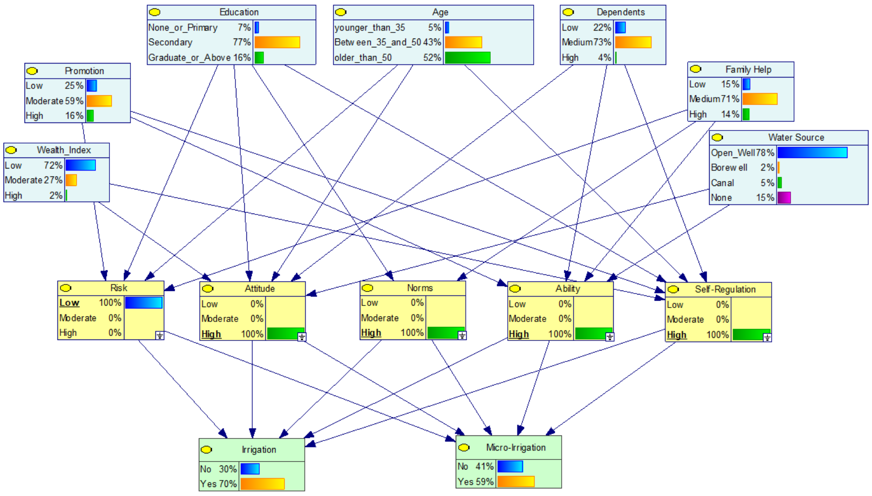

Figure 6.21: BBN Mapping for all RANAS factors set to 100% high with Risk 100% low

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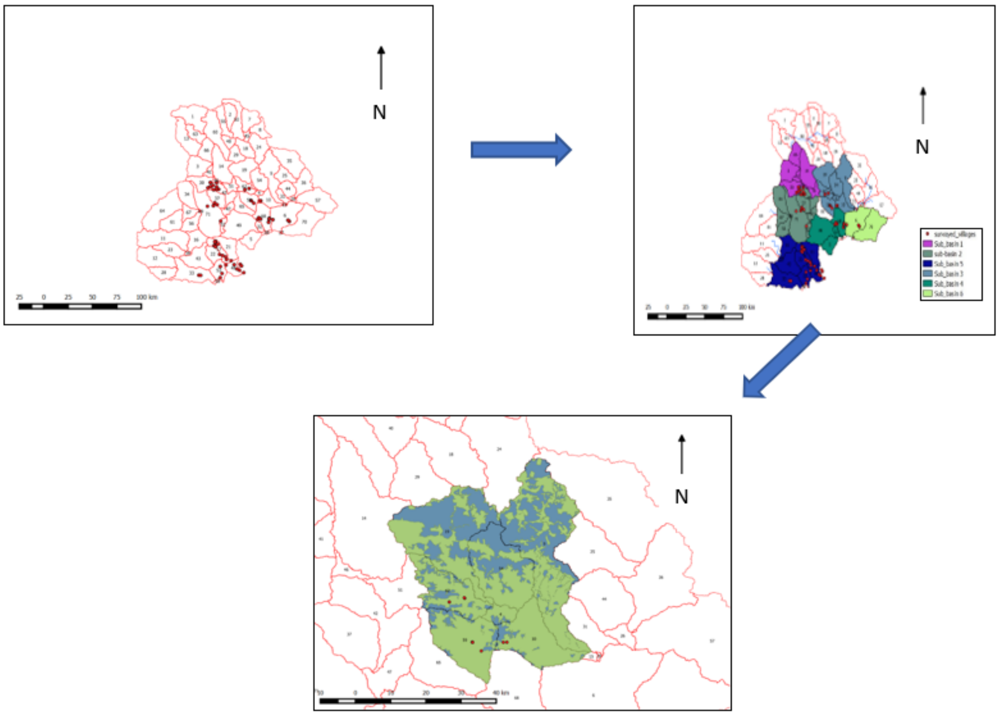

Figure 6.22: The upper-left map shows the sub-basins and villages, the upper-right map shows an example for a group villages within merged sub-basins, the bottom map shows the land-sue land-cover map intersecting with the defined sub-basin

7 Discussion and Evaluation

7.1. Discussion Points

A reasonable inference that can be drawn by correlating the hotspot map with the yield data is that the taluks of Yavatmal, in particular indicate the highest farmer distress and also the lowest cotton yield. This is also in agreement from the analysis of the fieldwork survey that indicate insufficient irrigation facilities available to the farmers of Yavatmal along with other pressing issues of poor land ownership and poor education levels. In terms of observations made from the field visit, it was noticed that farmers who had private wells in the proximity of a farm pond experienced higher rises of water levels in their wells as opposed to those farmers whose wells were not situated around farm ponds. This suggests that farm ponds can indeed be a viable intervention.

7.2. Model implications

Labor and fertilizer limitations are found to be just as influential on yield as water limitations. Water limitations are often pointed to as the most important reason for crop failure, but it is shown that labor and fertilizer dynamics play an equally important role. Furthermore, capital is seen to be very sensitive to loan and interest payments. Especially those farmers who have accumulated significant loan debts or have loans with high interest rates show a strong capital response. Lastly, irrigation has the impact of both increasing yield and stabilizing it, making it less susceptible to climatic variations. This stability effect can be rather important in making farmers more resilient to the variations in water.

7.2.1. Crop water stress and irrigation

In current calculations water deficit impact on yield is only present when the soil runs out of water fully. Water stress mechanics are not considered. Additionally, there is no distinction between water deficit impact early on and later in the growth cycle. It is likely that the water impact on yield therefore is higher in reality then what the model currently produces. This has implications for the effectiveness of water related interventions.

Additionally, the water limitations of irrigation are simplistic at best. Irrigation currently happens whenever the soil moisture storage drops below a certain percentage. In reality, farmers only irrigate two to four times per crop season but the amount applied is unknown as it is hugely dependent on the amount of available water in their water source. This is not represented accurately and can create deviations in the estimations of how much irrigation water is actually available and supplied. In many cases the constant replenishment of water, even though it's just a little bit causes the crop to suffer little to no water shortage. If water stress was to be modelled the effects of this irrigation method would have much more impact.

These two constraints both tie into a bigger limitation, which is that the actual hydrological model used is a simplistic bucket model. Hydrological models such as the widely used HBV Model[39] can have many different storage systems, while this one only has a single one, top soil. A multi-bucket HBV model is not necessary advised for use here. However a single bucket which only generates runoff when the bucket is full is simple for the case where irrigation water originates from limited supplies of runoff and shallow groundwater. Runoff especially has many different mechanics. This region is actually very amenable to Hortonian overland flow, where the rainfall intensity exceeds the infiltration capacity of the thick clay soil, generating vast amounts of runoff. The bucket model used is not able to capture such sensitive runoff dynamics and simply accepts whatever water is available.

7.2.2. Labour mechanics

As can be seen in figure 6.8 the yield demonstrates unexpected behavior prior to 2010. This cannot be attributed to the effects of fertilizer nor water shortage, but instead it is the effect of the labor divergence. As seen in the methodology, the selling price of cotton is tied to the world bank commodity price index. This price was increased by over 50% between 2009 and 2010, which suddenly makes it a lot more profitable to farm instead of work. Because the wage rate was set to a constant 250 Rs per day, before this sudden price increase it was much more profitable to work on someone else's land instead of farming your own land, which all farmers therefore decided to do. While this might be true for a single household, in a larger regional economy this wage rate would likely be much more flexible to the forces of supply and demand and the decision to shift would not be as well-informed as in the perfect-information model adding delaying barriers to shifting time capital. Therefore the actual labor shift from farming to something else would be much more mitigated than is currently seen in the yield function. An important takeaway from this is that, like many farmers told us during the survey, their well-being is impacted a lot by fluctuations in the market rate.

7.2.3. Fertilizer and soil fertility

The fertilizer function considers only nitrogen as a functional nutrient even though phosphorus and potassium are of equal necessity to crops. From survey experience it was found that most farmers use a wide range of different fertilizers (see D.9) and it did not appear as if they had a very good idea of how much they should use of each. The value of a more accurate fertilizer function including all three main elements is something worth looking into.

Additionally this fertilizer function did not represent farmers fertilizer practices who had completely switched to biological fertilizers and organic cotton as well. This in part is also due to the livestock equation not functioning as we experienced in reality (see next section).

There is also the issue of the soil fertility function still being disconnected from the model. Due to this the minimum crop yield factor for fertilizers is set to 0, which means that yield is directly related to the amount of chemical fertilizer applied. Effects of soil degradation due to this excessive fertilizer use as well as the use of pesticides can therefore not be expressed even though it's one of the critical motivators for organic farming practices.

7.2.4. Livestock evolution

As can be seen in figure 6.11 the amount of livestock completely collapses after the first year of simulation. This is not completely unimportant, because the livestock functions both as a supplier of additional fertilizer and as a safety net for when things get rough. This financial safety net is currently not being used, because the livestock dies on its own already before the farmers are able to sell their cows. Additionally for good farmers they don't get the full benefit in additional fertilizer. This drop in livestock happens, because the current carrying capacity which is a function of the grass demand per animal and the amount of available grass for fodder is much lower than should be the case. A clear cause for this was unfortunately not found, but some of the parameters might be off. It can also be due to the fact that supplementary animal fodder is not taken into account, which might be substantial.

7.2.5. Additional model limitations

- Single crop considered only. This has a few setbacks:
  - Crops grown on other fields which may provide more economic security are accounted for, but don't interact with climatic conditions or price fluctuations. Instead, it is a steady additional income.
  - Intercropping of cotton with other crops such as Toor can not be accounted for. This has impacts on fertilizer and water consumption.
  - Crop rotation practices which affect soil quality and water storage cannot be accounted for.

- Even though hard to model properly, the effect of pest attacks is currently left out of the equation completely while 6% of farmers attributed it as the main reason for crop failure (D.6).
- Farmer loans would normally change depending on their income. If the farmer is struggling he tends to take out more loans while with a good harvest he tends to reduce his loan. A steady loan, with steady interest is not the most accurate representation here, nor is a continuously accumulating one. This should not be overlooked, because this expense can have huge implications to capital development. The compounding effect of interest can be seen in some of the capital development figures.
- Many original parameters from the work of Den Besten[40] are still left in the model. Though most of these are not incredibly relevant and constant among farmers researched, the expansion and verifying of many of these parameters such as school fees or manure nutrient concentration.
- The expenditure cuts function of the model, which farmers face when hitting zero capital has a very arbitrary order and might have a more meaningful impact when investigated more in-depth.

7.3. Survey Limitations

The main limitations to the RANAS study relate to the questions and their accuracy in representing what they claim to represent. For instance, the KMO values resulting from the PCA indicate that the factors resulting from the analysis and used for the BBN are not as accurate at portraying the sub-factors as is desired. The sub-factors used for each RANAS factor were even optimized by testing different sets of questions to find the best representation, but it could not be found with very high KMO or variance percentages. Oftentimes, in this PCA segment of the study, the questions did not relate well enough and they had no alternatives to use to also represent that factor in the case of a poorly perceived question.

It would also be worthwhile to investigate the socioeconomic parameters with more precision. For instance, although promotion did incorporate different sources and different frequencies, it still focused on one general type of promotion and did not distinguish or include other types. The diversification of the type of promotion, especially considering the important implications it has in this particular analysis, could give more specific results that can be helpful for action items for policy makers.

Farmers who were interviewed were also selected on a voluntary basis and oftentimes with people who the organization had had prior contact with. These 'project farmers' (50% of all interviews) may have different perspectives than farmers who had no contact with the organization and their initiatives. Any differences were not investigated. The selection of farmers also favored men significantly and largely precluded women from involvement. There were a few valuable interviews with women as it was not uncommon for the woman of the household to be familiar with farming practices, seeing that many women worked in the farms. There were even multiple all-female self-help groups that emphasized strengthening the capacity of women in the villages to be more responsible. Women play very important roles, taking care of children while also working on their husband's farm or another to bring in income. This work ethic also made it more difficult to survey as many women as they were working a lot.

The input of passerby's may have altered responses as they often felt freedom to add their opinions. This could either produce a more accurate community representation, or misinform the survey of the farmer's own perception. The enhanced discussion regarding some of the more difficult discussions led to productive mining of information and understanding, however it limited oftentimes the capacity of a longer survey which would be advisable in the future, at least with regards to RANAS. Lastly, the truthfulness of responses is taken for granted and assumed, but there is always the chance it is not true. A particular bias in this study was commonly that farmers would paint a picture of pity hoping it would make them more eligible for rewards from the government. Thus, incomes may have been under-reported or expenses inflated in some cases.

7.4. Survey Implications

The output of the BBN model optimal case regarding socioeconomic characteristics gives expected results in the areas of education (highly educated), water source (open well), and family help (high).

It is expected that those well-educated are more capable and willing to engage in better water management practices and it is also expected that those with an open well (touted as the most reliable water source by farmers except for rainfall) would be most likely to use irrigation. The amount of family members helping being greater helps a farmer by supplying extra cheap labor that increases their capacity and decreases their expenses making it more likely that they can take up the initial extra costs of irrigation systems. The most surprising results are that moderate wealth and low promotion increase the likelihood of irrigation and micro-irrigation. Moderate wealth implies that irrigation solutions should be reasonable in cost and not exorbitant. From the sub-factor for willingness-to-pay (mean = 3.01/5), it can also be seen that the farmers are not willing to spend a lot, although they are willing to pay some. Low promotion is surprising because it would have been expected that more information from reputable sources should increase the farmers' willingness and ability to take up irrigation. It is conversely proposed that perhaps the spread of information regarding water scarcity and conservation practices has endorsed a fatalist perspective that discourages farmers from putting in more work and effort to increase their welfare. The increase of exposure to media that refers to their home region as the 'Suicide Capital of India' may also induce increased hopelessness. Many farmers, mid-interview, would bring up their inevitable lack of resiliency likely leading to their own suicide and would discourage heavily their own children from becoming farmers themselves. This is also seen in the average age of farmers(46) being relatively high.

Investigation of the alteration of behavioral factors directly and their impact on the behaviors can further add information. As a first test, when all factors are set to 100% High, this results in 100% adoption of irrigation and micro-irrigation as intended which gives confidence to the expected results. Keeping all factors at 100% High and shifting Risk to 100% Low reduces the adoption rates which indicates that perception of risk does have a significant impact. However, the rate is not as significant as those shown by Self-Regulation and Attitude. Another interesting shift when Risk is 100% Low is that the proportion of the population who is older than 50, perhaps indicating that the oldest don't perceive risk in the same way and are not as phased by concerns of drought or perhaps they are simply not as worried because they don't believe they will have to deal with the problems of the future as much. When Self-Regulation is set to 100% Low, irrigation retains its 100% probability, but use of micro-irrigation decreases to 1%. This implies that adoption of irrigation is not very sensitive to those who self-regulate well, but those who maybe take extra steps by using micro-irrigation systems also are the same who self-regulate well. Lastly, the adjustment of the Attitude factor to 100% Low brings the probability of irrigation and micro-irrigation both to 0%. The Attitude factor represents their attitude relating to irrigation so it is verifying that those who see irrigation in the worst light are the least likely to use it. The adjustment and investigation of behavioral factors is not able to help for policy planning but it is useful to validate certain conceptual tests of the model relating the behavioral factors to the behavior and also to the socioeconomic characteristics.

Interpretation of the sensitivity analysis and of the optimal cases can help create a picture of who is most likely to adopt irrigation and what are the motivating behavioral factors behind it. In the sensitivity analysis, it is found that promotion has the largest sensitivity for overall behavior. The lowest sensitivities are regarding Age, Dependents, and Education. This implies that across the spectrum of these parameters, there is no strong correlation between adoption and any of them. What the optimal case of socioeconomic characteristics showed is that low promotion and moderate wealth combined with open well users produced the most likely outcome. A take-home message from the model's output is that proposed interventions should not be too expensive and that promotional messages should be more selective and positively focused. Perhaps, farmers do not need constant reminders of the peril they face and fewer, more constructive promotional exchanges could be more positive. And while Ability and Norms did not have a large impact in the sensitivity analysis, in the optimal case they were shown to be 99% and 97% probability of being high meaning they are a likely prerequisite for successful adoption. While Norms had a very high probability of being High for current conditions, Ability had a higher probability of people in the Moderate category. Improving ability through positive promotional material would improve both the behavioral factor and also the indirect socioeconomic factor that contribute to better adoption.

7.5. Beyond our Scope

Our intervention studies are mainly centred around irrigation and water recharge structures, whereas there are many other factors involved in cotton farming. A brief overview of other major influencing factors mentioned by farmers is shown in figure 7.1. When considering the aim of the project which is to improve farmer welfare, these other factors outside of the scope of improving water supply to cotton become important to at least understand, if not intervene on. Through further research and discussion with farmers, several different potential solutions were discussed to address these external challenges.

Timing of rainfall was frequently listed as a concern among farmers primarily for safe and prosperous germination; this can be partially solved by adequate water storage that can supply cotton early in the season even without rain but the development of nurseries could also allow for optimized management of young plants and protection from equally threatening intense rainfall that can wipe out entire fields of young cotton.

For many farmers, particularly those with larger plots of land, finding and hiring sufficient labor during moments of need is a challenge. This was also mentioned in the interpretation of the results of the hydromodel, where labor can be an important factor for successful cultivation. Integrating mechanization could be a positive force that reduces the need for so many people; however, its downside is the large upfront requirement of capital. Women in the villages play an important role for the supply of labor as many women spend most of their days working in their fields to bring in some income to their family.

A factor that was found to be important in literature, interviews, and the socio-hydrological model output was the pricing of cotton. The selling prices of cotton have a large impact on the profitability of any given year. It has also been found that cotton prices reported by farmers were notably lower than global average prices for raw cotton. Increasing these prices for farmers would have a substantial impact on the improvement of their financial capacity. There are different methods that could be proposed regarding the protection and increase of sale prices. A government-regulated price floor could be implemented that could even be tied to the global cotton price to make sure that farmers exist in the competitive market. Integrating farmers along a bigger section of the supply chain could also remove the profit losses that go to middlemen that restrict farmers' ability to grow their capital. If organic cotton is also to be grown, supply chain management becomes increasingly important seeing that the reduced yields could bring about short-term losses despite reductions in capital inputs and potential long-term gains. Short-term losses are not something most farmers can accept so proper management of the prices and incentives to utilize a safer, more sustainable option such as organic cotton will be instrumental in the maintenance and improvement of farmer welfare.

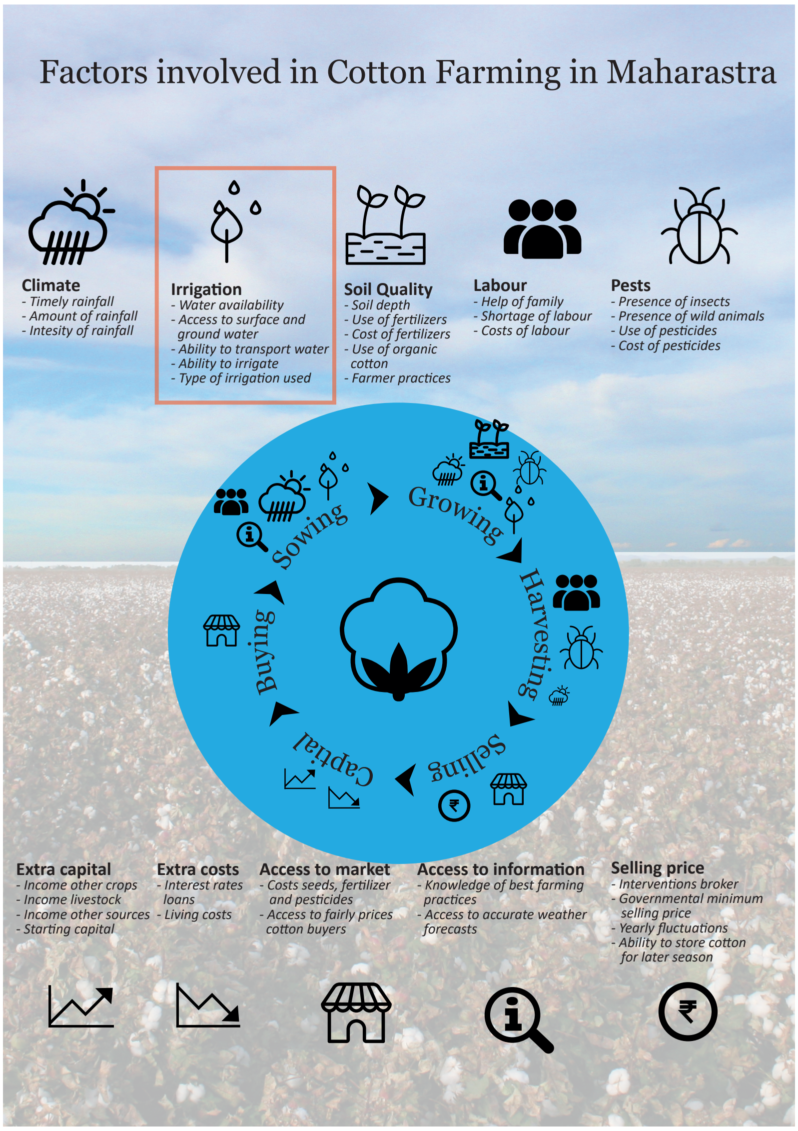

Figure 7.1: Mapping of factors involved in cotton farmer. The symbols represent what factors are involved in what part of the crop cycle and to what extent. Larger symbols indicate a higher significance. The rectangle indicates where our proposed interventions are suggested.

8

Recommendations

8.1. Interventions

Based upon previous sections' analysis, recommendations for interventions are based around four main factors: 1) **Promotional Activities**, 2) **Water Storage Interventions**, 3) **Regulation of Market Prices for Cotton**, and 4) **Safe Loan Management**.

8.1.1. Promotional Activities

Promotional activities should be done with limited frequency with less focus on the negative consequences of water scarcity. They could also feature positive aspects of different cultivation practices that have been shown to be important here including appropriate fertilizer management.

The RANAS evaluation demonstrated that farmers exposed to low amounts of promotional activities were more likely to increase farmer adoption of irrigation and micro-irrigation. Acting on this, promotion should be done very selectively, and in a positive light, emphasizing opportunities rather than just the troubles that are faced. Negative promotion has the potential to drive farmers into despair. Other important factors including cultivation practices regarding fertilizer application besides irrigation management have been shown to be important in the socio-hydrological model. Positive promotional activities could include more information on other relevant cultivation techniques to help farmers farm intelligently with all the resources they have as water is not the only part of the equation. Promotional activities should also be used to introduce more farmers to government-sponsored opportunities such as free soil-quality testing which helps farmers further optimize their practices, encouraging them, rather than seeding doubt. Of course, solutions should not veer from the truth, but focus on solutions in a positive light to increase the likelihood that farmers adopt interventions and increase their productivity.

8.1.2. Water Storage Interventions

Construction of water storage and recharge structures is recommended as it would increase farmer access to irrigation. Solution costs should not be too high however, as the psycho-social evaluation demonstrated that solutions are more likely to succeed if they are more likely to be adopted by farmers who are not wealthy.

Access to water storage has been shown here to be important to improving farmers' yield stability and in general, increasing their yields. In the model, access to water has been shown to be more important and at least an important first step, before adoption of micro-irrigation practices. It may not always be the case that water efficiency improves from micro-irrigation technology as many farmers simply use whatever water is available. Therefore, the best step to increase productivity is to increase access through storage rather than investing in costly micro-irrigation before water is even available for many farmers. Water storage could capture a significant amount of water that could buffer farmers' water stress and potentially reduce germination failure rates when monsoons come late. Large-scale farm ponds may seem to offer an efficient way of capturing water but may take up significant space and also require substantial distribution networks, a well-known limitation in the area. A more holistic, community-participation-based approach to having smaller, more localised water recharge structures seems to be a more viable option which is worth specific investigation. This also supports the finding that there is a higher probability of adoption among only moderately wealthy households, implying that expensive solutions are not optimal. Smaller structures should be more affordable and they also afford extensive costs of distribution networks and any pumps or maintenance that may also be required. Recharge structures also serve effectively as water storage, facilitating infiltration into underground reservoirs that protect against evaporation losses.

8.1.3. Market Prices for Cotton

Interventions related to the regulation and protection of market prices are recommended. Price fluctuations and low prices relative to world prices keep farmers from achieving their financial potential.

It has been demonstrated that variability of prices over time has a significant role on farmer incomes. Farmers have little they can do to protect themselves from falling prices (few have options such as cotton storage to wait for a better price) and likely do not have much leverage to push for better prices as they have little to no alternative to sustain their families. Protecting prices of cotton sale by farmers can provide a buffer for farmers against unexpected losses and keep them competitive globally. As described in the *Beyond our Scope* section, different methods of doing this include integrating farmers deeper into the supply chain such as the proposition of contractually obligating prices and yields with a clothing company directly. This sidesteps several steps which all take their cut, reducing the profit the farmer earns. Another potential method would be to enforce higher governmental regulation of minimum prices that could be fixed and adjusted bureaucratically or they could be tied to the global cotton price index directly.

8.1.4. Safe Loan Management

Facilitation between farmers and banks for less predatory loans should be pursued. High interest rates compound debt punishingly, harming farmers for years.

The socio-hydrological model demonstrated the powerful impact that interest rates can have on farmers, particularly those that may have trouble paying their loans, even if it is only once. While many farmers claim they would not even pay their loans as they wait for a new political regime to abdicate them of their debt, suicides are most frequently attributed to debt that can not be overcome. Government loans, ones most commonly not paid, have the friendliest rates generally. However, many farmers are forced to resort to money lenders who charge very severe interest rates and the chances that these loans are waived off are negligible. These loans are resorted to when government loans are not an option due to existing defaulted loans. The loan policies of the government banks and private banks should be examined to be more inclusive of more farmers in need. Complete loan forgiveness policies, although helpful for a moment, are expensive and do not target the root of the problem. Improving these loan policies to increase acceptance of farmers' requests would also reduce the amount of farmers who turn to money lenders who cause extreme debt growth. These loans are also more feasible to be paid-off with their lower interest rates as the model demonstrates and would be the first step towards introducing a healthy financial system for all involved. When done in combination with methods such as price guarantees to increase profits, the farmers and banks should be able to work together to develop healthy communities less reliant on desperate sources.

8.2. Future Studies

- **Geohydrological study**. An improved analysis of recharge locations and site-specific transmissivity and storativity values would improve understanding of recharge and groundwater dynamics, which is crucial for a community that is so heavily reliant upon shallow groundwater. Simple hydrological models like the one used here can give an estimate as to how much water is used perhaps by farmers based on local climatological data, but there is a lack of knowledge regarding the abstractions of other industrial or agricultural water users in the area that may impact the farmers ability to store water in the ground to use as a buffer for their supply. Understanding the specific local hydrogeology in combination with estimates of other relevant users can help in the plan of interventions so as to more accurately follow where the water is going.

- **Water quality study**. Following the reports of salinity as a complaint among several farmers, a simple water quality analysis may improve the picture for what may limit some farmers. Also the unregulated application of fertilizer and pesticides could pose problems for the local water supply in general. Unprotected well openings could exacerbate any water quality issues that may arise as well.

- **Climate projections for the area**. Rainfall patterns might be strongly affected in a future of climate change, and before designing appropriate long term interventions, this should be taken accurately into account. In particular extreme events and a delayed monsoon are parameters that may be changing that farmers are very wary of knowing their impact. A delayed monsoon oftentimes may hurt them more than simply a lesser monsoon season; this timing is crucial so adapting strategies that incorporate how the climate is projected to change could help mitigate further crop failure for the farmers.
- **Usage of aerial data**. The usage of aerial data in the area to investigate what farmers already use in terms of irrigation systems could substantiate the survey if more detailed information is sought after regarding the details of irrigation practices.
- **Larger survey with more targeted questions**. A larger follow-up survey with a few added questions would be useful. Questions related to primary finding here could be expanded upon while other simpler socioeconomic questions may not be as necessary. It would be useful to extend the survey to include more questions relating to the women's experience now with a better understanding. An increase in the number of participants of the survey particularly among women, done by targeting them more would add to a more complete picture and validate results more confidently.
- **Improved socio-hydrological model dynamics updated to better represent conditions observed** Better research into socio-hydrological model parameters and mechanics could significantly improve performance. Current capital figures lack the necessary context due to model limitations as discussed previously and are mostly interesting for relative comparison. With more accurate parameters and mechanisms, they could become a lot more meaningful. To see what specific changes would be worthwhile, the limitations are described in the discussion section regarding the socio-hydrological model.

9

Conclusion

Using high-resolution satellite climatological and geophysical data, hotspots (regions of good and bad performance) were identified to be surveyed to develop a baseline analysis of farmers' situations in the districts of Amravati, Yavatmal and Wardha, India. In total 345 farmers were interviewed to understand cotton farmers' practices and to understand what may be causing some farmers to succeed and some farmers to fail.

Both the socio-hydrological model and the survey confirm that Yavatmal shows lower performance than the other districts. When comparing farmers with high and low incomes per area, high yields are a strong, controlling factor that increases probability of high income-per-area. Irrigation and micro-irrigation have a positive effect on income-per-area as do increased age and moderate education, implying that farming experience pays off. It was found that low exposure to promotional activities and moderate wealth gave farmers a higher probability of adopting irrigation and micro-irrigation technology interventions. Women were observed to play major roles in working on the farms and have crucial roles in the maintenance and care for the farm and home. Women were, however, not well-represented in the survey but the vital position they hold need be considered in any proper intervention.

As seen in the socio-hydrological model, irrigation interventions do play a role in increasing yields and also increasing stability of capital development. It was found that farmers' capital is very sensitive to cotton selling price and interest rates, with high interest rates on loans sending farmers oftentimes into deep debt. The socio-hydrological model also demonstrated the complicated interactions of many factors and the importance of namely, fertilizer application and labour dynamics on crop production.

Based on these analyses, recommendations of four main categories (promotion, water storage interventions, cotton price regulation, and better loan management) were made. These recommendations centered around the scope of the study and incorporate the main financial and hydrological limitations farmers face. Separately, considerations outside of the main scope were considered for it was found that for successful cotton production and farmer welfare, many factors must be maintained and improved, not just water despite the critical role it serves.

10 Acknowledgements

First and foremost, we would like to convey a big thank you to Dr. Saket Pande. He was involved right from the start of the project and checked in with us every single week to see how we were doing. He connects so very deeply to the plight of the farmers and has constantly urged us to think along the lines of how, we as students with a technical background, can make a difference.

We thank Prof. Dr. Susan Steele-Dunne who in spite of a very busy schedule, guided us with the preparation phase and helped us understand the optimal use of the right remote sensing products.

We also thank a supporting team member Karlijn Adank a Bachelors student of civil engineering, TU Delft, who helped us carry out the fieldwork and provided us with timely insights.

It goes without being said that to truly relate to the pulse of the farmers, a one to one interaction with them is an absolute necessity. In this regard, we are extremely grateful to the translators from Solidaridad - Rahul, Aniruddha and Asaray. Their energy and zeal in being involved with the cause of the farmers, masked all signs exhaustion despite the long and tiring work days.

We extend our patronage to the other Solidaridad personnel - Ashray and Anukool for trusting us with their project, hosting us in their country and guiding us thoroughly. The work they do is utmost inspiring.

Last but certainly not least, we thank all the farmers, the weavers and the other humble workers of the cotton textile production industry who welcomed us into their homes and patiently explained to us about the work they do and the difficulties they face. A big take away from this project has been through them. Despite their struggling incomes and modest homes, they went well beyond their way in offering us food and chai and making us feel entirely at ease.

The project as a whole has been an immensely gratifying learning experience and we carry with us not only the weight of all the technical learning that the project demanded but also the weight of the moral responsibility to connect with the society.

A

Field Experiences and Stories

During our fieldwork we came across many beautiful and special families. Every single one of the farmers we interviewed was kind and welcoming for which we are very thankful. Some visits reserved a special place in our hearts and we would like to highlight them in this section.

A.1. Girl Power

During our field trip we unfortunately did not have the chance to interview many women. The ones we did encounter were however very special. The picture in figure A.1 shows a group of very special women in Yavatmal. Throughout the interview these women were laughing continuously and seemed to have so much fun together. They started as a self help group for women and aim to start their own farmers collective in the future. They have the ambition to buy their seeds and sell their produce collectively to cut costs. Monika Choudhari and her mother Wandana Subbash Chaudhari, the 'leaders' of the group, are true examples of girl power, see figure A.1. We wish these women the best for the future and hope to stay in touch somehow.
Another particularly insightful experience is the story of Savita Gopal. She is one of the very few female farmers who apart from working in her 2.5 acre farm of cotton, soya and toor also works as a cook and heads a self help group for the women of the village. It's so wonderful to see a woman take charge of her household (in the rural Indian setting) own farmland and also lead an organisation to uplift the other women of the village.

A.2. Feels like Family

On the 2nd of August 2019 we went to the village of Kadajna near Hinganghat in Wardha to interview farmers. The family we interviewed was so kind and welcoming, they offered us chai and insisted us to have food with them as the monsoons outside were getting intense, see figure A.2. The disparity between the rich and the poor even amongst farmers is apparent in many villages. While the former have safety nets through livestock, large acres of land, access to canals and some amount of discretionary power in even deciding the price of the crop, the latter are left to struggle with mounting debts from private lenders. The whole process of even having these conversations with the farmers instills a sense of responsibility in us towards ensuring where and how we source our fabric from. A back of the envelope calculation indicates that a marginal farmer owning less than 2 acres of land seeds the raw material for over 3500 cotton shirts in a year. How many of us are truly sharing responsibly for all the toil that goes into this rung of the textile production chain. Well at the very least this field work was a huge eye opener.

A.3. Self Reliant

Investing time and taking the risks to experiment and understand can make all the difference. This is Mr. Gajanan and his family from the village of Karmama in Yavatmal. He knows his land well enough to explain the geology of the soil layers and the water holding capacity of the various layers of clay, murram and rock. This equips him to provide measured amounts of water that meet the requirements

Figure A.1: Women self empowerment group ready to start their farmers collective

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Figure A.2: Family farmer discussions over chai

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Figure A.3: Group Interview in Yavatmal. Aniruddha on the right, our translator and hero who has been immensely helpful during the surveying

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of his cotton crop with minimal crop loss.
Not relying entirely on aids from the government and other organisations, he urges fellow farmers, men and women, to be self reliant. He urges them to make use of the power of technology where weather data is available in their very own phones. ”There are inaccuracies, but some information is better than no information” he says.
He wishes that the stages of the cotton manufacturing industry is extended within the village beyond the current stage of only producing the raw material. We hope that the textile industry, the ginning centres and weavers, together with the farmers, form a more inclusive society to enable an economically sustainable cotton production and manufacturing sector.

B Outreach

As the issue of farmer suicides in Maharashtra is a important and relatively under the radar in Europe, we felt the urge to share updates and information with our community. We did that by being active on social media, participating in presentations and events, contacting local communities and by attempting to fundraise money. We created our own logo, that is visible on our social media and front page of our report.

B.1. Social Media

Since the start of the project we were highly active on Facebook, with around a 100 followers. We posted pictures and movies at regular intervals to keep co-students, friends, family and other interested people up to date. In addition, we have a weblog to explain the project.

B.2. MDPitch

On the 15th of May 2019 we pitched our MDP at the Civil Engineering Business days. In a one minute pitch we presented for about 100 people, and got chosen as the best presentation by the organising company! Unfortunately we did not go home with a price as the voting system depended on audience votes only.

Figure B.1: MDPitch presentation

B.3. Mahindra United World College

We kept close contact with a school near Pune, Maharasthra, that may take up a project along those lines in the future. We aimed to get some of their students involved but unfortunately due to a delay in communication and coincidence of our visit with their summer holidays we could not realise the collaboration as of yet. We will be sending the final report to them and we are still in touch as they are planning to organise a global affairs session on the topic. Hopefully they can get involved in the future too, there are many students eagerly looking for interesting project and graduation theses!

B.4. Fundraising and Windmill Tournament

Every year the largest ultimate frisbee tournament of Europe, Windmill Tournament, asks players for a 'green' contribution to offset their carbon footprint in their travelling to the tournament that can then be spend on a climate change related project. We pitched Project Cotton Water and won second place. First place was for another project in India that promotes biogas cooking for women in Indian rural communities that more is more directly related to carbon offsetting than our project. Windmill Tournament did sponsor us by providing us with tablets to perform the interviews on!

B.5. Final presentation

On the 11th of October 2019 we will present our results to a wide audience of co-students, friends, teachers and anyone interested! We hope that this will inspire others to take up a project like this and to engage in socio-hydrological questions. After this event we hope to get in touch with some of the farmers we interviewed, especially the women's collective in Yavatmal, and the family that was so kind to host us in their homes and made us stay for dinner.

C

Appendix: Survey Questions

Background Questions
Name of the Village:
Date and Time:
Are you a project farmer?
GPS latitude:
GPS longitude:
Name of Interviewer:
Name of Interviewee:
Gender:
Age:
How many dependents do you have?
How many in your family help you farm?
Highest Education level completed:
If other education
House Material
If other housing material
Roof Material
If other roofing material

Financial Information
How large is your total area for farming?
How large is your farming area for cotton?
What crops do you grow other than cotton?
If other crops grown
What months of the year are your fields barren?
How many cows do you own?
How many bulls/bullocks do you own?
How many goats do you own?
How much income from all crops do you receive roughly per year?
What is the total expenditure for all crop inputs per year?
Do you take any loans for farming?
Who have you taken loans from?
If other source of loans
Have you been able to pay your loans completely?
What is the total amount of loan debt you have now?
What is the interest rate of the loan(s) you have taken for farming?
Have you taken crop insurance?
How much income do you receive from other work besides farming per year?
How much total income do your family members receive per year?

Crop Practices
What is the main cause of crop failure for you?
If other reason
What is the main cause of crop success for you?
If other reason
How many acres of organic cotton do you grow?
From where do you get your cotton seeds?
If selected other
What is the price of a package of seeds (450 g/packet)?
How many packets of cotton seeds do you apply per acre?
What is your yield of cotton?
What is a good yield to you?
How much do you sell your cotton for?
Who do you sell your cotton to?

Water Sources

How many open wells do you have access to?
How many open wells do you own?
How many borewells do you have access to?
How many borewells do you own?
How many farm ponds do you have access to?
How many farm ponds do you own?
How many rivers do you have access to?
How many canals do you have access to?
Is there any other water source that you use? If so
Has your primary water source changed in the last 10 years?
How far is the nearest canal/pond/river/well?
What is the depth of your well?
What is the premonsoon depth of water of the nearest open well?
What is the postmonsoon depth of the water in the nearest open well?
Is the water level in the well increasing or decreasing in the last 10 years?
What is the soil depth around your farm?
What is the quality of the soil around your farm?
How has the soil quality changed in the last 10 years?
How many acres of your cotton is irrigated?
How many times do you irrigate per crop cycle of cotton?
What kind of irrigation technology do you use?
If selected other
What type of pump do you use?
If other type of pump
Do you own your own irrigation equipment or do you use someone else’s?
How responsible are you for your own water source?
How much do you pay for your water source/irrigation services?
How willing are you to pay for irrigation systems?
How much more time do you believe using irrigation takes?
How much more effort do you believe using irrigation takes?
People who are important to you
How confident are you that you could operate an irrigation system (such as drip or sprinkler)?
How much more crop production do you believe you could have if you used an irrigation system?
How much do you think irrigation systems increase the long-term water supply?
What proportion of people in your village use irrigation systems?
Have you ever received information about awareness on water scarcity or farming practices?
How helpful do you believe this information was?
How often do you receive this type of information?
From who did you receive the information on these topics?
If selected other
What type of information would you want to receive that you think would be useful?
If other type of info desired
How important is it to you that you use water as efficiently as possible?
What is the most reliable water source?
If other is most reliable
How does the current water supply compare to the water you need for your crops?
To what limit could you withstand water shortage?
Has it become more or less difficult to get water in the last 10 years?
How confident are you that you have enough water in the next 5 years ?
How severe is the impact on you when you do not have any water for your crops?
Is your household capital increasing or decreasing in recent years?

Fertilizers and Pesticides
What type of fertilizer do you use?
If other type of fertilizer used
How much fertilizer do you apply for cotton fields?
From where do you get your fertilizer?
If selected other
How much do you pay for fertilizer?
How much do you pay for pesticides?
Who do you think is responsible for taking action to solving problems in your community related to crop production and farmer welfare?

D

Appendix: Questionnaire Statistics

This appendix contains multiple tables with survey data.

Table D.1: Sex demographics of surveyed farmers

n = 342	Male	Female
Count	334	8
Percentage	98%	2%

Table D.2: Cotton Yield and Price Statistics

	Yields (quintal/acre)	Good Yield (quintal/acre)	Prices (Rs/acre)
Mean	6.3	11	5085
SD	2.15	3.1	418
Min	2.5	5	4000
Max	19	20	6300
Median	6	10	5000

Table D.3: Age and Area [in acres] Information with Percentage of Farmers who Grow Specific Other Crops

Age	Total Area	Cotton Area	Organic					
	Mean	46.3	7.1	4.7	0.3			
	SD	12.85	6.8	4.1	0.5			
	Min	19	1	1	0			
	Max	95	40	35	5			
		Other crops						
n = 311	Pulses	Soyabean	Wheat	Bajra	Veg	Sugarcane	Turmeric	None
count	260	151	46	3	28	3	6	11
%	84%	49%	15%	1%	9%	1%	2%	4%

Table D.4: Income Statistics

Rupees	Crop Income	Additional Income	Family Income	Total Income	Crop Expenses	Net Crop Income	Net Total Income
Mean	226194.6	24359.8	8949	259503.4	155544.5	70650.1	103958.9
S.D.	295519.8	76051	31956		573425.6		
Min	10000	0	0		2000		
Max	2500000	1000000	300000		10000000		
Count >0		118	63				
Mean for >0		62813	45318				

Table D.5: Education Statistics

Education Completed	Percentage
None	2%
Primary	13%
Middle School	22%
10th	24%
12th	23%
Bachelors	13%
MS	2%
PhD	0%

Table D.6: Main Causes of Crop Failure and Success

Main Cause of:	Crop Failure		Crop Success
Too Little Water	52%	Timely Rain	97%
Untimely Rain	29%	No Pests	2%
Pests	6%	No Animals	1%
Wild Animals	3%		
Too Intense Rain	9%		

Table D.7: Costs and Amount Applied of Main Crop Inputs

Costs/Acre (Rupees/acre)	Irrigation	Seeds	Fertilizer	Pesiticides
Mean	2659	1495	3580	2907
SD	5948	880	2196	2214
Count >0	264			
Mean Amount Applied:		900 g	176 kg	

Table D.8: Average number of livestock owned and number of farmers who own any livestock

n = 254	Total Livestock	Goats	Cows	Bulls
Mean	3.36	0.55	1.54	1.35

Table D.9: Percentage of farmers who use different types of specific fertilizers

n = 343	Manure	Potash	NPK	DAP	SSP	urea	chem
Percentage	67%	61%	74%	62%	37%	89%	24%

Table D.10: Sources of Fertilizer, Seeds, and Loans and also Cotton Buyer Statistics

	Fertilizer Source					
	Livestock	ASC	Company	Govt	Open Market	
n = 336	52%	95%	1%	0%	2%	
	Seeds Source					
	Market	ASC	Govt	Other farmers	FPC	Other
n = 345	3%	93%	1%	0%	4%	3%
	Cotton Buyer					
	ASC	Broker	Market	Ginning Center	Welfare Org	Govt
n = 319	1%	12%	73%	20%	2%	0%
	Loan Source					
	Private Bank	Gov't Bank	Money Lender	ASC	Other	
n = 301	11%	77%	9%	1%	3%	

Table D.11: Irrigation Usage Statistics

	Irrigation			
Yes	67%			
No	33%			
	Drip	Sprinkler	Furrow	Other
For irrigating farmers:	6%	38%	54%	1%
	Irrigation Times Per Cotton Season			
Mean	3.1			

Table D.12: Water Source Statistics

Stats n = 319	Open Wells	Borewells	Farm Ponds	Rivers	Canals	Rain	
Have Access to	63%	9%	9%	10%	32%	–	
Own	60%	9%	7%	–	–	–	
Fraction Access to 1	13%	1%	1%	0%	0%	–	
Fraction Owning 1	6%	1%	0%	–	–	–	
Most reliable	42%	3%	1%	2%	6%	50%	n = 332

Table D.13: Well and Reported Water Level Statistics; Percentage Who Have Changed their Water Source in the Last Decade

	Well Depths (ft)	Seasonal Water Level Fluctuations
Mean	37	21
SD	10.5	3.4
Min	15	5
Max	65	55
	Water Source Changed?	
	Yes	No
Percentage	41%	59%

Table D.14: House and Roof Construction Material Statistics

House Material			
Cement	Brick	Mud	Steel
52%	40%	34%	6%
Roof Material			
Cement	Steel	Tiles	
43%	49%	11%	

Table D.15: Responsibility for Local Problems and Reported Household Capital Trends

Who is Responsible					
	Myself	Local Govt	Natl Govt	Company	Village Head
n = 262	55%	33%	10%	1%	1%
	Capital Last Years				
	Increase	Decrease	Same		
n = 332	28%	57%	16%		

Table D.16: Loan and Crop Insurance Information

Loans		
	Debt	Interest Rate
Mean	128000	11.6
SD	227355	15.5
Min	0	0
Max	2750000	79.5
Percent who have loan:	84%	
Percent who have crop insurance	34%	

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