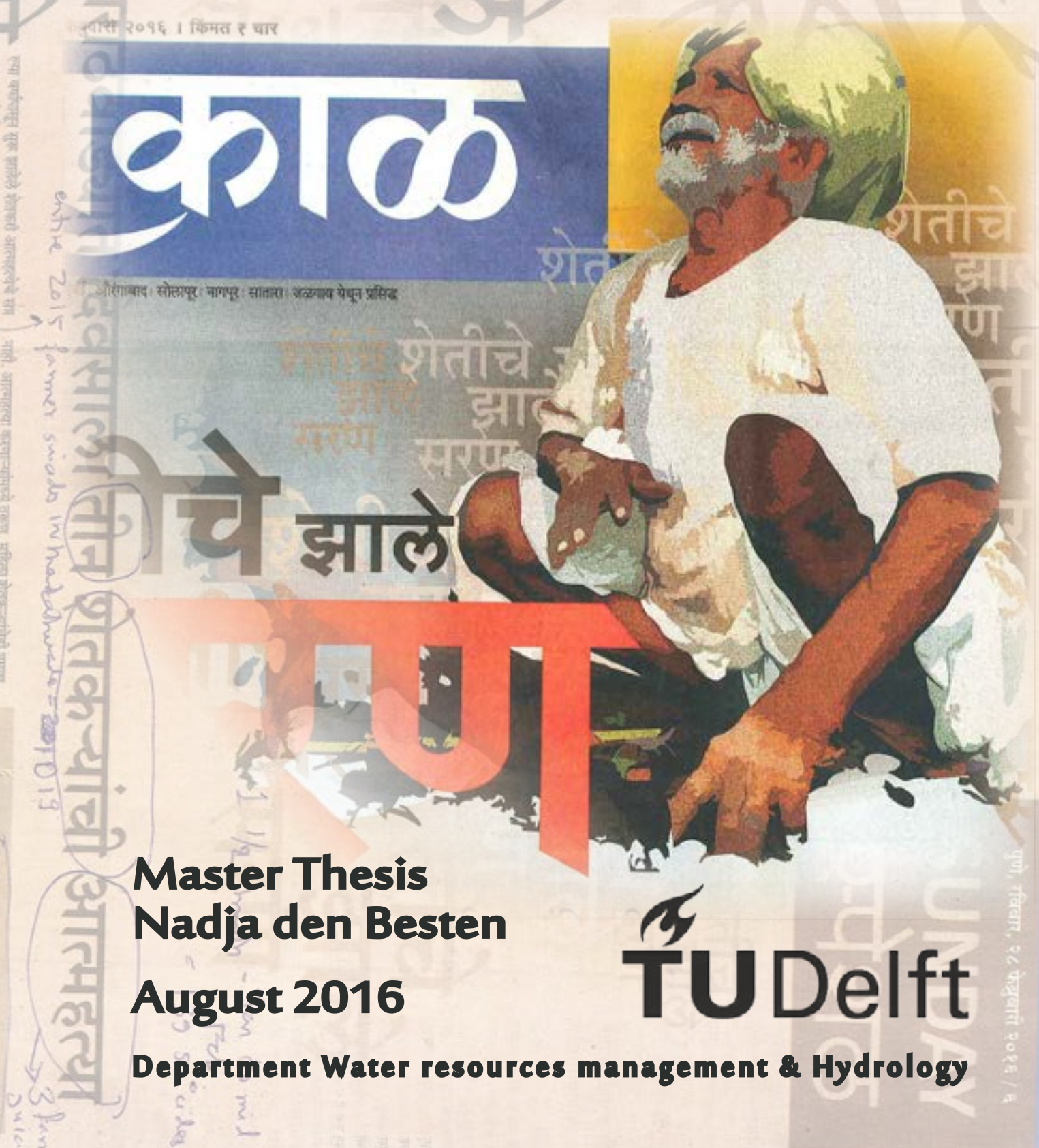


The socio-hydrology of smallholders in Marathwada, Maharashtra state [India]



Master Thesis
Nadja den Besten

August 2016

Department Water resources management & Hydrology


TU Delft

पुणे, रिवार, २८ फेब्रुवारी २०१६ / ६

Master thesis

The socio-hydrological situation of
smallholders in Marathwada, Maharashtra
state (India)

by

Nadja I. den Besten

to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on 26th of August, 2016 at 16:00.

Student number: 4401646
Project duration: October 1, 2015 – August 1, 2016
Thesis committee: Prof. dr. ir. H.H.G. Savenije, TU Delft
Dr. S. Pande, TU Delft, supervisor
Dr. D. van Halem, TU Delft

This thesis is confidential and cannot be made public until August 21, 2016.

An electronic version of this thesis is available at <http://repository.tudelft.nl/>.

Preface

Dear reader,

Less than three years ago I started studying Hydrology at the VU University Amsterdam, never imagining that I would end up studying Watermanagement at the Technical University here, in Delft. But here I am. Fortunately this unwanted change led to an awesome new journey. I have been able to finish all the exams and confronted all the challenges that came along, especially while writing my thesis. I became good friends with Python, which was my biggest challenge and eventually victory. A thesis is one big confrontation with yourself and requires most of all perseverance, that is best sustained by an encouraging environment. Therefore I want to thank my tutor Saket Pande for his patience, guidance and persistence during this year. Bannie, Swoep, Stinkie, Maggie, the rest of the family, and friends for the mental support and encouragements when needed. And Mali Mrav for the moment of peace during our little trip that made me ready for the final spurt. Also Huub Savenije for his comments, ideas and positiveness throughout the year.

A special thanks go out to all the fantastic people that I have met during my stay in India. I had the chance to meet a lot of interesting and inspirational people that also helped me getting the data I needed. Thank you SOPPECOM members, Joy, Neha, Craig, Sarita, for your guidance. Rupa for your unmissable hospitality. Thanks Anish Kamble and Vasundhra for helping me interview farmers around Parbhani and giving access to meteorological data. And Waseem for mentally supporting me during my stay in Parbhani. A big thanks to Nikalje's family for the kindness in Aurangabad. My gratitude towards Madhuri and Prakash for taking me in the field and showing me around and Sadeek in Ellora. And of course all the farmers that were willing to answer the questionnaire: Dhanyavada!

In this thesis I have used a lot of different kinds of information. Besides modelling, I also tried to incorporate other disciplines than hydrology. If you get ideas on how to improve things or incorporate things better: let me know! If you want to know more about my experiences in India or my thesis, go to: <http://nadjadenbesten.wix.com/smallholder-blog>. I hope you enjoy reading my thesis!

*Nadja I. den Besten
nadjadenbesten@gmail.com
Delft, Summer 2016*

Abstract

India's rural population accounts for sixty percent of the total, where agriculture provides the main source of income. This is no different for the mid-southern state Maharashtra. A state where the monsoon drives the climate, hence determines crop yields of abundant rain-fed farmers. The state also witnessed high suicide rates among farmers in the last decade, despite high growth of the Indian economy

A socio-hydrological modelling is used as a tool to interpret the crisis. A recently developed smallholder socio-hydrological modelling framework is deployed that conceptualizes the system dynamics of a farmer. First a comparative assessment is done by applying the model to two adjoining divisions of Maharashtra: Marathwada and Desh. To obtain insight into the dominant factors behind the crisis in Marathwada, which witnessed higher farmer suicide rates than Desh. It reveals that the difference in farmer distress can be attributed to differences in soil characteristics, hydro-climatic variability and cropping pattern.

The role of unsuitable cropping patterns in triggering farmer distress is then assessed historically (over a 30 year period of 1981-2011) simulating 3 types of smallholders: a food grain producer, a farmer who changed his cropping to pulses (after 1992), and a farmer who switches to producing cash crops (after 1992). These assessments are based on observed changes in cropping patterns in Marathwada and support the argument that marginal farmers switching to risky cash crops, that are not appropriate for the local conditions, may be behind elevated farmer distress.

Finally, various on-farm socio-hydrological processes, that were inspired by farm surveys conducted in March and April 2016 in Parbhani, were improved in order to enhance the realism of the developed model for Marathwada. These included the effect of high intra-seasonal variability on crop yields and the on-farm characteristics. All led to improved correlation with observed suicide rates.

Results demonstrate that socio-hydrological modelling provides an explanation behind regional differences in suicides rates. Cash crops increase the vulnerability of small farmers to crop failure, yet farmers take more risk hoping for high returns from selling cash crops. Weak credit and crop insurance systems are accelerating the distress amongst farmers in the region. In fact, the effect of droughts is accentuated by the choice of growing cash crops. In conclusion, finding on-farm water storage solutions are not sufficient to alleviate farmer distress. Policy intervention should focus on promotion of watershed development and financial incentives may be needed to motivate a change in cropping pattern or off-farm labour alternatives.

Contents

| | |
|---|-----------|
| Abstract | v |
| 1 Introduction | 1 |
| 1.1 An introduction on smallholder agriculture | 1 |
| 1.2 Smallholders in India | 2 |
| 1.3 Modelling smallholder systems | 3 |
| 1.4 Research aim and contributions | 3 |
| 1.5 How to read this document? | 4 |
| 2 Methodology | 5 |
| 2.1 General approach. | 5 |
| 2.2 Background information | 6 |
| 2.2.1 Marathwada's regional characteristics | 6 |
| 2.2.2 Agriculture in Marathwada. | 7 |
| 2.2.3 The socio hydrological modelling framework | 8 |
| 2.3 Socio-hydrological research inquiry. | 9 |
| 2.3.1 Comparative socio-hydrology | 9 |
| 2.3.2 Historical socio-hydrology | 11 |
| 2.3.3 Process socio-hydrology | 12 |
| 3 Results | 19 |
| 3.1 Results comparative socio-hydrology | 19 |
| 3.2 Results historical socio-hydrology | 22 |
| 3.3 Results process socio-hydrology | 22 |
| 3.3.1 Dry spell analysis and daily time-step | 24 |
| 3.3.2 Improving the water balance and incorporating a crop growth model | 24 |
| 3.3.3 Assumptions model and fieldwork. | 28 |
| 4 Discussion | 33 |
| 4.1 Comparative socio-hydrology. | 33 |
| 4.2 Historical socio-hydrology | 34 |
| 4.3 Model sensitivity | 34 |
| 4.4 Process socio-hydrology | 34 |
| 5 Conclusions and recommendations | 39 |
| 5.1 Why are farmers distressed in Marathwada? | 39 |
| 5.2 What do the updated simulations tell us? | 39 |
| 5.3 On what aspects should policy focus? | 40 |
| 5.4 How can the socio-hydrological modelling framework be enhanced? | 40 |
| 6 My thesis: a retrospective | 43 |
| Bibliography | 47 |
| A The Socio-Hydrological Modelling Framework | 53 |
| B The questionnaire | 59 |
| C Parameters | 67 |
| C.1 Crop factors. | 67 |
| C.2 Parameters for comparative assessment | 67 |
| C.3 Parameters for historical assessment | 67 |
| C.4 Crop growth parameters | 69 |
| C.4.1 Initial canopy size and Canopy growth coefficient | 69 |

| | |
|--|-----------|
| C.4.2 Remaining parameters | 69 |
| C.5 Adjustments pan evaporation | 70 |
| C.6 Elaboration discussion | 70 |
| D Dry spell analysis | 73 |
| E Outcome surveys | 75 |
| E.1 Outcome survey farmers Marathwada | 75 |
| E.2 Summary Interview and Outcome survey Agrowon | 84 |
| F Succes story | 87 |



Introduction

"*Drought drives farmers to suicide.*" states one of the biggest Dutch news providers on Tuesday, May 3rd, 2016 (NOS, 2016). The NOS was covering the rural situation in Maharashtra, where two years of severe drought has led to crop failure leaving farmers with nothing but debts. Since the mid nineties a total of 300,000 farmers have taken their lives in India, and the mid-southern state Maharashtra tops that list with 60,000 farmer suicides (Umar, 2015; Mishra, 2014). Suicide rates among farmers have increased since 1995 in two states: Kerala and Maharashtra (Basu, 2016). Two regions located in Maharashtra, Vidarbha and Marathwada, are referred to as the epicentre of farmer distress.

While India's economy is accelerating, the growth rate of the agricultural sector is declining (Kalamkar, 2011). Its rural inhabitants cannot mechanize and innovate as fast as the knowledge intensive sectors, like IT and Telecom, can. While the economy in the west of Maharashtra is blooming, in cities like Mumbai and Pune, 25% of the province's inhabitant live under the poverty line and can predominantly be found in the eastern rural part of Maharashtra. The distress seen in regions such as Marathwada is probably related to hydro-climatic variability, but it is surely not the only factor affecting the agricultural sector in Maharashtra. To understand the context in which the farmers are producing and the factors that trigger their well-being, a multi-disciplinary approach is needed. This approach then requires one to answer questions such as: Why do so many farmers choose to take their lives? Which factors trigger the accelerated distress? And what measures will alleviate their well-being?

When trying to understand a smallholder's situation, one must understand the interactions of factors influencing the smallholder's well-being. Unfortunately, when framing this in a multi-disciplinary approach, complexity becomes difficult to avoid. In an attempt to understand the general dynamics of farming, a socio-hydrological modelling framework was set up by Pande and Savenije (2016). This modelling framework uses a water-centric approach to describe the farmer situation in Marathwada region. In order to understand the current agricultural crisis in Maharashtra, this thesis is parameterized to suit a single farmer situation in the Marathwada region (see Figure 1.1 for the location). This customised model forms the basis for this research and will be extended and thoroughly examined through different socio-hydrological approaches.

1.1. An introduction on smallholder agriculture

This research will focus on marginal- to small-scale farmers, from now on denoted as smallholders, owning less than four hectares of arable land. The definition for the term smallholder is a bit arbitrary as it suggests that land-size solely defines the well-being of a farmer, while other factors such as crop choice, availability of capital and water are just as important (FAO, 1992). Smallholder agriculture is responsible for approximately four-fifths of the food in developing countries. Thereby, these farms make up a vital part of the local and national food production chains, despite being individually small in size (IFPRI, 2013). However, smallholders are vulnerable to market fluctuations and climatic variability e.g. because of their lack of (economic) resilience. Therefore many smallholders and their (local) consumers tend to be trapped in a low economic state, in literature referred to as the "poverty trap" (Stephens et al., 2012).

A characteristic of smallholders is that they deplete their natural capital in order to maximize agricultural production (Funtowicz and Ravetz, 1989). Besides, most accessible fresh water will be allotted, on a global level, by 2025, but nevertheless the fresh water demand for food production will continue to rise alongside in-

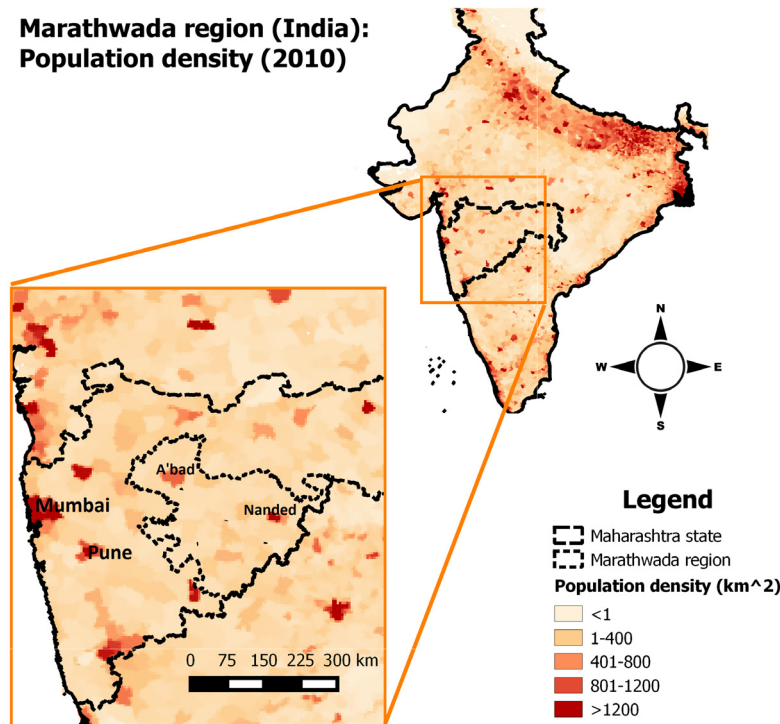


Figure 1.1: The map gives the location of Marathwada, Maharashtra state, India. Marathwada is not very densely populated compared to northern India, 19 million people reside in the area. Big cities located in Marathwada are Aurangabad (A'bad, northwest) and Nanded (east).

creasing populations (Makurira et al., 2011). More sustainable agricultural production methods are therefore required.

Enhancing the development of smallholders has been set as a goal by international development work (Beekman et al., 2014). Stabilizing the economic situation of smallholders is key to address two main challenges: securing (global) food production and markets, and sustainably utilising natural resources (such as soil nutrients and fresh water reservoirs). In order to understand what will improve the current socio-economic situation of smallholders, it is important to study the nexus between a smallholder's physical characteristics and his/her socio-economic situation. Thus, by improving knowledge on factors and feedbacks within a smallholder system, this thesis is providing vital information which will aid international development goals.

1.2. Smallholders in India

Smallholders in India are confronted with the same issues as many smallholders in other parts of the world. The steady rise of the population in India increases pressures on the agricultural lands and natural resources. Key commodities (mostly high value) lag behind demand, also a vast majority of the production manners are unsustainable and many farmers subsist in poverty (Ferroni, 2012). Efficiency is needed to improve all aspects of agricultural production and influential factors, especially where water availability plays a key role.

In India smallholders contribute significantly to the total value of agricultural output (IFAD, 2009). India's smallholders account for 80% of the farmers, yet they only own one third of the agricultural lands (Singh et al., 2002). Despite the relative small amount of land ownership, smallholders contribute to 41% of the country's food production. This is indicative of relatively higher productivity of smallholdings when compared to medium- and large-size farms (Singh et al., 2002).

The fragility of smallholders is very noticeable in India, finding expression in the aforementioned suicide rates. In the early 1990s the agricultural sector was liberalized, resulting in exposure of farmers to international prices, absence of subsidies and uncontrolled credit systems. This liberalization perhaps partly triggered an agricultural crisis in India. Farmers with certain socio-economic characteristics, such as cash crop

producers¹, smallholders, and debts, were visibly more susceptible to bankruptcy (Kennedy and King, 2014). A combination of other factors further accentuated the crisis. These factors include poor biophysical characteristics, high intra- and inter-annual rainfall variability and lack of off-farm labor opportunities (Nagaraj, 2008).

Finally, approximately 600 million Indians, more or less half the population, are dependent on agricultural activities. The sector agricultural is huge, however overlooked in India's policies (The Economist, 2016). The recent increase in suicide rates in India's rural areas has brought a lot of attention to the subject. The agricultural sector in India needs reforming and an understanding of the dynamics of smallholders, specifically, can be of immeasurable value.

1.3. Modelling smallholder systems

So far many studies have been performed to explore the dynamics behind agricultural systems, mainly for policy guidance and improved management. Whole-farm simulations have been on-going since the invention of system dynamic modelling, which originated in the mid-1960s and was refined in the years thereafter (Peart and Curry, 1998). Recent years show a proliferation on the subject resulting in many studies and models, especially on smallholders, in developing countries (Robertson et al., 2011). A distinction can be made between studies which either emphasise the economics or rather the biophysics (Robertson et al., 2011). Examples are models such as NUANCES (Wijk et al., 2009) or IMPACT (Herrero et al., 2007) which are household models in developing world agriculture. Other studies include the effect of livestock intensification on smallholders (Komarek et al., 2012), allocation studies on mixed crop and livestock within smallholder systems (Thornton and Herrero, 2001), and various other aspects within a smallholder's system.

An example of a "bio-economic model" was developed by Stephens et al. (2012), named CLASSES. The model simulates the interaction between biophysical characteristics and economic decisions and integrates a few vital aspects of a smallholder (e.g. Livestock numbers, soil nutrient, household cash available etc.). With the help of System Dynamics modelling methods they integrated data from rural regions in Ghana and expert knowledge in one model, to study the processes within a smallholders' system. Different interventions (e.g. agricultural yield shocks, market access shocks) were simulated and it was shown that the natural resource base and farm size are very important in the development of the smallholders' system. Additionally, on-farm production diversification is a good strategy to overcome decreasing revenues. However, hydrological aspects are not included in the CLASSES-model, while erratic rainfall patterns do affect a lot of smallholders in semi-arid regions (Rockström, 2003).

Recently socio-hydrology, a new research approach within hydrology, studied several coupled human water systems in models (Sivapalan et al., 2012b). These included human-flood interactions (Di Baldassarre et al., 2013), urban water security (Srinivasan, 2013) and conceptual socio-hydrological frameworks (Elshafei et al., 2014). From this new paradigm a socio-hydrological modelling framework arose that had a water-centric approach to smallholder's situation linking a so-called water balance with different features in a smallholder system (Pande and Savenije, 2016).

1.4. Research aim and contributions

This proposed study will focus on enhancing the realism of the socio-hydrological modelling framework for a smallholder. The objective of this study is (1) to contribute to existing knowledge on the distress seen in Marathwada with the help of the modelling framework, (2) to enhance the structure and highlight possibilities of the approach, and (3) to verify and validate the functioning and results of the model thus far. In order to accomplish this, this research:

- Comparatively assessed the framework spatially by applying it to two adjacent regions, experiencing different distress levels amongst farmers.
- Historically assessed the framework to visualize what happens to the farmer after certain changes in time.
- Verified outcomes and model assumptions with data and observations conducted during a fieldwork in Maharashtra at the beginning of 2016.
- Downscaled and elaborated the soil moisture balance within the model.

¹Cash crops are non-food crops as cotton, sugarcane and soyabean; primarily produced for their larger revenues.

- Introduced a crop growth model that incorporates the effect of dry spells on the crop development.
- Proposed a direction for new policy interventions.

With the progresses enumerated the study will be part of a bigger perspective to develop this model into a tool that can be used to analyse policy interventions and effects of external forces such as climate change. In the end, a framework can be created that can outlay the location specific constraints disrupting the development of the smallholder.

1.5. How to read this document?

The chapter following this introduction gives background information about the study site, the current agricultural status of the region, and a description of the performed fieldwork. Thereafter the modelling theories and methodologies used in this thesis will be explained further (see Chapter 3 Methodology). The fourth chapter will display and describe the results found by applying the methodology to the socio-hydrological modelling framework. After that, the results will be compared to existing narratives and literature, to discuss the relevance and validity of the outcomes displayed in the results. Based on this discussion, some conclusion will be drawn that sustain current debates on the topic and improve insight in effective measures that can be taken to improve the well-being of smallholders in Maharashtra.

2

Methodology

2.1. General approach

Sivapalan et al. (2012a) introduced a new approach in hydrological sciences named socio-hydrology, where the interactions between people and water are studied. Socio-hydrology is a new approach, in the sense that it makes the human agent endogenous to the hydrological system rather than keeping human influences as an external factor/parameter. The study performed in this thesis follows the socio-hydrological approach proposed by Sivapalan et al. (2012a). An overview of this iterative approach to scientifically review a new socio-hydrological theory or model can be found in Figure 2.1.

Pande and Savenije (2016) postulated a theory about farmer-water interactions for a smallholder in a socio-hydrological modelling framework. In their work they already conducted the first two steps of the scientific inquiry, as shown in Figure 2.1, by building the modelling theory and experimenting with it; for results of their work see Appendix A. In order to verify the outcomes and structures of the modelling framework and improve the model, this thesis implements the following areas: (1) comparative socio-hydrology, (2) historical socio-hydrology and (3) process socio-hydrology. The comparative assessment consists of a comparison of two adjoining regions in Maharashtra. Subsequently, this thesis gives a historical assessment by looking at the change in cropping patterns post-1991. Finally processes were studied in order to enhance the model, supplemented with field observations. All the aforementioned steps and their methods will be explained in the chapter that follows. First, however, background information concerning the research area and an introduction to the model will be provided.

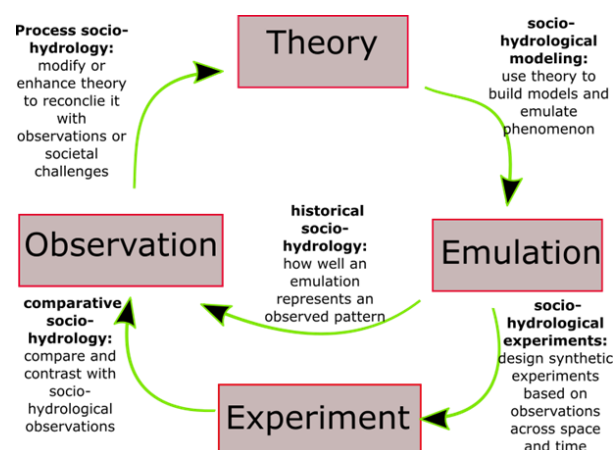


Figure 2.1: The figure above lists and mentions the methodology that can be used to postulate and improve a socio-hydrological theory. The figure was obtained from Pande and Sivapalan (Under review).

2.2. Background information

2.2.1. Marathwada's regional characteristics

Marathwada is situated in the middle of the state Maharashtra, (see Figure 1.1), mid-south India. It consists of eight administrative districts: Hingoli, Parbhani, Beed, Latur, Nanded, Aurangabad, Osmanabad and Jalna. Marathwada has a semi-arid climate with an average precipitation between 800-900mm/a. The climate is monsoon driven and Marathwada receives its main rain showers during June, July, August and September. Due to its inland location and erratic rainfall pattern, Marathwada is a drought-prone region. The Indian Meteorological Department (IMD) conducted a drought frequency study (with rainfall data from 1875-2009) that found a drought probability of thirteen percent. To clarify, a drought was defined by if there was a rainfall deficiency over 25 percent (of the average); occurrences fitting this definition were counted. Two consecutive years of drought are quite uncommon and it only happened once in 1985-85 (Attri and Tyagi, 2010). The only other time Marathwada experienced a consecutive drought was recently: 2014 and 2015.

Maharashtra has three meteorological seasons: Kharif, Rabi and summer. Kharif is the rainy season from June until September - October, hereafter (until summer) the Rabi season starts, and summer is the hottest and driest period from March until May or the beginning of June. The minimum average temperatures are around 20 degrees Celsius in summer and the average maximum temperatures are around 30+ degrees Celsius in summer, however temperature during the day can easily exceed 40 degrees Celsius (Climate-data.org, 2016). Figure 2.2 displays the average monthly potential evaporation and rainfall for Parbhani, a northern district within Marathwada.

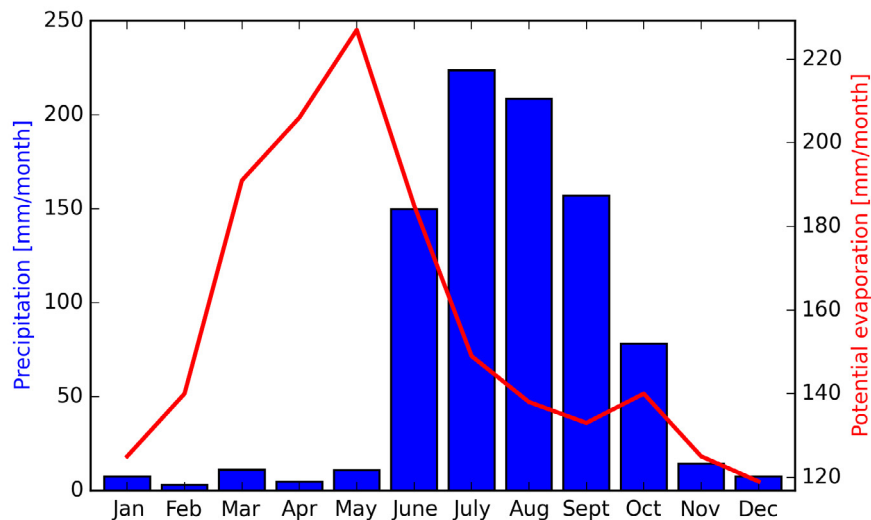


Figure 2.2: The figure above gives the average rainfall and potential evaporation for the district of Parbhani (north of Marathwada), the average is conducted from a timeseries from 1981-2015. The data was obtained from a weather station at Parbhani's Agricultural University Marathwada.

The dominant soil types in Marathwada are Chromic vertisols (clay [light]) with inclusions of Vertic Cambisols (clay [light]) and Lithosols (loam), abstracted from the Harmonized World Soil Database v1.2 (Fischer et al., 2008). Vertisols, colloquially denounced as "black cotton soils", cover a quarter of Maharashtra's surface. In the western part of Maharashtra the soil types alter slightly, however, throughout Maharashtra the dominant soil textures are classified as loamy to clayey (Fischer et al., 2008). The black cotton soils are known for their high water holding capacity and good plant availability of nutrients such as phosphate: a good soil to grow cotton in, even in semi-arid areas (Shodhganga, 1995). A fully moisturized Vertisol in middle India, can hold as much as 250 mm. Due to this large soil moisture storage capacity the black cotton soils show large seasonal swelling and shrinkage. With decreasing water content the soil starts cracking creating an unworkable environment making initial infiltration rates very high. However, once the cracks have been filled, the infiltration rates drastically decrease: increasing the run-off and halting further increase of the soil moisture (Virmani et al., 1982).

Marathwada comprises an area of 64,798 km^2 and the height above sea mean level lays between 300-650

metres (Shodhganga, 1995), well visible in Figure 2.7. The morphology is determined by fluvial processes, as Marathwada is part of the Godavari river basin. The interior of the basin is a plateau and has a general slope eastwards (WRIS, 2016b). Apart from Godavari's tributaries (as the Manjira river) Marathwada does not have other large surface water bodies. Therefore the government has attempted to increase the water availability by increasing the number of dams. Maharashtra has the most dams out of any other states in India. Contrarily there is a lot of controversy about the dams, because these dams also sustain industry (e.g. sugarcane mills) and consequently undermine their original intent, which is to improve the water availability to farmers (Asthanai and Shukla, 2014; Iyer, 2015).

2.2.2. Agriculture in Marathwada

As stated in the introduction, agriculture is still a major source of income for many people in India, and in Marathwada this is no different. Marathwada is inhabited by approximately nineteen million people, of which 75 percent live in rural areas with their income dependent on on-farm activities (Census, 2010-11). The farmers grow most of their crops in Kharif and Rabi season. The main crops that are grown are cotton (32%), soybean (27%), jowar (23%) and sugarcane (8%), and these numbers are from the year 2013-14 (Sood, 2013). Around sixty percent of the farmers are smallholders (< 4 ha landowners). A mere eleven percent of the cultivated area is under irrigation in Marathwada (DAC, 2010-2011).

The credit system plays an important role in rural India. Many (small-scale) farmers do not have the capital to invest in material, prior to the cropping season, that is necessary to persist their agricultural businesses. Most of the farmers therefore rely on agricultural credit relying on the crop yields to pay off the loans. In India the credit system has been institutionalized in the 1980s where cooperative, commercial, and rural banks form the channels through which subsidies and cash transfers reach the farmer (Mohan, 2006). Despite efforts of the government to combat informal credit systems, money-lending systems still burden the rural areas.

The land under cultivation and fallow land comprises 83,5% of the whole area. Only a very small percentage covers Marathwada with forest - 3.5 percent - and 13% of the area is not available for cultivation or un-cultivable. Since the beginning of the 1980s these land-use statistics did not change significantly (Munsande, 2014). However, the average area per farmer under cultivation has declined. 38.3% of the farmer is landless (leasing land from landowning farmers), while 3% of the farmers own 28% of all land. Between 2000-01 and 2010-11, the number of farmers have decreased, while the number of farm labourers have increased (Sood, 2013). A lot of farmers in distress are landless farmers or agricultural labourers, that have a low social status, excluding them from formal credit availability e.g. (Deshpande et al., 2001). It should be noted that the largest share of farmer suicides occur among marginal to medium sized farmers owning their own land (Dandelar et al., 2005; Khairnar et al., 2015).

A lot of other changes occurred in the agricultural sector throughout India. By adopting the rules and mechanisms of the IMF in 1991, India liberalized its economy. From 1992 onwards India's agricultural sector was no longer protected, but could compete alongside super-powers as America and China (Pillai, 1999). India, as a whole, shifted away from goals such as self-sufficiency and a dominant public sector, in favor of a more open economy and increased privatisation (Pillai, 1999). The effect of commercialisation is also visible in the change of cropping pattern. Cash crops, such as sugarcane, cotton, and soybean, have greatly increased since liberalization. Also, the introduction of HYV (High yielding variety) and GM (Genetically Modified) seeds increased the use of insecticides and pesticides. By adopting more and more foreign practices, the farmers in Marathwada (and throughout India) became increasingly dependent on external inputs (Madhumanti, 2007).

As a consequence high return values tempted many farmers, even subsistence farmers, to choose for more risky investments. By improved credit availability and subsidized agricultural input (seeds, chemicals e.g.) farmers increasingly chose to produce cash crops, as cotton (Madhumanti, 2007), see Table 2.1. In 2006 Bt cotton was introduced, a genetically modified crop (GMO), and with its introduction, the yields in Maharashtra increased, but input prices also rose accordingly. Additionally the GMO seeds cannot be re-used and needs to be bought every year. Furthermore fertilizer use increased as well (Lalitha et al., 2009). Currently, use of Bt cotton is largely adopted in Marathwada.

Though the average farmer income increased since the eighties, farmers in India are under distress. The agricultural crisis seems to hit farmers harder in some states than others. By comparing the suicide mortality rates (SMR) of farmers (farmers + agricultural labourers) to the SMR of non-farmers, one can see that Maharashtra is indicated as a state where the farmer suicide rates increased compared to the non-farmer suicides from 95s onwards (Figure 2.3) (Basu, 2016). Particularly the drier regions Marathwada and Vidarbha (east

Table 2.1: Percentages of farmers choosing to grow cotton. From each farm-size category the percentage of the total in that category is given.

| | Marginal (< 1ha) | Small (1-4ha) | Medium (4-10ha) | Large (10 <ha) |
|--------------|------------------|---------------|-----------------|----------------|
| % of farmers | 27 | 24 | 17 | 15 |

of Marathwada) are experiencing a high concentration of farmer suicides. The annual distress starts mostly from July onwards (see Figure 2.3) coinciding with the first months of the Kharif growing season.

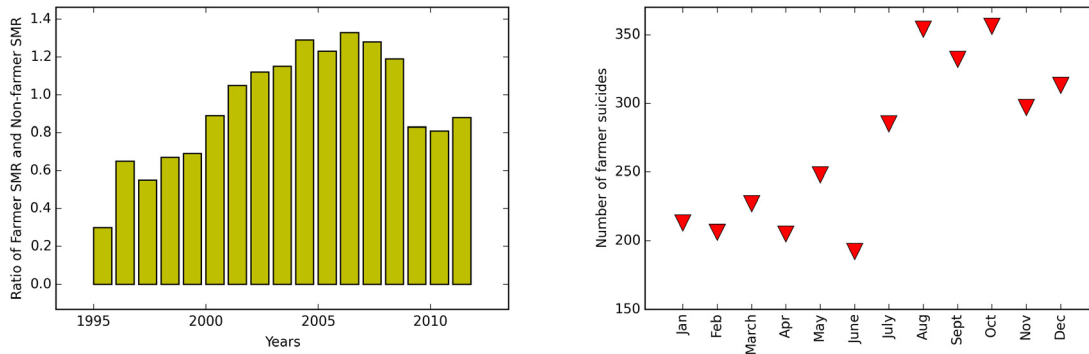


Figure 2.3: These graphs give more insight into the suicide statistics. To indicate the seriousness of the farmer suicides: the left graph shows the ratio of farmer suicide mortality rate (SMR) against the SMR of non-farmers in Maharashtra (Basu, 2016). The right graph gives the seasonal distribution of the suicide statistics: suicides start to rise short after the onset of the monsoon (Agrown, 2016). These numbers are recorded in 2015 in Marathwada.

2.2.3. The socio hydrological modelling framework

To understand what the determining drivers behind the distress seen in Marathwada are, a socio-hydrological modelling approach can be applied to filter the essential factors and feedbacks influencing the smallholder. To give a broad understanding of the framework used in this thesis, a detailed summary can be found in Appendix A. However what follows is a broad summary covering the socio-hydrological modelling framework.

The situation of a smallholder in the modelling framework is described by six coupled differential equations. Each differential equation describes one of the six socio-hydrological state variables: soil moisture, soil fertility, capital, livestock, fodder and labour availability. Seven socio-hydrological flux variables determine the interrelationships between these state variables, i.e., crop production, livestock sales, expenditure, livestock production costs, crop production costs, labour factor, and fertilizer factor. Climatic forcing and off-farm wage rates are external to the smallholder model system and influence the system as such.

Water availability plays an essential role in the model as it links to crop yield and fodder production, whom are linked to the income and, hence, capital development of the smallholder. To explain the modelling framework in a nutshell, consider a small farmer experiencing a year with disappointing crop yields due to poor rainfall, e.g. his/her capital encounters deficits as a result and therefore the farmer cuts down on his/her expenditure by selling livestock, cutting down on investments, school fees etc.. The farmer stops cutting down on his/her expenditure when capital becomes positive again. These adjustments consequently affect the socio-hydrological state variables for the next year. The evolution of farmers capital thus depends on how much he or she is exposed to hydro-climatic variability (which affects crop yields), price volatility (that affects crop income), and whether or not the farmer has access to hydrological or financial instruments that can buffer these variabilities.

Table 2.2 displays important assumptions used in the model and these will be tested and considered while enhancing the model.

| # | Assumption used in model |
|---|---|
| 1 | A reservoir with maximum water storage capacity S_{max} is assumed to represent a smallholder's subsurface. |

| | |
|----|---|
| 2 | No seepage at the bottom of the reservoir is assumed. |
| 3 | Moisture in excess of Maximum Storage is immediately removed from the smallholder system as excess runoff. |
| 4 | If irrigation is applied then it is assumed that the amount applied is such that evaporation is equal to potential evaporation. |
| 5 | Fodder availability (stock) is primarily driven by grass biomass stock. |
| 6 | The evolution of soil fertility is measured in terms of nitrogen content. |
| 7 | Nitrogen loss is mainly due to soil erosion loss (calculated with USLE ¹). |
| 8 | Livestock plays a dual role of productive and liquid asset. |
| 9 | Livestock is assumed to grow logistically with a varying capacity that depends on the available biomass. |
| 10 | Income generated from agricultural production is further assumed to be composed of income from crop sales and from selling livestock. |
| 11 | Expenditure includes interest on loans taken, taxation on income, and purchase of non-food items. |
| 12 | Expenditure cuts are made in a certain order when capital falls below zero. |
| 13 | When marginal value of on-farm labour is lower than the value of off-farm labour, off-farm labour is preferred. |
| 14 | The feedbacks between hydrology, local ecology, livestock and capital are primarily studied. |

Table 2.2: An overview of assumptions in the model.

2.3. Socio-hydrological research inquiry

The research conducted in this thesis will continue on the efforts done by Pande and Savenije (2016) and the challenging context of rural Marathwada. The methods used to perform the last steps of the socio-hydrological scientific inquiry will be described in the following sections. It should be noted that the original model was programmed in Matlab. The model used in this research, however, was coded in the programming language ©Python 2.7.9 win32 by the author. The adjustments made in the process hydrology section of the model were made specifically to focus on the soil moisture balance and capital calculations.

2.3.1. Comparative socio-hydrology

In order to see if the framework is able to grasp spatial variations in cropping pattern and biophysical characteristics, the model was comparatively assessed. In order to achieve this two regions were selected. A region with preferential biophysical characteristics and a lower suicide rate amongst farmers (the region being Desh) was compared to a region with inferior biophysical circumstances and a higher suicide rate (the region being Marathwada), see Figure 2.4 for the locations. By looking at cropping pattern, hydro-climatic variability and soil storage difference between the regions, an assessment was made to show if the deviation in suicide rates could be explained. The cropping pattern, hydro-climatic variability and soil storage data for the model were spatially variable, other data parameters about the socio-economic situation of the smallholders (e.g. off-farm labour availability) remained constant, see Appendix C for an overview of the parameters used. Thus, it was checked whether a spatial distribution of the biophysical characteristics and crop choice the difference in suicide rates could be (partly) explained.

First, the dominant crops among smallholders were identified for the two regions. The agricultural income mainly depends on cotton and/or sugarcane production. Besides these crops, jowar (Sorghum), rice and soyabean cultivation are also abundant. Near to sixty percent of the smallholders in the regions under study produce these five crops (DAC, 2010-2011). Table 2.3 gives the percentage of the amount of farmers choosing for the crop as a total of the region. Note that the numbers for Hingoli and Parbhani are stacked, as

¹USLE stands for the Universal Soil Loss Equation that approximates the annual soil erosion through a mathematical model, by looking at rainfall pattern, soil type, topography, crop system and management practices (Stone and Hilborn, 2000).

Table 2.3: The percentage of smallholders that produces a certain crop weighted to the market share of that district to the region (Marathwada or Desh), based on Census data for the year 2010-11 (DAC, 2010-2011).

| Percentages for Marathwada | | | | | |
|-----------------------------------|--------|-----------|------|-------|----------|
| District | Cotton | Sugarcane | Rice | Jowar | Soyabean |
| Aurangabad | 7.9 | 0.5 | 0.0 | 2.0 | 0.2 |
| Nanded | 10.3 | 0.7 | 0.1 | 5.5 | 7.1 |
| Latur | 0.9 | 1.0 | 0.8 | 5.4 | 3.5 |
| Parbhani | 8.3 | 0.4 | 0.2 | 3.3 | 5.1 |
| Jalna | 9.0 | 0.2 | 0.1 | 1.5 | 2.2 |
| Bid | 6.9 | 0.8 | 0.0 | 3.6 | 2.2 |
| Osmanabad | 0.5 | 1.5 | 0.4 | 5.4 | 2.4 |

| Percentages for Desh | | | | | |
|-----------------------------|--------|-----------|------|-------|----------|
| District | Cotton | Sugarcane | Rice | Jowar | Soyabean |
| Kolhapur | 0.0 | 6.0 | 5.8 | 0.9 | 2.3 |
| Pune | 0.7 | 5.0 | 2.0 | 12.6 | 0.2 |
| Sangli | 0.2 | 3.6 | 0.7 | 10.0 | 2.8 |
| Satara | 0.1 | 2.5 | 2.0 | 7.3 | 2.9 |
| Solapur | 0.1 | 8.0 | 0.1 | 23.9 | 0.3 |

before the year 2000 these districts were not separated and will ease analysing historical Census data.

The dominant soil types in the study regions were obtained through the Harmonized World Soil Database v1.2 (Fischer et al., 2008). All dominant soil textures throughout Marathwada and Desh are classified as loamy to clayey textures (USDA Texture classification) in the subsoil (Fischer et al., 2008). It is therefore assumed that Available Water Storage Capacity (AWSC) lies between 175 mm/m for loam and 200 mm/m for clay. The soil water storages for every district are then calculated by weighted mean soil depth (WRIS, 2016a) of the districts is then multiplied by the previously mentioned AWSC. These calculated soil moisture storages were used as input for the model.

Precipitation and potential evaporation data-series are created based on satellite products provided by Jones and Harris (2015); Zomer et al. (2008). Freely available Global Potential Evapo-Transpiration (Global-PET) data with a spatial resolution of 30 arc seconds (~ 1km at equator) is used to compute average potential evaporation on district level. The product used provides monthly averages over the years 1950-2000. These monthly averages are assumed to represent the potential evaporation over the simulated years. For precipitation a coarser product from the CRU-TS 3.0 Climate Database, with a 0.5 degree (30 arc minute) spatial resolution on land areas, is used. A monthly timeseries from 1983-2009 was extracted. Fertilizer and crop prices are obtained from The Worldbank (2015) with an exchange rate of ₹45 = 1USD to convert The Worldbank (2015) prices to ₹/kg². Crop specific yield coefficients are obtained as described by FAO (2015). Assumed application of fertilizers is as follows: 27 kgN/ha for Jowar, 57kgN/ha for Paddy and 10 kgN/ha applied for soybean production (FAO, 2005). The three crops are modelled as Kharif crops, growing from June until maximum October. All the crop factors have been obtained from FAO (FAO, 2015), see Appendix C.

By simulating all the different smallholder situations for both the farmers in Desh and in Marathwada, the results were computed for every farmholder situation with a different main crop. To compute the average capital development of both Desh and Marathwada, the simulation outcomes were weighted according to their market share (the factors are presented in Table 2.3). The market share was defined per region per crop and weighted according to the number of farmers producing that crop.

$$K = \sum f_d \times (f_i \times k_i) \quad (2.1)$$

Where:

K is the weighted mean of the capital of a region [₹/a]

k_i is the calculated capital for a specific crop [₹/a]

f_i is the fraction of farmers that produce the specific crop within a district [-]

f_d is the fraction of the crop production in the district contributing to the region [-]

²₹ stands for Indian rupees, the national Indian valuta.

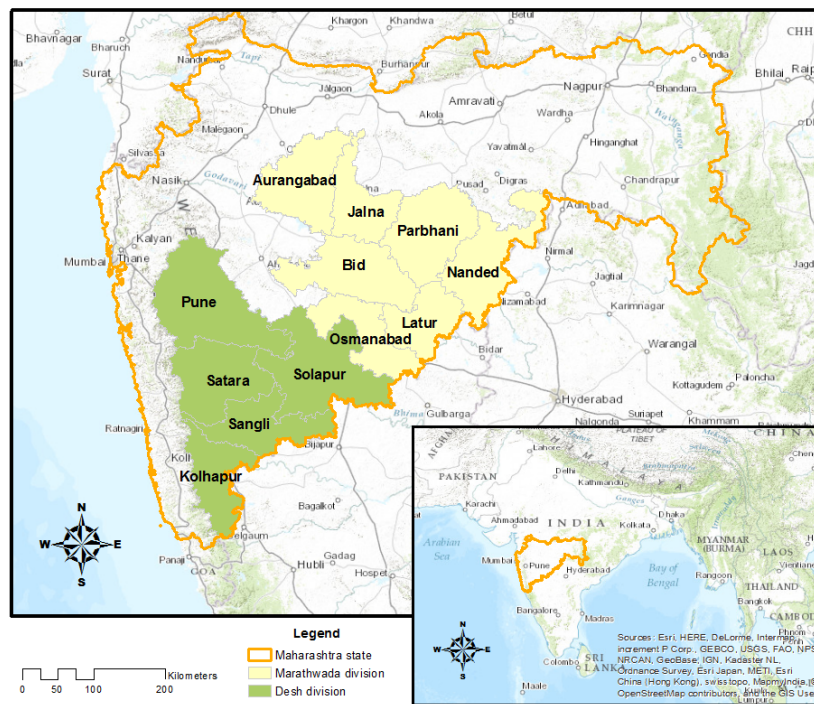


Figure 2.4: Location of simulated districts. Model simulations for the following eleven districts were conducted in Maharashtra, the districts in Marathwada: Aurangabad, Beed, Jalna, Latur, Osmanabad, Parbhani, and the districts in Desh: Pune, Sangli, Satara, Solapur, and Kholapur. Note that the district of Hingoli and Parbhani are merged, this was done because the Census data tended to merge the Parbhani and Hingoli districts. Spatial variable datasets on potential evaporation, soil properties and rainfall were weighted on district level.

2.3.2. Historical socio-hydrology

The comparative assessment showed if the contrasts in the field can also be observed by the socio-hydrological modelling framework. In this section changes in the framework are made to see what the effect of an observed change in cropping pattern has on the smallholders well-being. The cropping pattern changed significantly since liberalization. Consequently, to understand if the underlying dynamics and modelling outcomes can clarify the contemporary situation by looking at the effect of cropping pattern changes over time, different smallholder situations are simulated.

From Figure 2.5 it can be seen that the changes in cropping pattern are shifted after 1992 (liberalization): shifting from food grains to cash crops. Therefore, three farmer situations are simulated: a farmer that sticks with cereal production after 1992, a farmer that chooses to produce primarily cotton (cash crop) after 1992, and a farmer that produces primarily beans (pulses) after 1992. Changes in the parametrization and input data were made, see Appendix C for input data and parameters used in order to get the results for this section. In the simulations we focussed on the district of Parbhani in Marathwada, as we took most interviews in this district.

It should be mentioned that total cultivated area did not significantly change over the last two decades (see background information) and the changes visible in Figure 2.5 is a good estimator for the crop choice behaviour amongst farmers. Sorghum (cereal), sugarcane (cash crop), cotton (cash crop) and chick peas (pulse) were taken into account to observe the effect of the changed behaviour.

It is aimed to use a consistent data source for all crops, however, a consistent historical crop pricing series is unavailable. International prices (The Worldbank, 2015) are available for all crops under study, except for chick peas (or any other pulses). Local farm harvest prices (for Parbhani) were available for all crops under study (VDSA, 2011), except cotton. Therefore several simulations were done to see the effect of using different sources on this historical assessment. The local farm harvest prices were adjusted for inflation according to the consumer price index (CPI) (calculatorstack.com, 2016), by taking 2010 as a base year (like The worldbank prices).

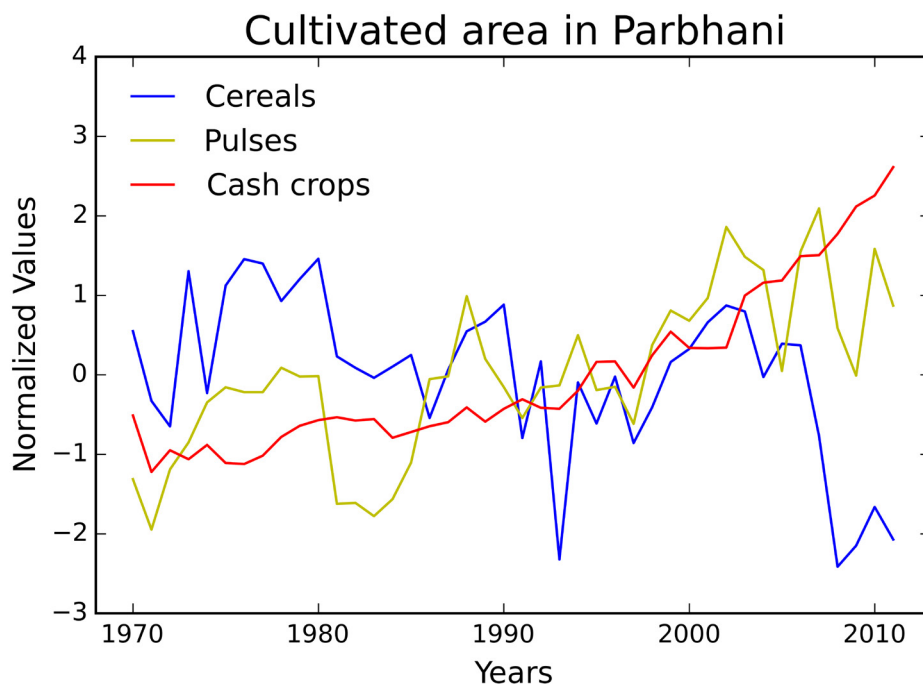


Figure 2.5: This picture shows change in cropping pattern for Parbhani district, from 1970-2011 (VDSA, 2011). The normalized values are calculated by subtracting the values by the mean of the time series and dividing the value by the standard deviation of the time-series. Cash crops include cotton, soyabean, and sugarcane. Cereals are crops such as Jowar, e.g., and Pulses take into account the area under chick peas, green gram e.g.. One can clearly see a shift in cropping pattern after 1991. The cultivated area under cash crop increases at the cost of cereal production, especially.

2.3.3. Process socio-hydrology

With the help of the comparative and historical assessment we extended the model in space and time and outline its shortcomings. These limitations will be partly circumvented by taking a look at different processes within the socio-hydrological modelling framework. By zooming in to processes, in and around the framework, a better understanding of different aspects within the smallholder's situation is created and the modelling outcomes and structure is tested. With the help of data and documentation of the interviews held with farmers during a fieldwork, several assumptions within the smallholder modelling framework are verified. In this section the missing links are outlined and new strategies are proposed.

Dry spell analysis and daily timestep

A dry spell analysis was conducted for the different districts in Marathwada and the trends in rainfall patterns are analysed to examine the hydro-climatological situation. In the version of Pande and Savenije (2016) the calculations for the soil moisture balance are on a monthly basis, the crop yield is based on these monthly calculations. The dry spell analysis in this section will be analysed to visualize the importance of shifting to a daily time step to calculate the soil moisture in this area. The dry spell analysis is done with daily precipitation data obtained from the Agricultural University in Parbhani and is available for all districts within Marathwada. The precipitation time series originates from the main weather stations in these districts and covers rainfall from 1981-2010, for Parbhani district the rainfall time series is available from 1981-October 2015.

The probability of dry spell occurrences from 3 days until 25 days is visualized by focussing on the most important months of the growing season: June, July and August. These months are considered most important for the farmers since this is the beginning of their growing season. The precise method used to calculate the probabilities is explained by Savenije (2006) and is elaborated further in Appendix D. Also, the soil moisture balance is run at of on a daily time-scale, to observe possible changes in previous outcome.

Improving the water balance and adding a crop growth model

In the model by Pande and Savenije (2016) the Specific yield coefficient (K_y) and a calculated water stress yield factor determine the response of the crop to water (stress). To visualize and analyse the effect of dry spells on the crop yield, this research will improve the representation of crop water dynamics. A new crop

growth model will be proposed, that is inspired by features in FAO's Aquacrop v4 model (Raes et al., 2012) and a soil moisture balance of Makurira et al. (2011). The crop growth model aims to calculate the yield based on a crop growth based transpiration, that is adjusted for soil moisture stress.

The maximum water available to the crop, either in the root zone or another way of storage, is described by S_{max} . The enhanced version of the soil moisture balance links the water availability to a crop growth model and calculates on a daily time-step. Features such as deep percolation, interception and soil evaporation are introduced. The status of the soil moisture is linked to a crop growth function (described in terms of ground cover development), and influences the crop development when there is limited soil moisture. These calculations are crop specific and can be extended to other crops. For a conceptual overview of how the crop growth is linked to the soil moisture development, see Figure 2.6. Also the evaporative demand of soil and transpiration of the crop is improved by integrating crop growth development, with Canopy Cover (C) development and Leaf Area Index (L_{AI}). The development of the soil water storage is described as follows:

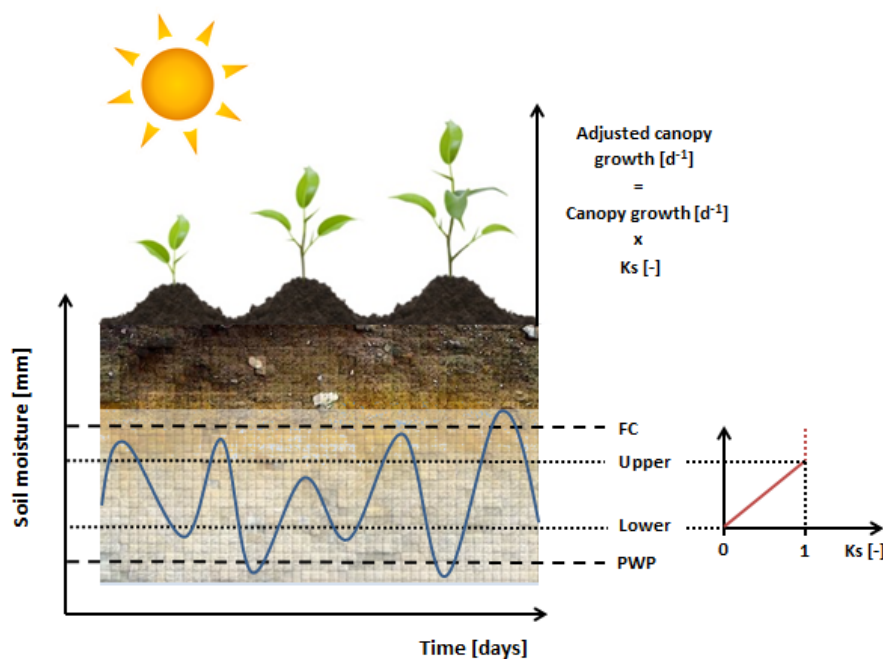


Figure 2.6: An overview of how the stress factor (K_s) can be determined from the soil moisture status in the soil column. This concept was used to interlink the status of the soil moisture to crop growth. The soil moisture is calculated on a daily time step and between Field Capacity (FC) and Permanent Wilting Point (PWP) there are two crop-specific thresholds (Upper and Lower) that linearly link to water stress experienced by the crop. If the upper threshold is reached, there will be no stress (value=1). If the lower threshold is reached the crop growth is completely halted (value=0). In between these two thresholds the stress varies between zero and unity.

$$\frac{dS}{dt}(t, T)\Delta t = \min(S_{t,T} + (F_{t,T} - E_{t,T}^m - R_{t,T})\Delta t, S_{max}) - S_{t,T} \quad (2.2)$$

Where:

$S_{t,T}$ is the soil moisture available at time t, T [mm]

$F_{t,T}$ is effective precipitation when interception is taken into account [mm/day]

$E_{t,T}^m$ the evaporative demand that was met [mm/day]

$R_{t,T}$ the root zone depletion, recharge [mm/day]

S_{max} the maximum available soil water storage [mm]

t is the index used for daily time steps and T for yearly time steps, likewise Δt and ΔT . Moisture in excess of S_{max} is considered as run-off (Pande and Savenije, 2016).

$$F_{t,T} = P_{t,T} - I_{t,T} \quad (2.3)$$

$$I_{t,T} = \min(P_{t,T}, D_{t,T}) \quad (2.4)$$

Where:

$P_{t,T}$ daily rainfall [mm/day]

$I_{t,T}$ interception [mm/day]

$D_{t,T}$ the minimal amount of interception during a rainfall event [mm/day]

The new soil moisture balances includes interception as described above and deep percolation (Makurira et al., 2011):

$$R_{t,T} = \max\left(\frac{S_{t,T} - S_{FC}}{k}, 0\right) \quad (2.5)$$

Where:

$R_{t,T}$ deep percolation [mm]

k is the maximum number of days during which field capacity can be exceeded after high infiltration rates [days]

S_{FC} soil moisture at field capacity [mm]

The evaporative demand that was met at a particular time-step can never exceed the water available in the soil and is therefore defined as:

$$E_{t,T}^m = \min(S_{t,T} + F_{t,T}, E_{t,T}^d) \quad (2.6)$$

Where:

$E_{t,T}^d$ evaporative demand through soil evaporation and crop transpiration [mm/day]

The evaporative demand of the land is approached by contributions of both the soil evaporation and crop transpiration, based on Leaf Area Index (L_{AI}) calculations. Outside the growing season, transpiration and L_{AI} zero; only soil evaporation is considered.

$$E_{t,T}^d = T_{t,T}^p + E_{t,T}^s \quad (2.7)$$

Where:

$T_{t,T}^p$ potential crop transpiration [mm/day]

$E_{t,T}^s$ potential soil evaporation [mm/day]

The potential crop and soil evaporation are calculated with crop factors and potential evaporation. The L_{AI} is used to adjust for the ground cover covered by the crop per m^2 .

$$T_{t,T}^p = E_{t,T}^0 \times K_c \times K_s \times \min(L_{AI}, 1) \quad (2.8)$$

$$E_{t,T}^s = E_{t,T}^0 \times K_b \times \min\left(\frac{\max(S_{t,T} - S_{WP}, 0)}{S_{FC} - S_{WP}}, 1\right) \times \min(1 - L_{AI}, 1) \quad (2.9)$$

Where:

$E_{t,T}^0$ the reference evaporation [mm/day]

K_c crop factor [-]

K_b soil evaporation factor [-]

K_s crop water stress factor [-]

S_{PWP} permanent wilting point [mm]

L_{AI} leaf area index [m^2/m^2]

Since there are no L_{AI} measurements or good approximations an approximation for the biomass development needs to be calculated. An approximation was found in equations used by Aquacrop (Raes et al., 2012), that approximate the development of ground cover and the response to water stress. These calculations will be converted to L_{AI} to sustain the evaporation calculations in Equation 2.8 and 2.9. Every iteration the crop cover is calculated on the basis of available soil moisture, which determines the soil evaporation and transpiration as well. The crop growth is described by two equations. Equation 2.10 is valid when groundcover

is halfway to its maximum ($C \leq C_{max}/2$) and is an exponential growth function (Raes et al., 2012). After this, the plant growth rate starts decreasing and its crop development can be described by an exponential decay function, see Equation 2.11 (Raes et al., 2012).

$$C = C_0 \exp^{dG} \quad (2.10)$$

$$C = C_{max} - 0.25 \frac{(C_{max})^2}{C_0} \exp^{-dG} \quad (2.11)$$

Where:

C is canopy cover at time t [-]

C_0 is the initial canopy size at $t=0$ [-]

C_{max} is the maximum canopy cover [-]

d is the day of the growing season [day]

G is the canopy growth coefficient [day^{-1}]

To link this to the availability of water, the canopy growth coefficient is adjusted for water stress, with a stress factor (K_s).

$$G_{adj} = K_s \times G \quad (2.12)$$

Taking into account the Equation 2.10 and 2.11, note that water influences the crop growth more in the first half of its growth period. The stress factor (K_s) is determined by evaluating the soil moisture availability in the soil. We take into account soil properties as Permanent Wilting Point (PWP) and Field Capacity (FC), but introduce an upper and lower threshold within the Total Availability of Water T_{aw} that is crop specific (Raes et al., 2012).

$$T_{aw} = S_{FC} - S_{PWP} \quad (2.13)$$

T_{aw} is the total available (soil) water to the plant [mm]

S_{FC} soil moisture is at field capacity [mm]

S_{PWP} soil moisture content at permanent wilting point [mm]

$$S_{lower} = p_{lower} \times T_{aw} \quad (2.14)$$

$$S_{upper} = p_{upper} \times T_{aw} \quad (2.15)$$

Where:

S_{lower} lower threshold expressed as root zone depletion [mm]

S_{upper} upper threshold expressed as root zone depletion [mm]

p_{lower} depletion fraction of T_{aw} where there is not expansion in growth [-]

p_{upper} fraction of T_{aw} that can be depleted from the root zone before a halt in crop growth is triggered [-]

The water stress factor (K_s) is determined by taking the upper and lower threshold into account, and is a factor between zero and unity:

$$K_s = \min\left(\frac{\max(S_{t,T} - S_{lower}, 0)}{S_{upper} - S_{lower}}, 1\right) \quad (2.16)$$

A relationship between C and L_{AI} was empirically defined by Farahani et al. (2009). To convert the C outcomes to L_{AI} the following relationship was used:

$$L_{AI} = 100/77 \times \log\left(\frac{1}{1-C}\right) \Delta t \quad (2.17)$$

Aquacrop also incorporates a salt balance and nutrient stress, since the scope of this thesis is to improve the hydrological and capital modules of the model the other stresses are left out. From Figure 2.6 one can see that the relationship between p_{lower} and p_{lower} is linearly affecting the soil moisture stress. Through 2.10 and 2.11 the impact of the soil moisture stress on crop growth is non-linear.

To determine the biomass production of the crop under study one must determine the actual transpiration per growing day. This was done as follows:

$$T_{t,T}^a = E_{t,T}^m \times \frac{T_{t,T}^p}{E_{t,T}^d} \quad (2.18)$$

Where:

$T_{t,T}^a$ The water transpired per day of growing season [mm/day]

By calculating the actual transpiration one can approximate the biomass produced over the growing season, where the crop water productivity C_{WP} indicates the water use efficiency of the crop under study. By adding up the water transpired over the growth period, the water productivity translates the resulting biomass that can be produced with the actual amount of transpiration:

$$B = C_{WP} \sum T_{t,T}^a \quad (2.19)$$

Where:

B The cumulative above ground biomass production [kg/ha]

C_{WP} Crop water productivity [kg/ha and per mm]

Not all biomass is sold as yield, in the case of cotton for example, the percentage of lint cotton obtained from seed cotton is 35%. This is the average harvest index, however it depends on the farmer and type of cotton seed used. To acquire the sell-able yield multiply the cumulative biomass production with the harvest index:

$$Y = H_I B \quad (2.20)$$

Where:

Y Crop yield [kg/ha]

H_I the reference harvest index [-]

By linking the above crop growth to a refined version of the soil moisture status, it is aimed to better incorporate the effects of a drought on the farmer's yield. The new parameters used in this crop growth model are specified in Appendix C. In this thesis the crop growth model is parameterized to Cotton, other crops can also be analysed with the described method.

Assumptions model and fieldwork

In order to provide additional information about the smallholder situation in Maharashtra and verify some aspects within the socio-hydrological modelling framework, a fieldwork took place in Maharashtra, India, from the 21st of February until the beginning of April 2016. The objective of the fieldwork was to collect socio-economic and hydrological data on smallholder farming in the region of Marathwada and to verify some assumptions in the model by interviewing approximately 50 farmers in a drought hit area. In general to result in a better understanding of the underlying factors that constrain the development of smallholders.

The following list gives an idea of the data and information searched for during the fieldwork: soil depth records, climate records (weather station), crop income data, household characteristics, historical crop prices, historical crop yields, village level suicide numbers (or another indicator of stress: selling-of land), water use characteristics, access to nearest market, off-farm labor alternatives, fertility use, status of technology, order expenditure cuts, motivation on crop choice, degree of indebtedness, risk awareness, farmer's experience to crop yields, livestock or not, governmental aid/subsidies, and, observe community dynamics (perhaps caste), etc..

The local NGO SOPPECOM (Society for Promoting Participative Ecosystem Management) greatly assisted in facilitating the preparations for the fieldwork. Also they introduced an on-line database VDSA (Village Dynamics in South Asia), of which an abundance of data was gathered. SOPPECOM's extensive library also provided numerous pieces of literature on the general and historical situation in rural Maharashtra. Some of these documents were used for descriptive purposes and cannot be found on-line.

To gain insight in the household situation and to test a few assumptions in the model, a questionnaire was set up. In total 45 farmers in Nanded, Parbhani, and Aurangabad district were interviewed (90 % of the target), see Figure 2.7. Initially the idea was to focus on a village and interview two groups of small-scale

farmers (<4ha), one group that produces cash crops and the other group focussing on growing food crops (as a control group). Unfortunately, the means were not available to pursue a study like this. Finally, a mix of different farmers across different regions were asked to answer the questionnaire with the help of a translator. The questionnaire started with a general inquiry about the farmer's personal and production characteristics (age, sex, landowner e.g.). After this the questions were more in-debt concerning their livelihood situation (irrigation facilities available, alternative livelihood, order of expenditure cost e.g.). Finally, the questionnaire focussed on the cropping pattern, changes and factors affecting their agricultural businesses. An example of the questionnaire can be found in Appendix B.

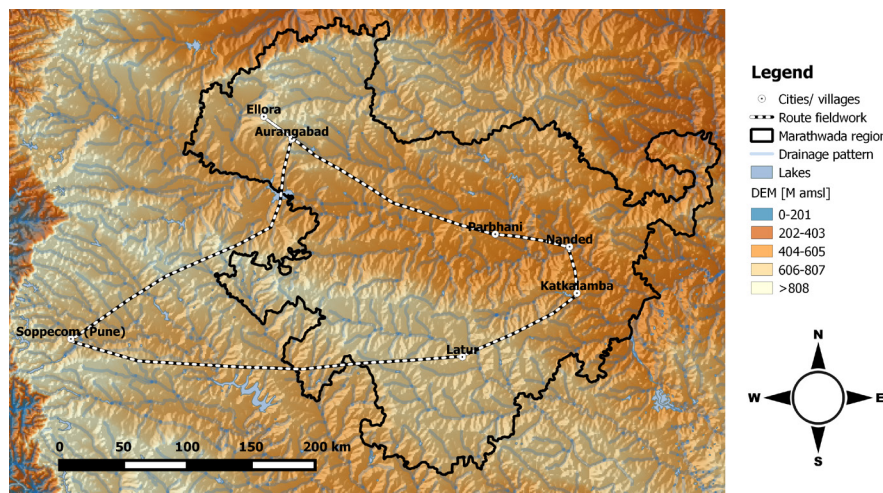


Figure 2.7: This map gives the route taken during the fieldwork and the places where farmers were interviewed. The basemap shows a DEM and presents the topography of the area in metres above mean sea level (M amsl). Initially the idea was to stay in Katkalamba and analyse farmers of one district that produce either cash crops, or cereals combined with pulses. Finally, Katkalamba was not suitable for such a study and the questionnaire was conducted in several places throughout Marathwada. Most of the respondents were met in and around Parbhani, with the help of the Agricultural University of Parbhani.

The Agricultural University Marathwada in Parbhani (VNMKV), facilitated most of the respondents in Marathwada. In and around Parbhani, several villages were visited to get answers to the questions in the questionnaire. Besides facilitating the interviews and providing translators, VNMKV provided daily meteorological data of Marathwada. From a weather station at their university campus, daily precipitation records from January 1981 until October 2015 were obtained, this was recorded by an automated raingauge. For the years 2011-2015 daily data on pan evaporation, temperature, wind speed etc. were retrieved. To successfully work with this short record of pan evaporation the data was adjusted to fit corresponding satellite potential evaporation data of Parbhani, see Appendix C for an elaboration on the adjustments. Daily precipitation records from 1981-2010 of other main weather stations in the remaining districts of Marathwada (Hingoli, Beed, Latur, Nanded, Aurangabad, Osmanabad and Jalna) were also obtained.

Finally, in Aurangabad an interview was held with two representatives of the agricultural newspaper in Maharashtra (named Agrowon). Last year (2015) they conducted a survey amongst the families in which a farmer suicide had occurred in Marathwada. Out of the 1109 suicide cases, Agrowon reporters managed to interview 1060 of the affected families. The question-list contained seven questions which inquired about the indebtedness of the farmers and off-farm labour alternatives e.g.. The question-list and a summary of its outcomes were translated and are provided in Appendix B and E.

3

Results

In the following chapter the socio-hydrological modelling framework will be put through the socio-hydrological research inquiry as described in the previous chapter. The research starts with a comparative socio-hydrological assessment of the framework: to see if regional variances in suicide rates can be explained. Secondly, the effect of a historical change in cropping pattern will be analysed with the model to see what the effect of this change has on the smallholder's capital over time. Finally, the modelling outcomes, assumptions and results are valued against ground-truth data and knowledge to renew socio-hydrological theory on smallholder farming. Some attempts to improve the socio-hydrological modelling framework are demonstrated.

3.1. Results comparative socio-hydrology

One of the first question that arises after the work done by Pande and Savenije (2016) is: if the model is explaining, to a large extent, the rural distress seen in Marathwada, is the model able to grasp regional variances as well? In order to analyse this, the capital development of a cotton producer in some districts of Marathwada and an adjacent region, Desh, are simulated. Due to their geographical locations these districts have different hydro-climatic characteristics and different soil storage depths. Figure 3.1 displays the performance of cotton producers from 1983-2009 of four districts, and from the graphs one can already see the variances between different districts. For example, cotton producers in Latur district (in Marathwada) are unfavorably conditioned: low annual rainfall and a low soil storage capacity. Whereas Aurangabad district (also located in Marathwada) has more favourable conditions as compared to other districts in Marathwada. These differences affect the capital development of the farmers over time, as can be seen in Figure 3.1. All parameters that were used for these calculations can be found in Appendix C.

Note that for all cotton farmers the capital goes down over time, and in some districts the farmers were already severely distressed before 1995. Table 3.1 displays the suicide number per district of the simulations shown in Figure 3.1, for last year (2015). Districts as Bid and Nanded have seen higher farmer suicide deaths than other districts in Marathwada. Desh has experienced low farmer suicide deaths, while a farmer in the region of Solapur does collapse according to the results. However, to value what is happening between the regions of Desh and Marathwada, attention must be placed on their difference in cropping pattern as well. Perhaps, the farmers in Desh are also choosing a different cropping pattern, that fits the biophysical characteristics more compared to Marathwada.

Table 3.1: Documented farmer suicides by Agrowon (2016). Parbhani represents the suicide number for both Hingoli and Parbhani. The farmer suicide deaths are weighted according to the district's inhabitants, in order to compare suicide deaths amongst the different districts. *The farmer suicide deaths are undocumented by Agrowon (2016), but Desh does not experience a farmer suicide epidemic as Marathwada does.

| | MARATHWADA | | | | | | | DESH |
|------------------|------------|--------|------------|----------|-----------|-------|-------|---------------|
| Districts | Bid | Nanded | Aurangabad | Parbhani | Osmanabad | Latur | Jalna | All districts |
| Suicides in 2015 | 42 | 34 | 28 | 22 | 15 | 14 | 8 | Undocumented* |

To investigate the influence of the cropping pattern on the farmer's income between the different regions, capital calculations were calculated for the following five major crops: jowar, sugarcane, soyabean, cotton,

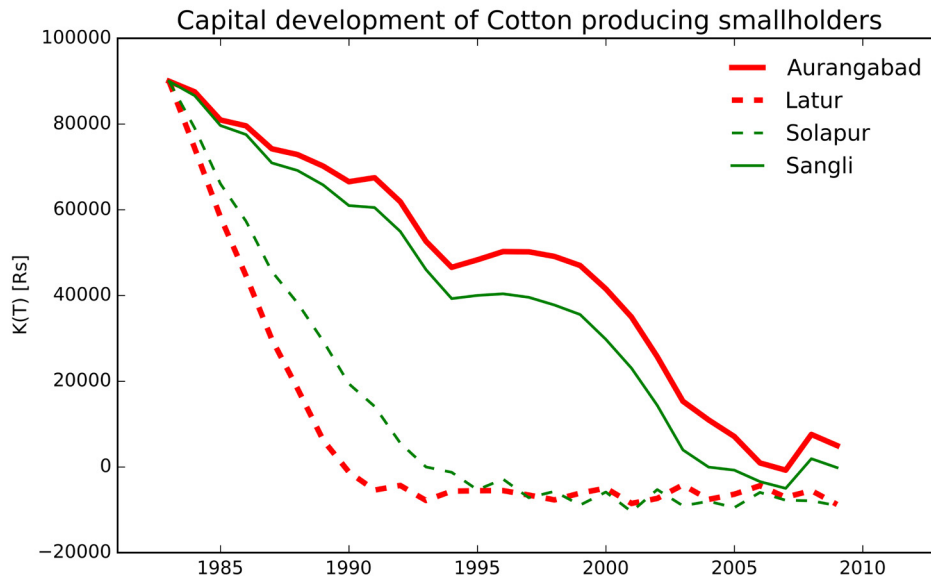


Figure 3.1: Different simulations of different districts showing the capital development ($K(T)$ in ₹) of cotton producers. The striped lines are the districts that are unfavourably conditioned, the solid lines display the capital development of the smallholders that are favourable conditioned. The red coloured lines are two districts from Marathwada. The green lines are located in Desh. The red lines are made thicker according to the farmer suicide deaths found in the districts.

and rice. All these calculations were weighted according to the number of farmers producing that crop in the district, and contributing to the total of farmers producing that crop in the district. When summing these weighted capital developments, an estimation of the average capital in each region is approximated. The result of an approximation of the average capital over time for Marathwada and Desh can be observed in Figure 3.2. Note how both average capital calculations in the regions increase over time, but after 1991 (liberalization) Marathwada's income stagnates, while Desh's average capital continues increasing. From 2003-2007 one can even observe a depression in the development of the average capital of a farmer in Marathwada.

To compare these farmer capital developments over time to a distress indicator, the suicide attenuation is displayed against the capital evolution. The results of this comparison can be found in the right graph of Figure 3.2. In order to compare these different numbers, the values were normalized. From the right graph in Figure 3.2 it can be observed that Marathwada is more in line with fluctuations observed in the suicide development. The annual suicides in Maharashtra are rising as the capital of the smallholder in Marathwada is diminishing. If the capital of the smallholders is rising, the crop income of Marathwada is decreasing. This suggests that the smallholders well-being (indicated with their capital) in Marathwada is more in line with suicide trends than Desh. The outcomes suggest that the suicide rates are related to differences in biophysical characteristics and crop choice. Nevertheless, a few features remain unresolved: Solapur (located in Desh) is also a very dry area producing mainly sugarcane and Jowar. The overall capital development according to the simulations are diminishing over time, however suicide rates are low in the district.

Eventually, the sensitivity and trustworthiness of the crop yields of the model were assessed. The socio-hydrological modelling framework calculates its crop yields by taking into account maximum potential yields, that is adjusted by three stress factors: labour, nutrient availability, and water stress. Since there are multiple references to refer to when choosing a maximum potential yield, two were chosen from two different sources. The maximum potential yields from the different sources were both used to calculate the actual yield with the model. In this case, it was calculated for soybean producers in Aurangabad to assess what happens to the crop yield simulations if one uses a different source for maximum potential yield. The results of this assessment is visualized in Figure 3.3 and compared to observed yields found for soybean production of the district Aurangabad. The graph shows that if chosen for a maximum potential yield documented by Panaskar et al, 2006, the yield outcomes shows a greater linearity with the observed yields. However, the correlation coefficient between the two calculated actual yields are the same, as the stresses pressing on the final yield calculations are similar. Choosing for a particular maximum potential yield is arbitrary, but can greatly influence the capital development of the farmer, hence the interpretation of the results. This demonstrates a more realistic representation of crop water dynamics is needed.

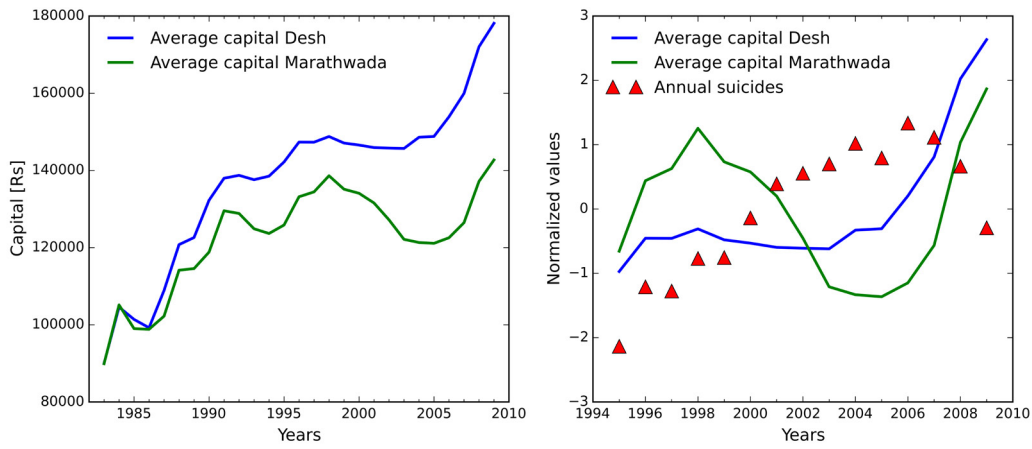


Figure 3.2: Results of the comparative assessment. The left graph displays the average capital development ($K(T)$, where rs = Indian Rupees ₹) per year; one can already see that the average crop capital is more stable in Desh. The right graph shows the same capital calculations (zoomed in to 1995-2009), but now on a normalized axis, to adequately compare it with annual suicides Mishra et al. (2015). The normalized values are calculated by subtracting the values by the mean of the time series and dividing the value by the standard deviation.

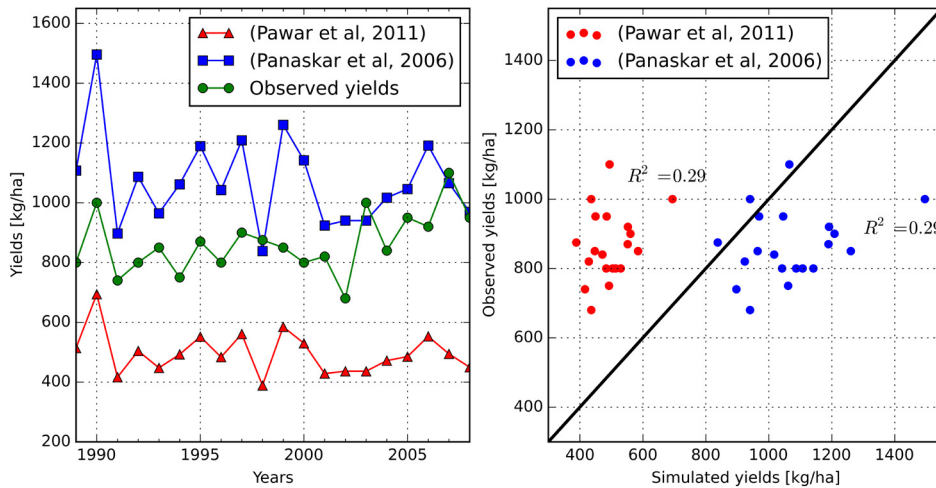


Figure 3.3: Comparing the soyabean yield calculations when taking two different input values for maximum potential crop yield. The simulated yields are compared with observed data to verify the calculations. Both sources results capture the same stresses, however Panaskar et al, 2006 is more in line with observed crop yields for soyabean production in Aurangabad.

3.2. Results historical socio-hydrology

In the previous section, the study demonstrated how the model functions when extending it spatially, now it will be observed what happens if the framework is assessed temporally. Moreover, a very important change in cropping pattern occurred post-1991. From 1991 onwards an increasing number of farmers switched from a cropping pattern based on foodgrains to more lucrative cash crops such as: soyabean, cotton, and sugarcane. This transformation surely affected the well-being of the smallholders. To see if the modelling framework can visualize the effect of the change in cropping pattern choice of the farmers, three smallholder situations are simulated. A post-reform situation where the farmer sticks to Jowar (cereal), and two other situations, where the farmer changes to chick peas (pulse) and cotton or sugarcane (cash crop), are analyzed.

The results of the simulations described can be found in Figure 3.4. Since a same source time series for the prices of the crops under study are unavailable, different sources are used. The cash crop prices in Figure 3.4 are obtained from international prices (The Worldbank (2015) referred to as (I)) and the sorghum (cereal) and bean (pulse) prices are obtained from a domestic price data series (VDSA (2011) denoted as (F)).

As one can clearly see from the two graphs in Figure 3.4 the farmers that continue to produce cereal after 1991, do not seem as distressed as the farmers that choose sugarcane, cotton, and chick peas. Moreover, the most affected farmers seem to be the sugarcane producers under non-optimal irrigation conditions. Cotton producers experience a rapid decline in capital after the year 2000 as a result of fluctuating prices and accelerating debt. Bean producers are also declining in capital, but are better off than the declines seen in the capital of the cash crop producing farmers.

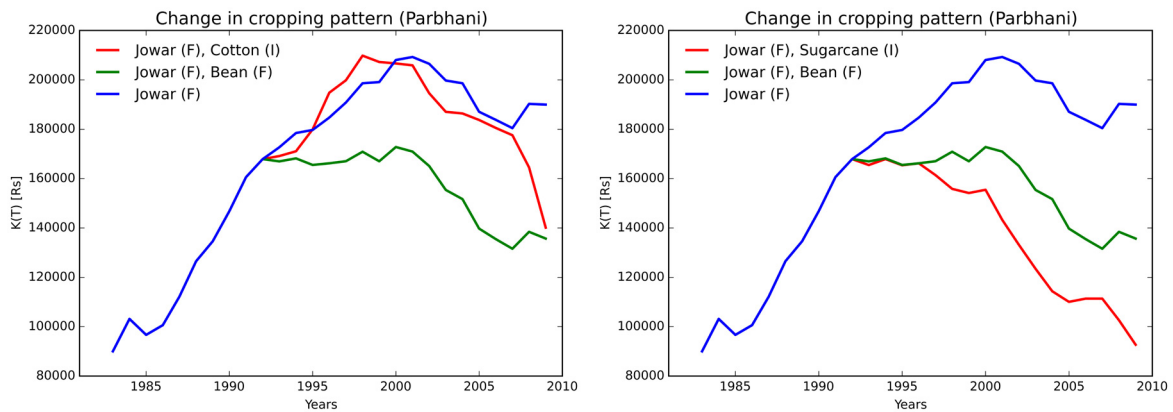


Figure 3.4: Comparing the capital evolvement, where rs = Indian Rupees (₹), of farmers shifting to cash crops, beans or continue producing jowar. The left graph shows the capital development of jowar, cotton, and bean producers. The right graph shows the capital development of jowar, sugarcane, and bean producers. Note that the (F) stands for Farm harvest prices of Parbhani and (I) for International prices. Over time the capital of the cash crop producing farmers are diminishing, as compared to jowar. The capital of bean producers are also decreasing.

To see the effect of using different sources of pricing on the development of capital, an example is given if the domestic prices for sugarcane are used compared to international pricing. The simulations using domestic prices increases the capital of the smallholder exorbitantly, Figure 3.5. Suggesting that it would be lucrative to produce sugarcane under rainfed conditions in a semi-arid region in Parbhani (Marathwada).

However, understanding what happens with pricing internationally and on the domestic markets, the pricing for jowar and sugarcane is compared (see Figure 3.6). As one can see the market pricing for Sorghum show comparable prices, however for sugarcane the prices are skewed. The domestic sugarcane pricing is approximately a factor of four higher than international prices. Revealing that the sugarcane market is stimulated and protected by the government in Maharashtra, as a consequence, making a very water consumptive crop in a dry area attractive for farmers.

3.3. Results process socio-hydrology

The temporal and spatial assessments revealed several shortcomings of the current modelling framework that will be partly enhanced in the following section. The research continues from this point on by updating the previous modelling framework and then integrating and comparing it with field data and observations in order to enhance the realism and postulate a new modelling theory on smallholder farming.

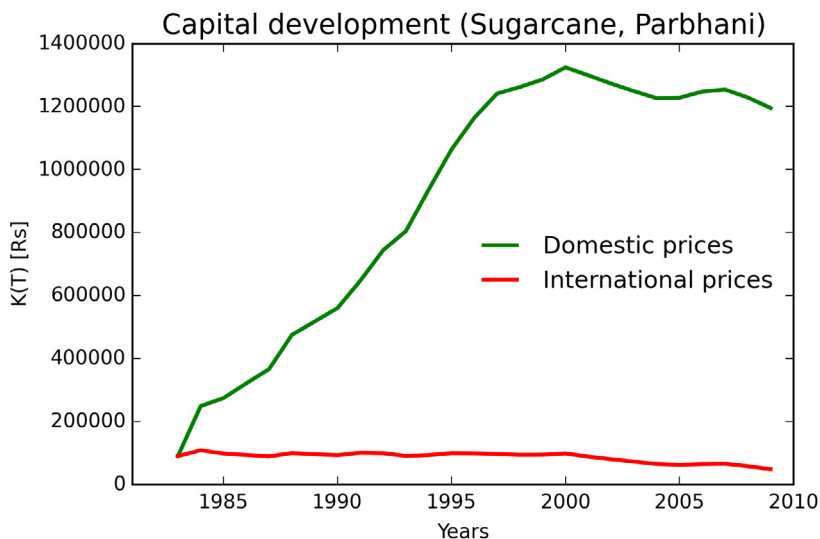


Figure 3.5: Using International vs domestic prices affecting the results of a sugarcane producing farmer, where rs = Indian Rupees (₹). When international prices for sugarcane are used in the model, capital development is decreasing over time. If domestic prices for sugarcane are used, the capital increases substantially. This suggests a huge price difference between international and domestic sugarcane prices.

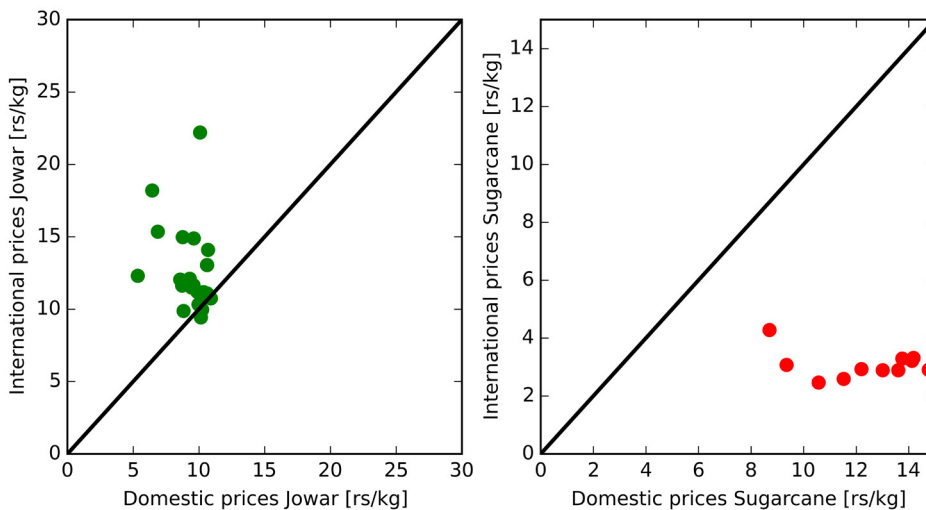


Figure 3.6: Comparing the prices domestically vs. internationally, where rs = Indian Rupees (₹). The left graph shows the comparison of sugarcane prices in ₹/kg and the right graph the Jowar prices in ₹/kg. The time series used range from 1983 until 2009. Both prices are adjusted for inflation with 2010 as a base year.

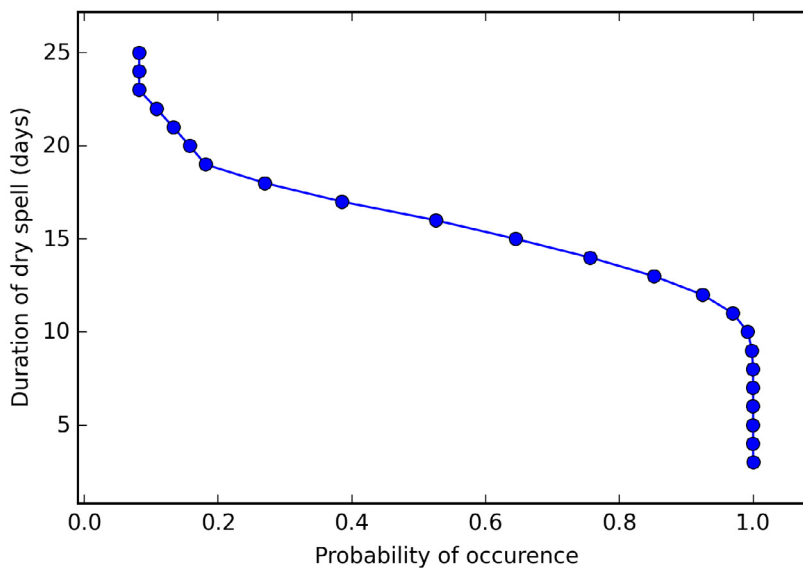


Figure 3.7: Dry spell analysis for Parbhani. The probabilities of occurrence for dry spells of 3-25 days were calculated. A daily precipitation data set was used from a weather station on a university campus in Parbhani, containing a time-series from 1981 until October 2015.

3.3.1. Dry spell analysis and daily time-step

In the last sections, the framework analysed the soil water balance on a monthly scale. As Marathwada is a drought-prone region and the rainfall pattern is erratic, it will be analyzed in what kind of hydrological circumstances the rain-fed farmers are producing. In order to analyse this, a dry spell analysis was conducted of Parbhani district. The dry spell analysis calculates the occurrences of days without precipitation during June, July, and August. As can be seen from Figure 3.7, the probability of occurrence of, for instance, a ten-day dry spell is high (reoccurring every year). The probability of occurrence is decreasing very rapidly from 11 until 18 days of dry spell.

To incorporate the effect of the frequently occurring dry spells on crop growth, hence improve the socio-hydrological modelling framework, the soil moisture is calculated on a daily scale. Figure 3.8 compares the monthly soil water balance simulations, with adjusted simulations done on a daily scale. The outcome of the adjustments and the extension of the data (meteorological and suicide rates) show an equal correlation with the suicide data, as was observed by the soil moisture calculations on a monthly scale. The year 2015 has been documented as the year with the highest suicide rates in the last two decades (Agrowon, 2016). The peak in farmer suicide deaths associates with the decrease in capital of the smallholder under study, due to an accelerated debt (with an interest rate of 35%) from 2006 onwards.

As one can see in Figure 3.8 the results differ if the soil moisture balance is scaled down to a daily time-step, for the situation of a smallholder with a low storage, no irrigation, and optimal fertilizer use. Nevertheless, the same trend in suicide rate is followed in the two simulations. The new results differ due to the fact that different precipitation and evaporation products were used and slightly different crop factors. The monthly evaporation and precipitation satellite data were obtained from Zomer et al. (2008) and the daily data was retrieved from weather station data.

3.3.2. Improving the water balance and incorporating a crop growth model

The daily calculated soil water balance incorporated in the previous section improves the reality of the socio-hydrological modelling framework by including a daily time-step. However, the structure also needs update as was observed in Figure 3.3. A more realistic representation of the crop water dynamics is needed. First interception, deep percolation, and soil evaporation is included in the soil water balance. The soil moisture balance was hereafter linked to a crop growth model to investigate the effect of a more detailed soil water balance on the crop development of a plant. Also to start developing a model that can visualize to what extend yields of different crops are sensitive to different lengths of dry spell.

The results for the elaborated water balance and how this is linked to a crop growth model can be seen in Figure 3.9. The model links the status of the soil moisture to a stress factor and consequently canopy cover.

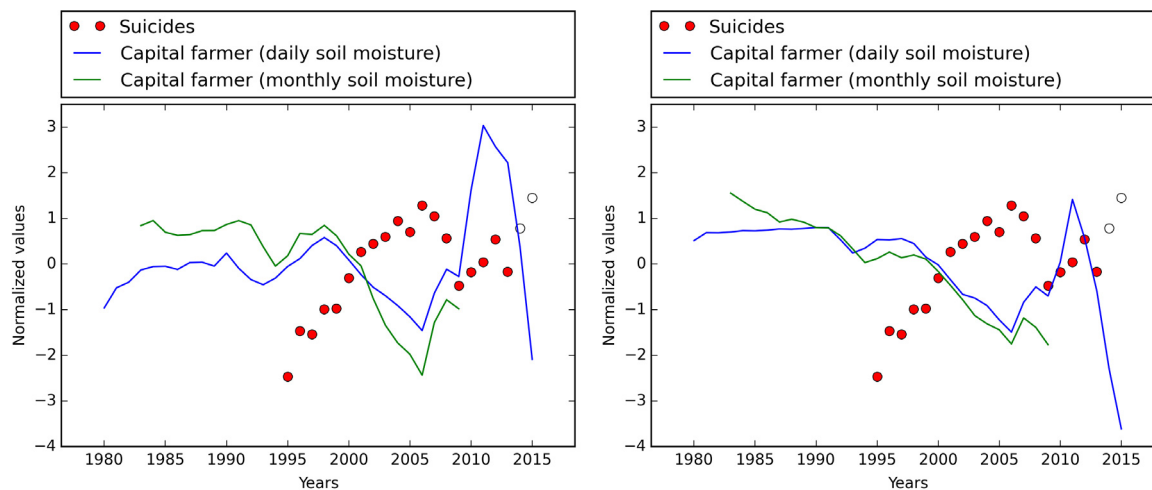


Figure 3.8: Incorporating a daily time-step in the socio-hydrological modelling framework. The two graphs show two types of cotton farmers, identified by Pande and Savenije (2016) as farmers under distress. Their capital development is simulated, where rs = Indian Rupees (₹). The farmer simulated in the left graph is a smallholder with a storage capacity of 50mm, irrigation, however no optimal fertilizer use. The farm displayed on the right graph is a farmer with 50mm of storage, no irrigation, but optimal fertilizer use. With new data, longer time-series and adjusting the water balance to a daily time-scale, the story by Pande and Savenije (2016) is more complete. The hollow dots on the graph are artificial dots, however literature states the suicide rates have increased in 2014 and 2015 as compared to previous years Agrowon (2016).

The model is able to detect the good and bad hydro-meteorological years (for example 2010 (good) and 2014 (bad)); the soil moisture affects the phenology by translating the water deficiency in a water stress factor. The resulting crop yields are accordingly affected as well, hereby improving daily phenomena in the model. The yield is calculated based on biomass production calculated from cumulative actual transpiration during the growing season. With the adjustments in the crop growth model the effect of intra-seasonal variability on the development of canopy growth in a year is incorporated. However, the canopy cover calculations still lack physical reality: in a few days the canopy cover can diminish almost entirely to rise again afterwards.

In the crop growth model we do not take into account the water stress in the initial stage (for cotton the first 30 days). Assuming the farmer is planning the planting of cotton well, according to weather forecasts, and no significant deficiencies will occur in the initial growth period. From Figure 3.9 we can see that the crop growth is hampered or sometimes even stopped by a limiting soil moisture availability. The lower soil moisture threshold that stresses the cotton crop growth is denoted with the lower black line in the soil moisture figures at the top of Figure 3.9. The upper black line gives the soil moisture threshold for cotton where there is sufficient soil water. Saturation stresses are not taken into account. In both years we observe water stress in the last two months (November and December) of the cotton growth. In the dry year (2014) the soil moisture deficiency halts the crop growth, however, in the wet year (2010) the cotton plant has already matured well enough to handle the water stress.

The updated soil moisture balance and incorporated crop growth model can detect what happens in good and bad meteorological years, but what happens if these new features are linked to the existing smallholder framework? What will the effect be on the farmer's capital? In order to answer the questions, six smallholder situations are simulated, these simulations were also done by Pande and Savenije (2016), see the light grey lines, but now producing different results. Smallholders with a low storage (upper graph), show an immediate collapse. A farmer with low storage and no irrigation is severely distressed. The red dotted line argues that the effect of applying fertilizers delays the collapse with a few years.

The middle graph shows an optimal capital development, under the location specific circumstances, and this is secured with irrigation and optimal fertilizer application. The lower graph in Figure 3.10 shows that even though there is good storage or low storage and irrigation, the farmer's capital decreases over the years, reaching a negative end balance in 2014 and 2015. Indicating that providing extra storage without irrigation is not a complete solution for the distressed smallholder. Dry spells are still bothering the crop yields, and consequently income. Overall, the updated results seem to be more depressing than the results of Pande and Savenije (2016) showed.

To continue, a farmer with adequate storage conditions, but without irrigation facilities is still dependent

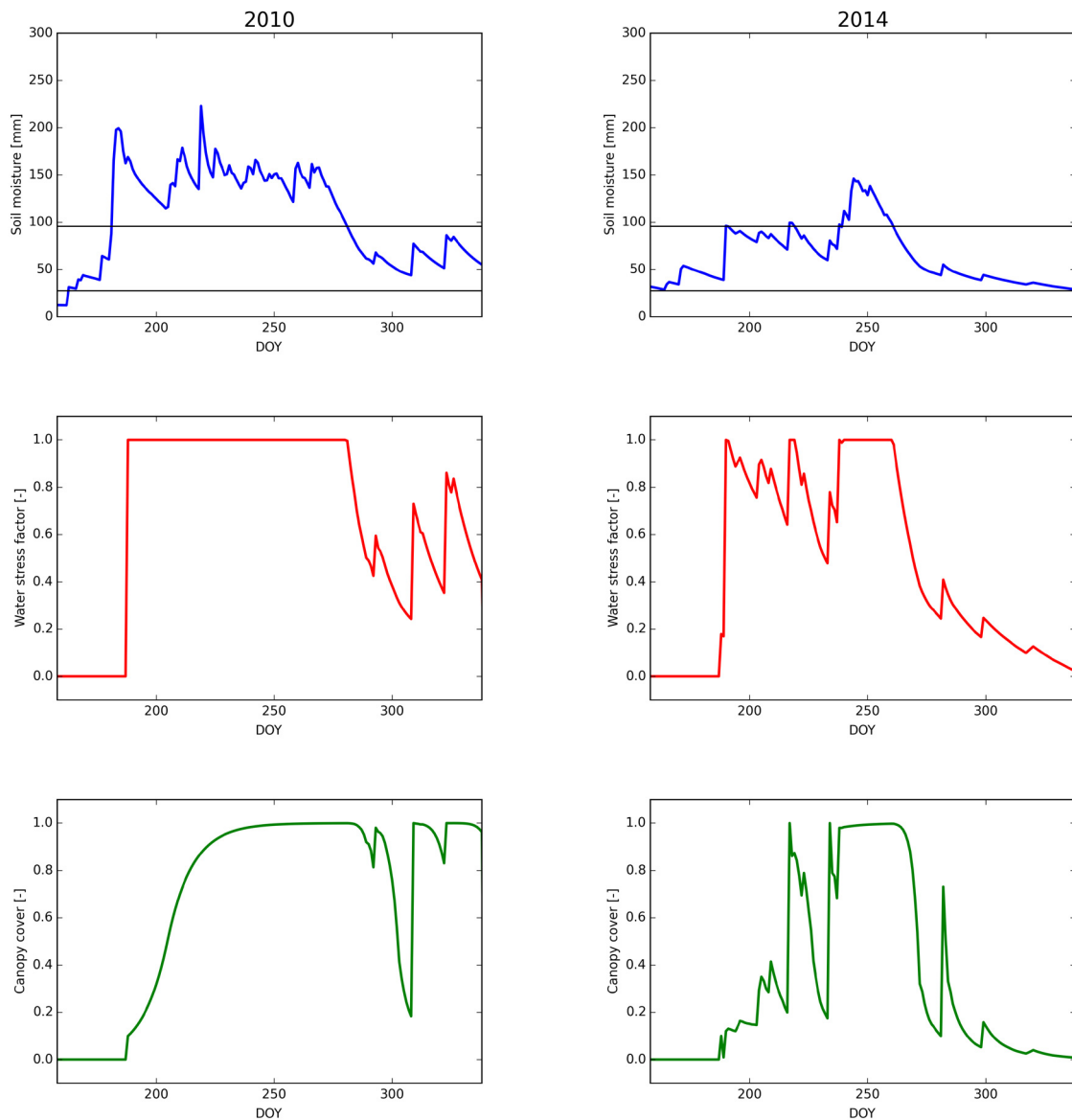


Figure 3.9: The left column (2010) displays the situation of soil moisture and coupled crop growth development in a relatively wet year; the right column displays the situation for a relatively dry year (2014). The calculated yields resulting from the crop growth model are 511 kg/ha (2010) and 289 kg/ha (2014), respectively. Both simulations are done for a Total Available Water capacity of 300mm with optimal fertilizer application. The two black lines in the soil moisture figures (upper, blue) display the lower and upper bound for cotton water stress, outside these bounds the water stress is either high (lower bound, value = 0) or there is not stress (higher bound, value=1). The water stresses are displayed in the middle graphs. These water stresses affect the crop growth development non-linearly, see the lower (green) graphs for the effect of the water stress on canopy cover development.

on erratic rainfall patterns. The advantage of an adequate storage is increasing the retention capacity of the soil. However, the storage is less fast filled than a lower storage capacity, resulting in a delay of adequate soil moisture conditions after a rainfall event. On the contrary, the residence time of the infiltrated rainfall in the unsaturated zone is increased. These delays can be seen in Figure 3.11.

Increasing the (soil) storage capacity on the arable land of a farmer is a form of rainwater harvesting, however there are many more rainwater harvesting techniques available. To get an idea of the potential of using rainwater harvesting in Marathwada, the transpiration demand was compared to the rainfall in the growing season for different crops. Table 3.2 gives the potential, expressed in percentages, of rainwater harvesting. For example, if rain-fed cotton farmers experience a transpiration demand deficit in 50 % of the years, this consequently leads to a significant loss in crop revenues. This demand deficit has an average order of magnitude around 220mm/a. However, if all the rain fallen was redirected and collected, a buffer could be created

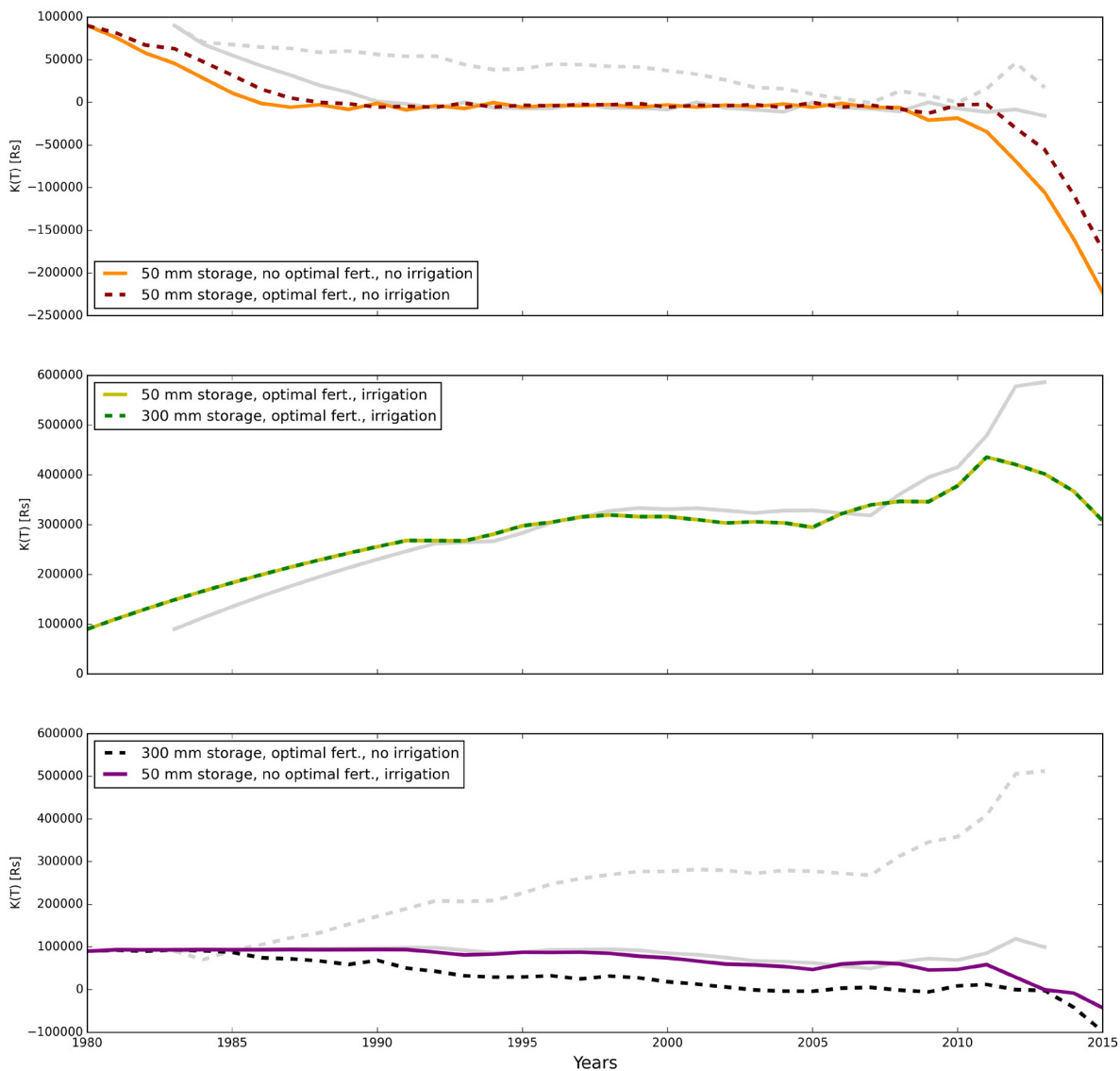


Figure 3.10: The capital development (expressed in Rs = rupees ₹) of six smallholder situations are simulated that show differences in their settings on water storage, fertilizer application and irrigation. The same simulations were done in the work of Pande and Savenije (2016), those outcomes are displayed in light gray, where the dotted lines and solid lines simulate the same type of smallholder in each subplot. Note that the simulations done by Pande and Savenije (2016) used different precipitation and PET data. In the updated simulations irrigation and optimal fertilizer application seem to create the optimal situation for the smallholder.

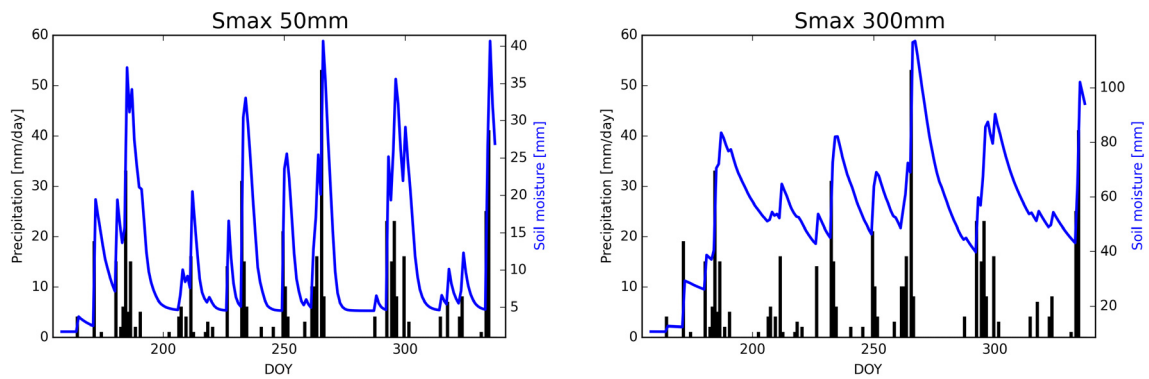


Figure 3.11: The response of soil moisture on precipitation by increasing the storage for a dry year (1997) during the cotton growing season (June-December). The left graph shows the development of a cotton producing smallholder with a low storage capacity [50mm]; The response to rainfall events is fast. The right graph shows the soil moisture development, but now with an increased storage capacity [300mm]; the response to rainfall events is slower; however, retained better. However the maximum amount of storage retained in the growing season approaches 120mm, which is not even half of the available storage for the smallholder.

Table 3.2: % Transpiration deficit, gives the percentage when rainfall is not enough to sustain crop water demand during growing season. The values in the brackets display the average monthly volume of these deficits in [mm] over the simulated time. % Rainwater buffer: gives the percentage of years where the amount of rain fallen is not enough to sustain the deficit during transpiration demand deficit, and consequently collecting all rainwater is not enough to sustain the deficit on a yearly basis.

Potential for rainwater harvesting in Marathwada

| Crops | % Transpiration deficit [magnitude] | % Rainwater buffer |
|-----------|-------------------------------------|--------------------|
| Sugarcane | 84 [-1080 mm/year] | 63 |
| Jowar | 31 [-70 mm/year] | 29 |
| Cotton | 50 [-220 mm/year] | 53 |
| Soybean | 44 [-120 mm/year] | 35 |

that decreases the deficit with 47 percent.

3.3.3. Assumptions model and fieldwork

The new additions to the hydrological aspects in the model give a better understanding of the crop water dynamics. The framework, however, has more features and structures that determine the development of the smallholder over time. With a fieldwork some of these internal assumptions were tested and observed, to outlay shortcomings and to test certain assumptions and outcomes of the model. This section will deal with the assumptions 8, 10, 12 and 13 (see Table 2.2) about some socio-economic circumstances of the smallholders in Marathwada, considering capital features in the framework. These assumptions were taken into the field and tested. First the outcomes of the Agrowon survey will be described and secondly the most important results of the questionnaire are displayed in Table 3.3 and put aside a representative smallholder simulation.

In Appendix E one can find an overview of all the results done by the surveys. To begin with, Agrowon spoke to 95% of the affected families of all farmer suicide cases in 2015 in Marathwada. 94% of the farmers that committed suicide in 2015 in Marathwada had a land holding size below 4 ha. 97% did not have an alternative income and nearly all farmers had a loan. Their loan was below 1 lakh rupees (around 2200 EUR) in 61% of the cases. The loans were generally taken in 43% of the cases from governmental banks, the rest of the farmers took a loan from commercial/corporate banks, moneylenders or family members/ friends, or a combination of the previous. It can be assumed that the vast majority of the farmers had minimal access to irrigation (Agrowon, 2016).

| | |
|---|--|
| <p style="text-align: center;">General</p> | <ul style="list-style-type: none"> ★ Almost half of the respondents were between the age of 30-45 years. ★ Most of them had children, on average 3 boys or girls. ★ Most of the farmers received education, but 73% dropped out before the end of high school. Due to the fact that they would help their family with the agricultural businesses. The average years of experience of a farmer was therefore 26 years. ★ All of the respondents were landowners with an average size of 4.7 ha, nevertheless smallholders were the most common respondent (71%). |
| <p style="text-align: center;">Hydrology</p> | <ul style="list-style-type: none"> ★ 33% had (seasonal) irrigation or supplemental water (e.g. open well or borewell), however most of these sources had dried out. ★ Most of the irrigated farmers received subsidies, however these were primarily the richer and larger farmers. These farmers primarily focus on horticulture or sugarcane. Moreover, if water is available, farmers shift to high water consumptive crops (as sugarcane), for their assured prices and less labour. ★ The most common reason given that limits the production of the farmers is water availability. Second argument is price volatility (23%). ★ The most determining factor in choosing a certain cropping pattern was water availability (62%). |
| <p style="text-align: center;">Livestock</p> | <ul style="list-style-type: none"> ★ 80% of the farmers have livestock, on average 3 units. ★ livestock has a dual role in the household: (1) as a financial buffer when yields are low (2) The family lives from the cattle's milk and uses its manure for fertilizer purposes. ★ on average the farmer uses 40% of its crop production for their own use. |
| <p style="text-align: center;">Income</p> | <ul style="list-style-type: none"> ★ Most of the farmers do not have access to alternative off-farm labour opportunities (80%). ★ Credits are experienced easily accessible. ★ 84% of the farmers experience their crop income as descending in the last decade. |
| <p style="text-align: center;">Expenditure</p> | <ul style="list-style-type: none"> ★ 87% of the farmers have loans, mostly crop loans. ★ If there is an economically bad year they either start loaning money or sell their livestock. In the worst case the farmers will sell off their land. |

| | |
|--------------------------------|---|
| <p>Cropping pattern</p> | <ul style="list-style-type: none"> ★ The common cropping pattern of most of these farmers was cotton, soyabean (and/or tur) with sorghum or wheat. ★ The most risky crops identified were cash crops, with cotton on top of the list. However, farmers do not see an alternative that can provide the same returns. ★ 69% of the farmers did not change their cropping pattern recently. |
| <p>Other</p> | <ul style="list-style-type: none"> ★ 58% of the farmers explained the crop year 2010/11 turned out best for them in the last decade, primarily due to good weather and pricing. ★ All farmers agreed upon the fact these last two years (2014 and 2015) were bad years, due to a persistent drought. ★ Market distances are also sometimes problematic, average distance was 20 km. |

Table 3.3: A field survey was held in March 2016. 45 farmers of different villages and size in Marathwada answered the questionnaire. This table will give a summary of the results. For all the results go to Appendix E.

From these results we observe that the farmers perceive water availability is limiting their agricultural development. Farmers of all sizes, prefer cash crops over food-grains, for the larger profits. In this sense most of these farmers are not subsistence farmers, but are aiming to make profit (40 percent of their yields is used for own consumption). The farmers perceive cash crops as risky crops, nevertheless they are willing to take the risk of producing them. If there was an economically bad year, farmers would sell their livestock or take loans; the majority of the farmers were indebted. The farmers use groundwater as their source for irrigation, but most of the wells have dried up (n.b.: interviews took place in summer). The farmers inherit their agricultural businesses and help their parents or take over at a young age.

The farmers experience their income over the last decade decreasing. The cropping year 2010/2011 was considered most profitable as far as the farmers can remember, due to good prices and weather. The last two years (2014 and 2015) have been worst for the farmers so far, due to falling prices and consecutive years of drought. These observations, together with other important events obtained from literature, earlier described in the section background information, are displayed in Figure 3.12. Considering the outcomes of the model and observations in the field, the farmer producing cotton with adequate soil moisture storage condition and no irrigation was chosen to represent the farmers in the model, hence simulated and compared to the observed suicide rates and other key events over the last three decades.

Figure 3.12 displays the farmer's experiences coincide with the results in the model. The cropping year 2010/2011 is valued a good year and shows a rise in capital, and falls within a depression of suicide rates. The last two years (2014 and 2015) are considered very bad, which in the model coincides with a crashing capital. Suicide rates in 2015 have been observed worst since record. Also after liberalization we see a decreasing capital, bothered by unstable crop yields (due to erratic rainfall), increasing input prices and price volatility. The increase of Bt cotton, caused an increase in yield, however required a rise in input cost (seed and pesticide expenditure), accelerating the farmer's indebtedness.

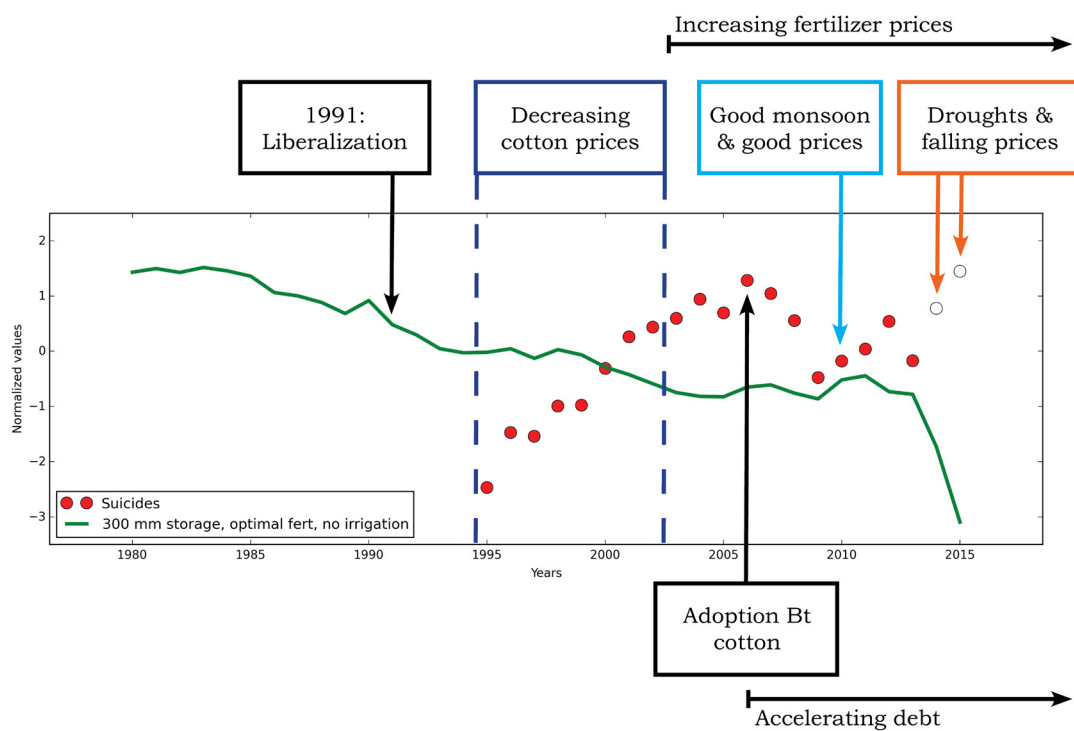
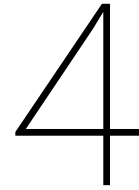


Figure 3.12: A simulation is displayed showing the capital development (in ₹) of a farmer with 300 mm of storage, optimal fertilizer application and no irrigation. To compare it with suicide rates the values were normalized by subtracting the mean and dividing by the standard deviation. The last two suicide rate numbers are fictional (unfilled dots), however suicide rates have been rising Agrowon (2016). Other key events obtained from literature or the outcomes of the questionnaire are also presented.



Discussion

In the coming discussion the results will be compared with existing literature and the interpretation will be discussed in detail. The model structure and data used poses some sensitivities and limitations that will be discussed and potential improvements will be proposed. Also, the work done in this thesis will be linked to the outcomes and model used by Pande and Savenije (2016) and how this has changed or enforced the outcomes done so far.

4.1. Comparative socio-hydrology

The state Maharashtra has frequently witnessed higher suicide rates among farmers than non-farmers over the last decade (Basu, 2016), making suicide rates amongst farmers a worrying development. Within Maharashtra, two regions experience higher suicide rates, the regions of Marathwada and Vidarbha (east of Marathwada). Geographically these regions lay more inland, far away from blooming economic and political epicentres such as Mumbai and Pune in the west. Additionally, these regions also lay in a "rain shadow region" of Maharashtra: the monsoon rainfalls sometimes do not reach far inland, accentuating the erratic monsoon rainfall even more. From the comparative assessment, the socio-hydrological modelling framework is able to combine the bio-physical differences and the cropping pattern the farmers choose to visualize the impact on the farmer's capital over time. A clear difference in average capital development between the two adjacent regions - Marathwada and Desh - have been observed. Moreover, the development of the average capital in Marathwada seems to be in line with the pattern in suicide rates: suggesting that the hydro-climatological differences, soil water storage differences, and cropping pattern may explain to a large extent the regional variances in suicide rate.

However, seeking the causes behind the suicide rates in Maharashtra, or any other region, is complex. Any suicide case involves a multitude of different problems affecting this final choice: depending on socio-economic, cultural, and psychological factors (Nagaraj, 2008). Nevertheless the natural endowments of a farmer do shape the behaviour and decisions of the farmer (Scherr, 2000). The results of the comparative assessment should be considered as a strong indication that the suicides are to a large extent related to cropping pattern and biophysical characteristics. However, no sociological or cultural factors were taken into account in the modelling framework. Though the explanation of sequential crop failures lead to indebtedness and distress for the farmer, it does not explain the full reasoning (Mohanty, 2005). For example, the region of Solapur in Desh is just as dry as the driest districts in Marathwada. Nevertheless, suicide rates are significantly lower in this area; something that is not explained with the socio-hydrological modelling framework.

To improve understanding the differences between regions one must also give attention to the cultural and sociological differences between regions that determine the behaviour or attitude of the farmers. Knowledge, values, or technology, for example, should be incorporated into the modelling framework to better understand the farmer - water interactions more accurately. A study by Mohanty (2005) for Yavathmal and Amravati (east of Marathwada) studied the factors behind suicide rates as well. They concluded, on the basis of a survey amongst 66 farmers (small - large), that economic distress is a "significant contributory factor", especially amongst smallholders (% 88 percent of the suicides were related to crop loss and indebtedness; larger scale farmers had a larger combination of other reasons). This is also in line with the results from Agrowon's survey. The outcomes of the Mohanty (2005) study also state that most suicides amongst smallholders oc-

curred among medium or lower castes, whom are traditionally not the main cultivators. Therefore, the farmers did not always have the skills needed to work with new commercial crops (Mohanty, 2005; Omvedt, 1999). It is therefore proposed to incorporate the farmer's knowledge into the model so that it can be linked to the Water Productivity or Harvest Index and ultimately affecting the calculated yields.

4.2. Historical socio-hydrology

Extending the socio-hydrological modelling framework spatially gave interesting results, therefore the framework was also analysed temporally. The change in cropping pattern after liberalization (post-1991) changed the cropping pattern of farmers from foodgrains to cash crops. It is observed that this change negatively influences the farmer's capital development. Nevertheless, a good year with an adequate monsoon and stable prices gives a profit that can never be reached with foodgrains. However, considering the price volatility, input needed, and erratic pattern of the rainfall events in Marathwada, the cash crop farmers take a risk that is not lucrative in the long term.

The rural study in Amravati and Yavatmal, by Mohanty (2005), also found 61% of the farmers committing suicide were cotton producers. Khairnar et al. (2015) found 58% of the affected families interviewed were primarily cotton producers. With a linear regression analysis of the available suicide data and characteristics of the diseased Kennedy and King (2014) also identified the smallholders choosing capital-intensive cash crops were most prone to distress, considering their lack of resilience. Mishra et al. (2015) also points out that the effect of climate change will worsen the situation of the cash crop producing smallholders even more if the market conditions stay volatile and the efforts of the government remain unreactive.

Pulses, such as chickpeas, have also shown a declining capital over the years compared to jowar (cereal). Farmers who shifted to chick pea (pulse) production experience a stagnant/declining capital. This is due to the revenues; while pulse price per kg exceed sorghum pricing, the farm yields of sorghum (jowar) are significantly higher than chick pea farm yields. Besides, from a water consumption perspective, pulses would be more preferable over cash crops. Moreover, pulses are one of India's staple foods. India is the biggest producer of pulses in the world and the national demand for pulses is high. However, since the 1990s the production has become stagnant and to meet the needs of the population growth India is even importing 2.5-3.5 Mt per year (Ali and Gupta, 2012). Besides an increasing domestic demand, the crops are drought resistant and nitrogen fixating, lowering the input costs (SNDRP, 2015).

However, instead of subsidizing the production of pulses, the Maharashtra government encourages farmers to produce cash crops such as sugarcane. As we have seen in the results, the international prices vs. domestic prices of sugarcane are skewed. It has become very tempting for the (small-scale) farmer to produce sugarcane; the state gives generous subsidies to sugarcane producers. As a consequence, a water-guzzling crop, such as sugarcane, has been made lucrative in an unsuitable semi-arid environment, and uses primarily groundwater to sustain the transpiration demand of the crop. Only 11% of the cultivated land in Marathwada is irrigated, but three quarter of the irrigation supply is reserved for sugarcane production (DAC, 2010-2011). Thereby, 30% of the sugar factories in Maharashtra are located in Marathwada, which also drain away large amounts of water that could have been used for more sustainable purposes (The Hindu, 2015).

4.3. Model sensitivity

The temporal and spatial extensions of the modelling framework outlined some sensitivities and limitations. Consistent datasets required for pricing and other parameters are hard to find, but determine the development of the model. The example of sugarcane pricing showed how the results change significantly with the introduction of another data-source. However, it revealed insights into the politics involved in sugarcane pricing. Calculating the crop yields and using different weather products of the previous version (Pande and Savenije, 2016) of the model also resulted in different results. Choosing different maximum potential crop yields had a significant influence on the simulated yields. Exposing the need for a different structure. Most of these issues were overcome by methodically analysing processes to study how the socio-hydrological modelling framework should be elaborated. The results of these changes will be discussed in the next section.

4.4. Process socio-hydrology

In June, July, and August, the chances of a dry spell of 14 days occurring is very common (65 %). These lengthy dry spells have a significant effect on the crop growth (Makurira et al., 2009). Long consecutive droughts will lead to a reduction of soil moisture and, consequently, a decrease of transpiration (Rodríguez-Iturbe and

Porporato, 2007). Plants growing in these circumstances are hampered or even prevented from growing when there is a significant soil moisture deficit. Therefore, the soil water balance is studied in more detail to better catch the effect of intra-seasonality on soil moisture and, consequently, crop growth.

A first attempt to improve the results was done by temporally downscaling the soil water balance in the model. The outcome shows the effect of using different meteorological data sources in the socio-hydrological modelling framework did not change the earlier conclusion made by Pande and Savenije (2016). The water balance used by Pande and Savenije (2016) is straightforward, only taking into account precipitation and evaporation on the farmer's plot. The simplifications will not sustain further analysis of daily hydrological mechanisms. Further elaboration on the soil moisture balance is needed to better incorporate daily scale mechanisms.

Therefore, the soil moisture balance was elaborated and intertwined with a crop growth model. The results showed that a larger availability of moisture in the root zone enhances productivity. Nevertheless, the dry spells occurring in the growing season can still make a farmer with an adequate storage capacity prone to distress. On-farm availability of water storage cannot over-bridge the high intra-seasonal variability. The intra-seasonality strongly influences the crop growth development. The simulations of Pande and Savenije (2016) resulted in different conclusions: increasing the storage was just as lucrative as applying irrigation. However, in the previous edition of the socio-hydrological modelling framework the intra-seasonality was not taken into account, as the soil water balance was calculated on a monthly scale.

In the crop growth model and soil water balance there is still room for improvement. At the moment the effect of moisture stress in the initial period (first 30 days) is not taken into account, for example. The stresses during this stage should also be incorporated as it is an important stage for the rain-fed crop development. Secondly, nutrient stresses are coupled to water stresses (Hsiao, 1973) and should therefore as well be linked in the model, currently it is treated separately. Thirdly, the vertisols (black cotton soil) found in Marathwada are known for its high storage/retentions capacity, but with heavy rainfall during monsoon, show problems with infiltration (Virmani et al., 1982). Thereby run-off is currently calculated as every volume of water exceeding maximum soil water storage. This can be improved by linking it to Canopy Cover and taking into account infiltration rates, in order to get a better idea at the amount of water leaving (and entering) the plot for which a separate off-farm basin can be created.

Even though the structure is improved by incorporating the crop growth model and elaborating the water balance, the yield calculations pose two main limitations: (1) The canopy cover calculations currently lack physical reality; (2) the biomass calculations are not directly linked to crop development. Since there are no observations done of the cotton development, the crop development must be approximated with a growth function. However, the current function translates water stress directly to the crop growth function, but does not adequately take into account crop development in antecedent days or other stresses (e.g. temperature). Therefore creating outcomes where the plant development can decrease significantly and rise within the same week. The soil moisture deficit is now linearly affecting the water stress factor, hence the canopy growth coefficient (see appendix C), perhaps a concave relation would enhance the results. Also more stress factors should be taken into account, besides water stress. If other stresses will be incorporated the stress factor will less heavily respond on moisture deficit, and a more realistic response on the canopy growth will be ensured. By doing so a way to directly link canopy development and biomass production should as well be found, as the biomass production is now indirectly calculated through transpiration of the crop.

Despite these limitations, the outcomes of the current version of the model are realistic. To illustrate this the simulated crop yields of a farmer with 300mm storage, fertilizer use, and no irrigation was put aside observed yields from Maharashtra (Lalitha et al., 2009). As one can see in the left graph of Figure 4.1 the crop yields are in accordance with observed yields of the state; the model is able to grasp most of the variances. The capital development of cotton producers are, naturally, influenced by the crop development calculations and most of the conclusions are drawn from these interpretations of smallholder reality. The right graph in Figure 4.1 therefore illustrates the effect on capital development if you alter the L_{AI} calculations. Farahani et al. (2009) parameterized Aquacrop and simulated cotton development for a Mediterranean climate in Northern Syria, they found a yield reduction of almost fifty percent under 40% irrigated conditions compared to fully irrigated conditions. Assuming the smallholders in Marathwada also experience similar non-optimal conditions, as described by Farahani et al. (2009), observe in the right graph of Figure 4.1 what the effect is on capital development. As one can see the outcomes of the simulations approach the outcomes of this thesis. Hence, the interpretations of the simulations done in this thesis are plausible. Nevertheless, the calculations should be improved as described earlier.

Besides elaborations on the canopy development, other features can also be analysed for further devel-

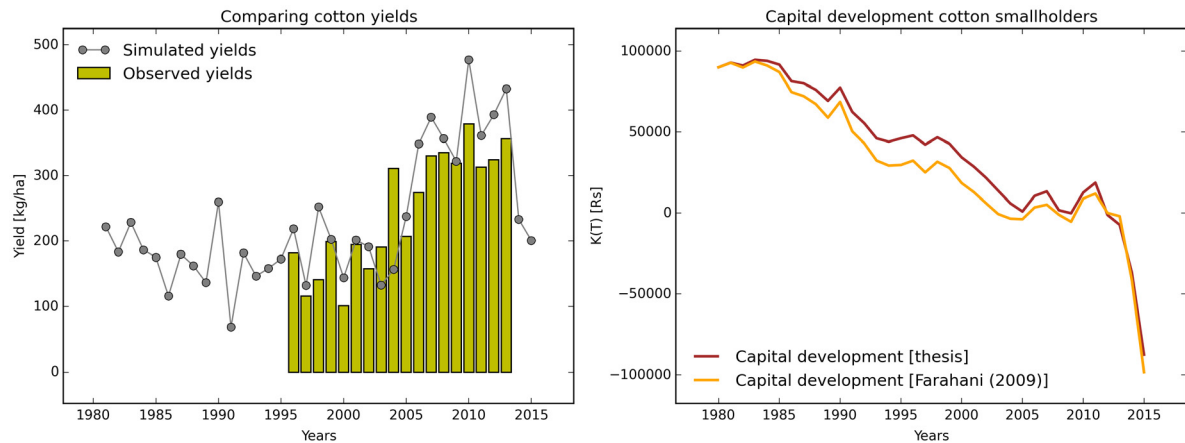


Figure 4.1: *These figures elaborate on some discussion points. In the left graph simulated yields (cotton farmer: 300mm storage, fertilizer use, no irrigation) for Parbhani (Marathwada) is compared to observed yields for Maharashtra (Lalitha et al., 2009). The simulated yields correspond with the variances in the observed yields. Note how droughts in 1991, 2014 and 2015 affect the crop yields. The right graph illustrates what happens if the L_{AI} calculations are altered to non-optimal conditions as described by Farahani et al. (2009), a reduction of fifty percent compared to optimal conditions can occur (for more information, see appendix C). This assumption is simulated and compared to capital simulations earlier done in this thesis. Both result in a corresponding result, making the current interpretations based on the simulations in this thesis plausible, even though the structure needs improvement.*

opment of the modelling framework. As was observed in the results, the distressed farmers are in need for more attention to watershed development to sustain their water needs. Analysing and modelling several case studies could be useful to understand the rainwater harvesting possibilities on watershed level. If improved, communal interventions are expected to close the yield gap significantly. In a further development of the model "common pool" issues can be discussed for both capital and water, where, for instance, multiple users can use the communal rainwater harvesting systems (Schluter and Pahl-Wostl, 2007; Anderson et al., 2002). Moreover, it would be interesting to simulate a group of farmers and their behaviour towards their water resources or availability of capital. From the survey it was also observed that farmers seem to behave in groups: they copy each others cropping pattern, they share each other's experiences, and especially in India, work in a certain hierarchy. For these and other issues, collaborations should be sought in different disciplines, such as social sciences, to better understand the social processes influencing the farmer-water interactions and/or relations.

Another feature of the model that needs further attention is the expenditure cut sequence of the model. The expenditure cut sequence influences the development of the capital, hence the results as well. Currently the model assumes a smallholder takes action when his capital falls below zero. To combat his/her negative end balance the farmer is assumed to cut his/her expenditure in the following order: first cutting down on investments, then school fees, interest payment on loans, tax on agricultural income, livestock costs, fertilize costs, livestock, and crop production labour cost, until the capital deficit is brought down to zero (Pande and Savenije, 2016). During the fieldwork, however, the farmers showed different reasoning. The farmers were asked what their actions would be if they had a negative end balance: most of the farmers responded that they would loan money, sell their livestock, or, in the worst case, sell off their land. Since most farmers function by taking up a loaned investment that is paid back after the season, a capital structure similar to this is proposed.

Rainwater harvesting can increase the water availability significantly as was estimated in the results. The rainwater harvesting technique assessed with the model was an example of increasing the water availability within the farmer's area. However, there are many more options to evaluate. In the case of a smallholder in Marathwada an extra storage buffer would only be functional if the farmer has a separate water harvesting system that can be applied to over-bridge soil moisture deficits during dry spells. Also this is in line with Rockström et al. (2010), in their plea for enhanced managing of rainwater globally in rain-fed agriculture, where dry spells are hampering the crop productivity. Just like many other semi-arid and dry sub-humid zones, the problem is not rainfall deficiency, but the extreme variability of the rainfall events. Even with rainwater harvesting, transpiration demand deficiencies are inevitable, however rainwater harvesting can significantly close the gap. The biggest benefits can be made by exploring options in communal rain-water

harvesting: farmers should collectively seek solutions within their watershed to disperse run-off in viable reservoirs or ponds that can serve as supplemental reservoirs. In other places, different On-farm System Innovations as: farm ponds, run-off harvesting, introducing trenches, or soil bunds can be assessed with the modelling framework for their potential (Makurira et al., 2011).

Unfortunately even with efforts to increase water availability, the population will continue to rise and due to climate change the rainfall pattern will probably become more erratic, and will not be enough to overcome the rural distress seen. Alternative employment options should be sought to overcome the marginalization of smallholders. This can be done by creating alternative rural employment or making credit more available for creative off-farm business ideas. Other interventions, aimed to buffer the capital of the distressed farmer should also be considered. From the surveys it was also observed that the farmers are indebted. This is not new and common among many agriculturalists throughout the world (Simkin, 2003; Gunnell, 2000), but in Marathwada the risky cropping patterns and erratic rainfall create a situation where many smallholders end up in a debt trap (Rasal, 2011; Behere and Behere, 2008). The suicides expose a deeper agricultural crisis bothering rural areas in Maharashtra, broader than reoccurring droughts, and demand a multi-disciplinary solution.

5

Conclusions and recommendations

The socio-hydrological modelling framework proved useful in being able to combine several different aspects of a smallholder in one model. In this research the model was extended spatially, temporally, put alongside field observations, and the structure was improved. The results show that, compared to western Maharashtra, the smallholders in Marathwada experience a stagnant income which is primarily due to differences in biophysical characteristic and cropping patterns. Furthermore, we have seen that the shift among farmers towards cash crops has caused a decrease in capital. It should be noted that farmers are stimulated to do so by the Maharashtra government by assuring prices. Finally, the amended modelling framework in this paper lead to different results from the original model. By applying a crop growth model and a daily soil water balance this improved model shows that, contrarily, on-farm storage is not sufficient to stabilize the well-being of farmers in Marathwada.

5.1. Why are farmers distressed in Marathwada?

The questionnaire and model outcomes conclude that the farmers that are under most stress are the smallholders that lack access to supplemental water or irrigation facilities. The farmers, and their families, solely depend on agriculture as alternative employment options are not available. Most of them primarily grow cash crops and the majority are in debt because of it. The investments that are needed for agricultural businesses has increased alongside the change in crop pattern forcing farmers to increasingly take out more loans. Farmers' increasing loans, be it from legal or illegal sources, increase the aforementioned stresses on farmers and lead them to resort to suicide. Also, this study recommends that the different social dynamics, such as varying colonial influences or differences among social classes, should be examined in order to further understand the suicide trends among farmers in India.

Post-liberalization, farmers have increasingly altered their behaviour from subsistence oriented farming to more profit-based practices thereby changing the water-farmer interactions. Surprisingly it is the government parties that give farmers strong incentives to change their crops and this decision exposes the already un-resilient smallholder to greater risks. This increased exposure to risk is therefore implicitly connected to governmental efforts nation-wide and state-wise and should be acknowledged if a solution lies in the interest of the ruling parties.

5.2. What do the updated simulations tell us?

The results of the original modelling framework showed that irrigation and adequate water storage are equally beneficial interventions for smallholders. The updated model, however, clearly demonstrates the importance of a daily time-frame when studying hydrological processes. The more elaborate model used in this research incorporated wider soil moisture balances and a crop growth model which in turn related the effect of intra-seasonal variability on the smallholders well-being. Dry spells occur frequently in Marathwada and the new results point out that increasing the storage in land will not be enough to enhance the situation of smallholders.

In accordance with other literature the model's outcome alludes to communal rainwater harvesting solutions. On average there is enough water to produce a variety of crops; although cotton may need some

additional irrigation, especially in the last month of senescence. Given the current irrigation sources (ground-water) the water consumptive crops such as sugarcane and horticulture should be avoided in Marathwada. It should be noted that from a hydrological perspective, however, that there are numerous other crops that can be grown. Droughts, such as the one experienced in the last two years (2014 and 2015), are devastating but their effects can be limited if water management is properly implemented and a resilience for these occurrences is built up. The problem in Marathwada is not a water availability problem, but rather a water management problem: dry spells create yield gaps and adverse governing priorities impose a threat to the smallholder.

This research also acknowledges an increased marginalization of smallholders, particularly in Marathwada. Since the contribution of agriculture to the GDP is steadily decreasing every year alternative employment options are necessary to alleviate the situation of smallholders now, and in the future.

5.3. On what aspects should policy focus?

Considering the inequity in distribution of irrigation water in Marathwada a crop such as sugarcane should be struck out from the political agenda. Instead of subsidizing an unsustainable cash crop incentives should be directed towards nourishing an ever increasing population and tackling the smallholder's exposure to risks: crops such as pulses should be politically encouraged.

Factors such as landlessness, unemployment and migration in rural areas should be considered serious issues affecting Marathwada's (and India's) rural population. Seventy five percent of the region is solely dependent on agriculture, a sector in which the income is declining every year.

This study shows how critical the need is for immediate political action. Not only should the policies give attention to the economic side of the story - by halting subsidies on unsustainable crops, increasing the availability of credit, and introducing weather index-based insurances - but they should also stimulate communal action to develop rainwater harvesting projects by promoting watershed development and spreading knowledge on how to do so. An example of a promising private initiative can be found in Appendix F.

While this year's monsoon may seem promising it is predictions like this that mask the serious issues¹ If the government can stimulate farmers to create a buffer in good hydro-meteorological years, then farmers will increase their resilience in times of drought. The outcomes resulting from this research contain important solutions to improve smallholder well-being, especially in times of increased population growth and rising effects of climate change. Unsurprisingly these solutions also apply for other semi-arid regions throughout the world.

5.4. How can the socio-hydrological modelling framework be enhanced?

This research has attempted to contribute to, and enhance, the socio-hydrological model. There are however a few aspects and constructions that could be further improved and added to, to which the scope of this research does not allow time for. The following summary are observations which have come up during this research and warrant further investigation or work.

- Include knowledge as a state variable and link it to a water use efficiency or optimal crop harvesting that can be, directly or indirectly, linked to the Harvesting Index and/or Water Productivity.
- The structure of the expenditure cut sequence should be further assessed. The fieldwork in this area suggests that a different structure should be sought out, one that is more in line with the observations.
- Currently the fertilizer application is not linked to water uptake. Since nutrient uptake is linked to water uptake a solution should be found for this.
- We currently only consider water stress deficiency during the growth period, there are, however, many other important stresses which should be incorporated.
- Different on-farm system innovations can be modelled to assess their viability. In order to do so runoff should be better incorporated, also those from neighbouring farm plots.
- To understand the societal and anthropological differences between regions and their influence on farmer-water interactions, try and work together with researchers from social sciences.

¹The Indian Meteorological Department stated this year's monsoon (2016) will be above average. In the second week of June the monsoon rain showers hit most parts of Marathwada (Express, 2016).

-
- By involving more disciplines in the research more attention should be paid to the actual necessity of the modelling framework. If the modelling framework wants to evolve into a tool that can be useful to policymakers or NGOs, their stakes and interest should be also incorporated in the further development. The same holds for the actual smallholder under study.
 - Farmers seldomly function as individuals but rather as a group. Efforts could be made to simulate the interaction between farmers in a watershed and what drives their interaction.
 - When further adjustments are made it would be interesting to see how the modelling framework works in other rural regions around the globe. An international comparative assessment could be useful to distinguish different drivers and feedbacks in the water-farmer relationship.

6

My thesis: a retrospective

During my thesis I encountered many interesting people and sources which lead to several insights that have been instrumental in my academic process. As the content of this thesis is primarily focused on the model, the verification, and the data, the format of this thesis does not allow for the opportunity to share these interesting insights that have been instrumental to the development of my understanding, and thus instrumental to the development of the model. With this chapter I want to create a space where I share a few of the insights I have gained along the course of this project. This background has been vital to this thesis and hopefully can also be helpful for future researchers interested in socio-hydrological modelling.

At the onset of this project I had the intention to not only validate the model's outcomes, but also to verify its purpose to create a tool that could serve an NGO or policy-maker. The idea was to create a user board of at least three companies or institutes, related to agricultural development, who could give their opinion and share their knowledge on the potential use of this kind of model. Therefore I approached several NGO's, and companies related to smallholder development. Soon the not-for-profit consultancy firm Aidenvironment professed interest in not only helping me with the user-board, but also with setting up a fieldwork project that would serve their interests. After having presented the research project to the board of Aidenvironment they decided to not further the collaboration and, more importantly, the funding. The reason being: the study was too scientific. It is here that I came in contact with the gap between the academical and commercial world. Aidenvironment wanted an immediate product they could use while the research project required a proper validation of the study. Functioning as a mediator between these two worlds while improving the model further and creating space for a fieldwork seemed too taxing. This is why I decided to leave Aidenvironment and continue down the academic route, however unfortunate this was for the funding of this project.

My experience with Aidenvironment lead me to ponder a few issues: what are the boundaries of socio-hydrology? Should it remain solely an academic endeavor? Or does including human behaviour in a hydrological context imply that hydrology as a science is re-assessing its interaction with society as well? These questions were partly answered when I had the chance to attend the EGU meeting in Vienna, 2016. Dr. Barthel spoke during the socio-hydrology session about the project DANUBIA, a project that can be considered an example of socio-hydrology, where sixty researchers from different disciplines tried to develop a model containing the most relevant aspects of the Danube river basin. After years of collaborating the project came to an end and failed, it was too complex and not coherent. He discussed what relevance the philosophy of socio-hydrology could have had, and concluded that it certainly could have helped to understand each other's disciplines. However, he also noted that the current socio-hydrological approach still lacks a plan for knowledge integration, visualizing this statement with Figure 6.1.

When looking at Figure 6.1 one can see that current research is primarily on the green line: focussing on improving model performance and understanding mechanisms. Where socio-hydrological models lack, however, is the relevance and usefulness of the model to the society. This is exactly what the DANUBIA project missed and why it failed, more focus should have been put on the implementation and usefulness of the model to stir its direction in a proper way. Furthermore, socio-hydrological models should also meet the intent of the Scientific Decade 2013-2022 of IAHS, "Panta Rhei - Everything Flows", where one practical aim is to *"improve our [hydrologists] capability to make predictions of water resources dynamics to support sustainable societal development in a changing environment."* (Montanari et al., 2013). Therefore collaborations should be sought with social sciences and the usefulness of the studies/ models critically analysed.

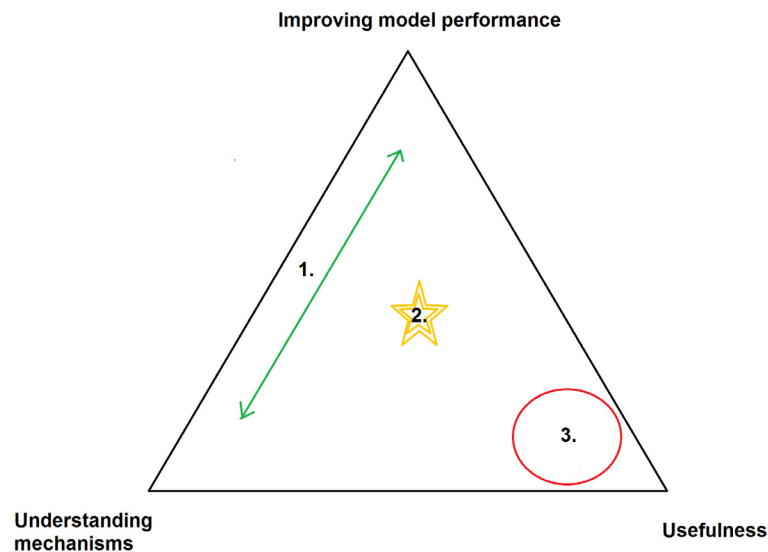


Figure 6.1: During the talk Dr. Barthel gave an explanation about the motivation of studying modelling socio-hydrological issues. He presented the nexus above as the three motivations: improving the model performance, understanding the mechanisms and Usefulness. Dr. Barthel pointed out that seldomly a researcher's motivation is to take into account the societal relevance of a model. point 3 is more something the government is focussing on. Point 2 would be the position of a perfect model, balancing between the 3 motivations. Point 1 indicates the focus of current research: more along the line of improving the model and understanding the mechanisms.

After letting go of validating the model's purpose with the help of a user board, I focussed entirely on validating the model and outcomes with a fieldwork. Following some struggle with finding a starting point and visa, I could enter India on February 21st 2016. I started collaborating with SOPPECOM (Society for Promoting Participative Ecosystem Management), an NGO located in Pune that works primarily in rural areas on anything related to Natural Resource Management. From their office I could arrange my fieldwork and collect the required data. The most important thing was to talk to the severely distressed farmer and to assess the condition of their livelihoods, because how can you develop a model for a smallholder without ever having talked to the people you are modelling? And how can you respectfully use suicide data as a proxy for a model without ever having stepped one foot on the grounds of the farmer's land? Not that a visit by some student of the Netherlands would change the dire situation, but it definitely enforces the legitimacy of your method and outcomes and in the end it contributes to (hopefully) further development of the framework.

I talked to many farmer, sons of farmers, nieces of farmers etc.. Since the majority of the population lives in rural areas, it seems like everybody has a family member that is linked to agriculture. The most striking visit and conversations I had were when my translators and I visited the village of Babhulgoan (Parbhani district), a village with 7000 inhabitants, twenty kilometres away from Parbhani city. The farmers immediately offered me tea upon my arrival, and later they told me that they were so deep into debt that tea-powder was one of the few luxuries that they could afford. The first farmer we spoke to that day started the interview very emotional. With tears in his eyes he told us how over the last two years his yields had been ruined, how he didn't receive any help from the government, and how the credit systems were corrupt and sometimes unaccessible. Due to the crop failures he had no income to support his family and was severely indebted. He said, speaking on behalf of the farmers in his village: "There is no reason for us to live anymore".

This farmer pointed to all that is wrong with the agricultural system in Marathwada (and probably other parts in India). Absent monsoon rainfalls emphasize the missing resilience of these farmers to endure drought, amplified by their risky choices in cropping pattern. All the farmers in this villages chose to produce cotton as their main crop, filling it up with soyabean and jowar or wheat. It should be noted that some of the farmers told me that in the last two years even their sturdy jowar yields had failed. After all the modelling and reading I had done, I was finally given a face to put to the literature, the farmer who is at the epicentre of the model. The

assumptions and outcomes within the model were experienced and implicitly tested by these observations.

I would recommend anyone modelling a socio-hydrological situation to go to the field and observe the dynamics within the system you are trying to model. Any assumption you make containing human behaviour should be experienced to get a feel for, or an affinity with the situation. By e.g. talking to inhabitants of a catchment or farmers in an area. During my fieldwork I was primarily alone. The work would have probably gone more efficient and better if I had been accompanied by another researcher, to share the experiences, to document observations and for safety purposes. Nevertheless, it was a magnificent learning experience and a great adventure. The fieldwork really helped to straighten my thoughts and pin-point what was relevant and what not. Also, being in the field showed me that an incorporation of the social sciences would have been very helpful as a student of socio-hydrology. The colonial history of an area, for example, determines to a certain extent the attitude of farmers in a region, and thus their adaptation strategies. Also, interviewing techniques or documentation of qualitative data could be a worthy addition for the student choosing a socio-hydrological theme. I found it hard to document all the conversations and observations in an academic way.

Finally, I found that during the research process I had to explain, to my fellow students and to the people around me, what socio-hydrology is and why it is useful, sometimes almost to a point of defending my research. There seems to be some confusion surrounding the term and I must admit that at stages even I questioned it. If socio-hydrology is about creating human systems endogenous to the hydrological cycle, are we then saying that humans are not part of the hydrological cycle in the first place? Then why the need for a new term? Doesn't that magnify a divide that should not be there in the first place? While I agree that the term can be divisive the movement that it represents remains very important. Socio-hydrology promotes a different way of looking at existing hydrological studies and creates a new platform which promotes collaborating with other disciplines to come up with new solution for the complexities of human-water interactions. With this thesis I hope to have shown how relevant the study of human-water interactions is and how it can give insights into complex situations such as that of the smallholders in Marathwada.

Bibliography

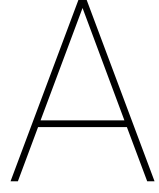
- Agrowon. personal communication, 2016.
- M. Ali and S. Gupta. Carrying capacity of indian agriculture: pulse crops. 2012.
- C.L. Anderson, L. Locker, and R. Nugent. Microcredit, social capital, and common pool resources. *World development*, 30(1):95–105, 2002.
- V. Asthanai and A.C. Shukla. *Water security in India*. Bloomsbury Academic, 1385 Broadway, New York, NY 10018, USA, 1 edition, 2014. ISBN 978-1-4411-7936-4.
- S.D. Attri and A. Tyagi. Climate profile of india. Technical report, India Meteorological Department (IMD), 2010. URL <http://weather.pme.gov.sa/applied-studies/dirasa14.pdf>.
- D. Basu. Farmer suicides in india. *Economic and Political Weekly*, Vol. 51(Issue No. 21), 21 2016.
- W. Beekman, G.J. Veldwisch, and A. Bolding. Identifying the potential for irrigation development in mozambique: Capitalizing on the drivers behind farmer led irrigation expansion. *Physics and Chemistry of the Earth*, 76–78:54 – 63, 2014. ISSN 1474-7065. doi: <http://dx.doi.org/10.1016/j.pce.2014.10.002>. Transboundary Water Cooperation: Building Partnerships (Part 2).
- P. Behere and A. Behere. Farmers' suicide in Vidarbha region of Maharashtra state: A myth or reality? *Indian Journal of Psychiatry*, 50(2):124–127, 2008. doi: 10.4103/0019-5545.42401.
- calculatorstack.com. <http://calculatorstack.com/inflation-calculator-india.php>, 2016. Accessed: 2016-05-29.
- Census. Population census. <http://www.census2011.co.in/district.php>, 2010-11. Accessed: 2016-06-09.
- Climate-data.org. Climate-data.org. <http://en.climate-data.org/location/2811/>, 2016. Accessed: 2016-06-19.
- Agricultural Census Division DAC. Agricultural census data base. An optional note, 2010-2011. URL <http://agcensus.dacnet.nic.in/>.
- A. Dandelar, S. Narawade, R. Rathod, R. Ingle, V. Kulkarni, and Y.D. Sateppa. Causes of farmer suicides in maharashtra an inquiry. Technical Report 9, Tata Institue of Social Sciences, Rural Campus, Tujapur, Dist. Osmanabad, march 2005. 36 cases.
- R.S. Deshpande, A. Jyotishi, and A. Narayanamoorthy. Indebtedness among agricultural labourers from deprived castes towards explanation. *Artha Vijnana*, Vol. XLIII(1-2):159–172, March-June 2001.
- G. Di Baldassarre, A. Viglione, G. Carr, L. Kuil, J. L. Salinas, and G. Bloschl. Socio-hydrology: conceptualising human flood interactions. *Hydrology and Earth System Sciences*, 17(8):3295–3303, 2013. doi: 10.5194/hess-17-3295-2013.
- Y. Elshafei, M. Sivapalan, M. Tonts, and M. R. Hipsey. A prototype framework for models of socio-hydrology: identification of key feedback loops and parameterisation approach. *Hydrology and Earth System Sciences*, 18(6):2141–2166, 2014. doi: 10.5194/hess-18-2141-2014.
- The Indian Express. Monsoon finally arrives in drought-hit maharashtra, 90receiving rains: Met dept, 2016. <http://indianexpress.com/article/india/india-news-india/monsoon-finally-arrives-in-drought-hit-maharashtra-90-of-state-receiving-rains-met-dept/>.
- FAO. Part one : Smallholders and their characteristics. *Economic and Social Development Department*, 1992. URL <http://www.fao.org/docrep/t0211e/T0211E03.htm>.

- FAO. Fertilizer use by crop in india. Technical report, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00100 Rome, Italy, 2005.
- FAO. Crop water information. <http://www.fao.org/nr/water/c>, 2015.
- H. J. Farahani, G. Izzi, and T. Y. Oweis. Parameterization and evaluation of the aquacrop model for full and deficit irrigated cotton. *Agronomy journal*, 101(3):469–476, 2009.
- M. A. Ferroni. *Transforming Indian agriculture India 2040 : productivity, markets, and institutions*. New Delhi ; Thousand Oaks : SAGE, 2012. ISBN 9788132110965.
- G. Fischer, F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, and D. Wiberg. Global agro-ecological zones assessment for agriculture (gaez 2008). *IIASA, Laxenburg, Austria and FAO, Rome, Italy.*, 2008.
- S.O. Funtowicz and J.R. Ravetz. Economy and environment: Charles perrings, cambridge university press, cambridge, great britain, 1987, 179 pp. isbn 0-521-34081-0. *Ecological Economics*, 1(2):197–201, 1989.
- D.J. Gunnell. The epidemiology of suicide. *International review of psychiatry*, 12(1):21–26, 2000.
- M. Herrero, E. González-Estrada, P.K. Thornton, C. Quirós, M.M. Waithaka, R. Ruiz, and G. Hoogenboom. Impact: Generic household level databases and diagnostics tools for integrated crop-livestock systems analysis. *Agricultural Systems*, 92(1–3):240 – 265, 2007. ISSN 0308-521X. doi: <http://dx.doi.org/10.1016/j.agsy.2006.03.008>.
- T.C. Hsiao. Plant responses to water stress. *Annual review of plant physiology*, 24(1):519–570, 1973.
- IFAD. Smallholder farming in transforming economies of asia and the pacific: Challenges and opportunities. Technical report, Thapa, G., 2 2009.
- IFPRI. From subsistence to profit transforming smallholder farms. Technical report, IFPRI, 07 2013.
- K. Iyer. Marathwada: India's emerging farmer suicide capital, September 2015. URL indianexpress.com. [Online; posted 13-September-2015].
- P.D. Jones and I. Harris. Climatic research unit (cru) time-series datasets of variations in climate with variations in other phenomena. *NCAS British Atmospheric Data Centre*, December 2015.
- S.S. Kalamkar. Patterns and determinants of agricultural growth in maharashtra. *Artha Vijnana*, LIII(2):156–181, 2011.
- J. Kennedy and L. King. The political economy of farmers' suicides in india: indebted cash-crop farmers with marginal landholdings explain state-level variation in suicide rates. *Globalization and Health*, 10(1):16, 2014. ISSN 1744-8603. doi: 10.1186/1744-8603-10-16.
- D.R. Khairnar, M.J. Bhosale, and M.A. Jadhav. Lack of irrigation facilities draught conditions and farmers suicides in marathwada region (india). *American Journal of Rural Development*, 3(3):74–78, 2015. ISSN 2333-4770.
- A. M. Komarek, C. K. McDonald, L.W. Bell, J.P.M. Wish, M.J. Robertson, N. D. MacLeod, and W.D. Bellotti. Wholefarm effects of livestock intensification in smallholder systems in gansu, china. *Agricultural Systems*, 109:16 – 24, 2012. ISSN 0308-521X. doi: <http://dx.doi.org/10.1016/j.agsy.2012.02.001>.
- N. Lalitha, B. Ramaswami, and P.K. Viswanathan. India's experience with bt cotton: Case studies from gujarat and maharashtra. *Biotechnology and agricultural development: Transgenic cotton, rural institutions and resource-poor farmers*, pages 135–167, 2009.
- Madhumanti. Examining the agrarian crisis in the context of globalisation: a study of cotton farmers, maharashtra. Technical Report 1, National Centre for Advocacy Studies, Serenity Complex, Ramnagar Colony, Pashan, Pune 411 021, Maharashtra, India, 9 2007. Obtained from SOPPECOM's library.
- H Makurira, HHG Savenije, S Uhlenbrook, Johan Rockström, and A Senzanje. Investigating the water balance of on-farm techniques for improved crop productivity in rainfed systems: A case study of makanya catchment, tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, 34(1):93–98, 2009.

- H. Makurira, H.H.G. Savenije, S. Uhlenbrook, J. Rockström, and A. Senzanje. The effect of system innovations on water productivity in subsistence rainfed agricultural systems in semi-arid tanzania. *Agricultural Water Management*, 98(11):1696–1703, 2011.
- K.K. Mishra, N. Gupta, and S. Bhabulkar. Sociodemographic profile of suicide attempters among the rural agrarian community of central india. *Industrial Psychiatry Journal*, 24(2):185–8, 2015. doi: 10.4103/0972-6748.181720.
- S. Mishra. Farmers suicides in india, 1995-2012: Measurement and interpretation. *Asia Research Centre Working Paper*, 62, 2014.
- Rakesh Mohan. Agricultural credit in india: Status issues and future agenda. *Economic and Political Weekly*, pages 1013–1023, 2006.
- B.B. Mohanty. We are like the living dead: Farmer suicides in mahrashtra (western india). *The journal of Peasant Studies*, 32(2):243–276, 2005.
- A. Montanari, G. Young, H.H.G. Savenije, D. Hughes, T. Wagener, L.L. Ren, D. Koutsoyiannis, C. Cudennec, E. Toth, S. Grimaldi, et al. Panta rhei-everything flows: change in hydrology and society-the iahs scientific decade 2013-2022. *Hydrological Sciences Journal*, 58(6):1256–1275, 2013.
- M.T. Musande. The general land use pattern and changes therein marathwada region: a geographical analysis. *Avishkar - Solapur University Research Journal*, 3:120–129, 2014. URL <http://su.digitaluniversity.ac/WebFiles/III-14.pdf>.
- K. Nagaraj. *Farmers' suicides in India: magnitudes, trends and spatial patterns*. Bharathi puthakalayam, 421, Anna Salai, Teynampet, Chennai, 4 edition, 3 2008. ISBN 9788189909574.
- buitenland NOS. Droogte drijft boeren in india tot zelfmoord, 2016. URL <http://nos.nl/artikel/2102944-droogte-drijft-boeren-in-india-tot-zelfmoord.html>.
- G. Omvedt. Dalit suicides? *The Hindu*, April 1999.
- S. Pande and H. H. G. Savenije. A sociohydrological model for smallholder farmers in maharashtra, india. *Water Resources Research*, 52(3):1923–1947, 2016. ISSN 1944-7973. doi: 10.1002/2015WR017841.
- S. Pande and M. Sivapalan. Progress in socio-hydrology: a meta-analysis of challenges and opportunities. *The Wire*, Under review.
- R. M. Peart and R. B. Curry. *Agricultural systems modeling and simulation*, volume 1. Marcel Dekker, 270 Madison Avenue, New York, 1 edition, 1998. ISBN 0824700414.
- G.M. Pillai. *Challenges of agriculture in the 21st century*. Maharashtra Council of Agricultural Education and Research, Agricultural College Campus, Shivajinagar, Pune 411 005, 1 edition, 12 1999. Obtained from SOPPECOM's library.
- D. Raes, P. Steduto, T.C. Hsiao, and E. Fereres. Chapter 3 calculation procedures aquacrop. Technical Report 4, FAO, FAO, Land and Water Division Rome, Italy, 6 2012.
- O. J. Rasal. *A study of socioeconomic risk factors identification and analysis of farmers suicides: a case of Maharashtra*. PhD thesis, Tilak Maharashtra Vidyapeeth, Department of Economics, 4 2011. <http://hdl.handle.net/10603/3415>.
- M. J. Robertson, D. Pannell, and M. Chalak. Whole farm models: a review of recent approaches. *Online*, 2011. URL http://aci.gov.au/files/node/13992/whole_farm_models_a_review_of_recent_approaches__42894.pdf.
- J. Rockström. Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth, Parts A/B/C*, 28(20–27):869 – 877, 2003. ISSN 1474-7065. doi: <http://dx.doi.org/10.1016/j.pce.2003.08.009>. URL <http://www.sciencedirect.com/science/article/pii/S1474706503001566>.

- J. Rockström, L. Karlberg, S. P. Wani, J. Barron, N. Hatibu, T. Oweis, A. Bruggeman, J. Farahani, and Z. Qiang. Managing water in rainfed agriculture: The need for a paradigm shift. *Agricultural Water Management*, 97(4):543–550, 2010.
- I. Rodríguez-Iturbe and A. Porporato. *Ecohydrology of water-controlled ecosystems: soil moisture and plant dynamics*. Cambridge University Press, 2007.
- H. H. G. Savenije. *Hydrology of catchments rivers and delta's*. TU Delft, Faculty of Civil Engineering, Water Resources Sections, 1 edition, 2006.
- S. J Scherr. A downward spiral? research evidence on the relationship between poverty and natural resource degradation. *Food policy*, 25(4):479–498, 2000.
- M. Schluter and C. Pahl-Wostl. Mechanisms of resilience in common pool resource management systems an agent-based model of water use in a river basin. *Ecology and Society*, 12(2):4, 2007.
- Shodhganga. Chapter 2: Area of study (maharashtra state). http://shodhganga.inflibnet.ac.in/bitstream/10603/4361/8/08_chapter%202.pdf, 1995. Accessed: 2016-06-06.
- S. Simkin. Seasonality in suicide a study of farming suicides in england and wales. *Crisis The Journal of Crisis Intervention and Suicide Prevention*, 24(3):93, 2003.
- R.B. Singh, P. Kumar, and T. Woodhead. Smallholder farmers in india: Food security and agricultural policy report, FAO, March 2002. URL <ftp://ftp.fao.org/docrep/fao/005/ac484e/ac484e00.pdf>.
- M. Sivapalan, H. H. G. Savenije, and G. Blöschl. Socio-hydrology: A new science of people and water. *Hydrological Processes*, 26(8):1270–1276, 2012a. ISSN 1099-1085. doi: 10.1002/hyp.8426. URL <http://dx.doi.org/10.1002/hyp.8426>.
- M. Sivapalan, H. H. G. Savenije, and G. Blöschl. Socio-hydrology: A new science of people and water. *Hydrological Processes*, 26(8):1270–1276, 2012b. ISSN 1099-1085. doi: 10.1002/hyp.8426.
- SNDRP. Pulse farmers: custodians of fertility, water and climate-friendly agriculture, 2015. <https://sandrp.wordpress.com/2015/10/20/pulse-farmers-custodians-of-fertility-water-and-climate-friendly-agriculture/>.
- J. Sood. Agricultural census. <http://www.downtoearth.org.in/news/farmers-have-decreased-farm-labourers-increased-census-report--40940>, 2013. Accessed: 2016-05-29.
- V Srinivasan. Coevolution of water security in a developing city. *Hydrol. Earth Syst. Sci. Discuss*, 10:13265–13291, 2013.
- E.C. Stephens, C. F. Nicholson, D.R. Brown, D. Parsons, C.B. Barrett, J. Lehmann, D. Mbugua, S. Ngoze, A.N. Pell, and S.J. Riha. Modeling the impact of natural resource-based poverty traps on food security in kenya: The crops, livestock and soils in smallholder economic systems (classes) model. *Food Security*, 4(3): 423–439, 2012. ISSN 1876-4517. doi: 10.1007/s12571-012-0176-1. URL <http://dx.doi.org/10.1007/s12571-012-0176-1>.
- R. P Stone and D. Hilborn. *Universal Soil Loss Equation, USLE*. Ministry of Agriculture, Food and Rural Affairs, 2000.
- A.K.K. The Economist. Why india has a water crisis. *The Economist*, page online article, 2016.
- . The Hindu. Dams and sugarcane have conspired to reduce marathwada to rack and ruin, 2015. <http://www.thehindu.com/news/national/other-states/dams-and-sugarcane-have-conspired-to-reduce-marathwada-to-rack-and-ruin/article8368956.ece>.
- GEM The Worldbank. Global economic monitor - commodities. <http://data.worldbank.org/data-catalog/global-economic-monitor>, 2015.

- P.K. Thornton and M. Herrero. Integrated crop livestock simulation models for scenario analysis and impact assessment. *Agricultural Systems*, 70(2–3):581 – 602, 2001. ISSN 0308-521X. doi: [http://dx.doi.org/10.1016/S0308-521X\(01\)00060-9](http://dx.doi.org/10.1016/S0308-521X(01)00060-9).
- B Umar. India's shocking farmer suicide epidemic, 2015. URL <http://www.aljazeera.com/indepth/features/2015/05/india-shocking-farmer-suicide-epidemic-150513121717412.html>.
- VDSA. Meso-database, 2011. data retrieved from Village Dynamics South Asia, <http://vdsa.icrisat.ac.in/>.
- S.M. Virmani, K.L. Sahrawat, and J.R. Burford. Physical and chemical properties of vertisols and their management. Technical Report CP 048, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 1982.
- M.T. van Wijk, Pl Tittonel, M.C. Rufino, M. Herrero, C. Pacini, N. de Ridder, and K.E. Giller. Identifying key entry points for strategic management of smallholder farming systems in sub saharan africa using the dynamic farm scale simulation model nuances farmsim. *Agricultural Systems*, 102(1–3):89 – 101, 2009. ISSN 0308-521X. doi: <http://dx.doi.org/10.1016/j.agsy.2009.07.004>.
- WRIS. Soil depth, 2016a. URL <http://india-wris.nrsc.gov.in/soilapp.html>.
- WRIS. Godavari. <http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Godavari>, 2016b. Accessed: 2016-06-06.
- R.J. Zomer, A. Trabucco, D.A. Bossio, O. van Straaten, and L.V. Verchot. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agric. Ecosystems and Envir.*, (126):67–80, 2008.



The Socio-Hydrological Modelling Framework

Pande and Savenije (2016) developed a model that simulates the evolution of six state variables: storage, capital, livestock, grazing area, soil fertility, and labour, that are of importance to a smallholder. These states are described by differential equations that are coupled. Fluxes are existent between the states and change over time. Figure A.1 visualizes how the model works. The dashed black lines are activated when capital falls below zero. The farmer in this case will start to cut down on its expenditure, that will influence the variables as livestock sales, livestock production cost, labor, and soil fertility. A second adaption mechanism is present in the model structure: when off-farm wage rate is higher than the on-farm marginal productivity, the farmer will choose to work off-farm. Climate and off-farm wage rate are external to the model. The blue lines indicate a positive feedback and the red lines a negative feedback. Follow the lines and observe what happens if there is a drought.

As mentioned the model is described by six coupled differential equations, of which the labour availability is steady state and does not change over time. The equations used in the model will be described beneath.

Hydrology

For the soil moisture status a simple soil moisture balance was used, including crop and transpiration and precipitation.

$$\frac{dS}{dt}(t, T)\Delta t = \min(S_{t,T} + (P_{t,T} - Ec_{t,T} - Eg_{t,T})\Delta t, S_{max}) - S_{t,T} \quad (A.1)$$

Where:

- $S_{t,T}$ is the soil moisture available at time t, T [mm]
- $P_{t,T}$ is precipitation [mm/month]
- $Ec_{t,T}$ crop transpiration [mm/month]
- $Eg_{t,T}$ grass transpiration [mm/month]
- S_{max} the maximum available soil water storage [mm]

$$Ec_{t,T} = \alpha \min(Ec_{t,T}^p, P_{t,T} + \frac{S_{t,T}}{\Delta t}) \quad (A.2)$$

$$Eg_{t,T} = (1 - \alpha) \min(Eg_{t,T}^p, P_{t,T} + \frac{S_{t,T}}{\Delta t}) \quad (A.3)$$

Where:

- $Ec_{t,T}^p$ is the potential transpiration for the crop [mm/month]
- $Eg_{t,T}^p$ is the potential transpiration for grass [mm/month]

α is the fraction of a smallholder's land that is under crop production.

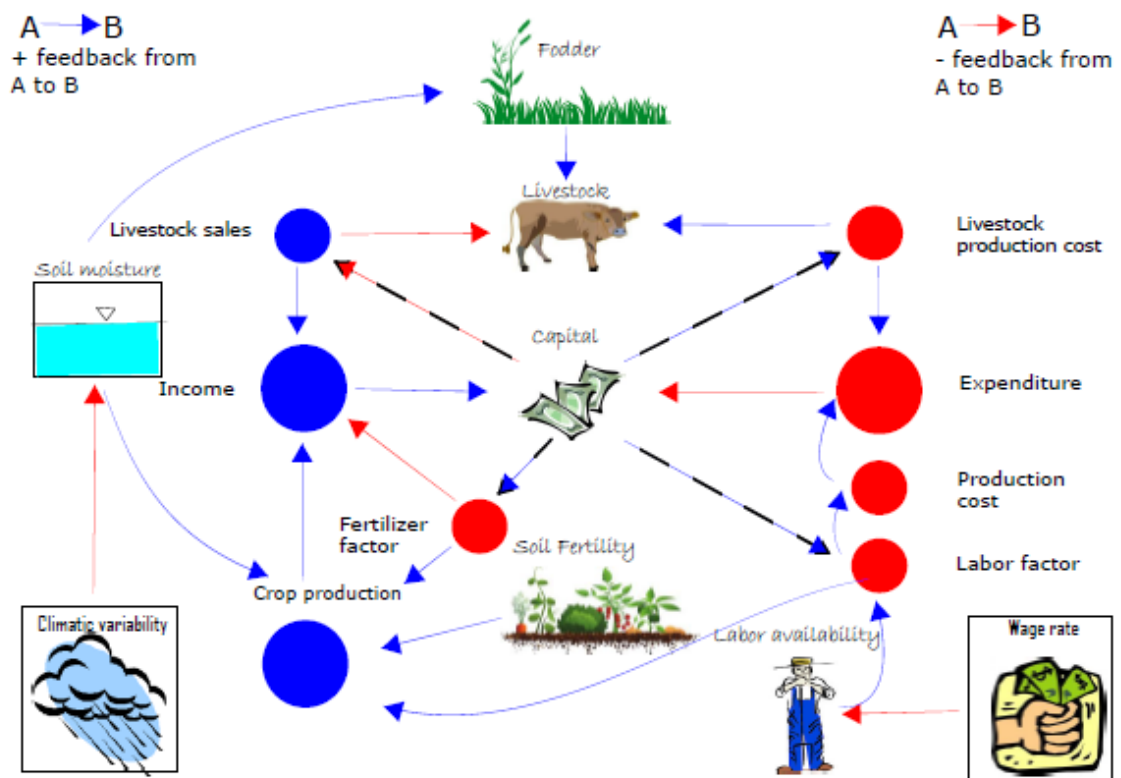


Figure A.1: This figure displays a graphical overview of the model. For example, if a drought occurs the soil moisture status will be negatively affected, which decreases the crop and fodder production. this in turn will decrease the income. If the capital enters below zero, the black dotted lines are activated and the farmer is forced to cut down on expenditure. These expenditure cuts will positively feedback on the farmer's capital.

Fodder

$$\frac{dG}{dT}(T)\Delta T = \min(G(T) + (A_g y_g - c_L^G(T))\Delta T, A_g y_g^{max} \Delta T) - G(T) \quad (A.4)$$

Where:

A_g is the area under grassland [ha]

$Eg_{t,T}^p$ is the potential transpiration for grass [mm/month]

y_g^{max} is the maximum possible grass yield [kg/ha/year]

$y_g(T)$ is the grass yield achieved in year T [kg/ha/year]

$c_L^G(T)$ is the amount of grass consumed by livestock as defined in the following equation:

$$c_L^G(T) = \min(G(T), L(T)n_L^f(1 - n_L^r)) \quad (A.5)$$

Where:

n_L^f is the feed requirement per livestock [kg/livestock/year]

n_L^r feed residue rate [-]

The grass yield is calculated by scaling the maximum possible yield by relative transpiration deficit β_{eg} .

$$y_g(T) = \beta_{eg}(T)y_g^{max} \quad (A.6)$$

$$\beta_{eg}(T) = \max(0, \min(1, 1 - K_g(1 - \frac{\sum Eg_{t,T}}{(1 - \alpha)\sum Eg_{t,T}^p}))) \quad (A.7)$$

Where K_g represents a grass specific scaling coefficient.

Soil fertility The soil fertility development $F(T)$ [kg] is measured in terms of nitrogen content of the soil.

$$\frac{dF}{dT}(T) = f(T) - u(T) - s(T) \quad (A.8)$$

Where:

$f(T)$ fertilization due to nitrogen fixation, by either applying commercial fertilizers and/or manure produced by livestock [kg/year]

$u(T)$ is the nitrogen uptake by crops, at a rate assumed that is needed for the crops [kg/year]

$s(T)$ nitrogen loss due to soil erosion, based on USLE [kg/year]

Livestock production The livestock development is also determined by a differential equation. It is assumed that the farmer buys livestock as a fraction of available livestock, $I_b(T)$ [livestock/year].

$$\frac{dL}{dT}(T)\Delta t = \max(L(T) + (r_L(1 - \frac{L(T)}{K_L})L(T) + I^b(T) - I^s(T))\Delta t, 0) - L(T) \quad (A.9)$$

Where:

$K(T)$ carrying capacity of a smallholder system [livestock]

$I^s(T)$ livestock sold [livestock/year]

Capital The evolution of capital is determined by the following differential equation $K(T)$ [₹/year]

$$\frac{dK}{dT}(T) = -\delta \frac{K(T)}{\Delta T} + m(T) - z(T) + w(t) \quad (A.10)$$

Where:

$m(T)$ income generated in year T [₹/year]

$z(T)$ the expenditure in year T [₹/year]

$w(t)$ is the loan taken in year T [₹/year]

Δ is a depreciation rate of the capital [$year^{-1}$]

The model elaboration above does not include all details of the modelling framework, but the most essential ones. For the full explanation of the socio-hydrological modelling framework, read Pande and Savenije (2016). With this model Pande and Savenije (2016) analysed a few smallholder situations, see Figure A.2 and A.3. These simulations are also performed, referred to and used in this thesis.

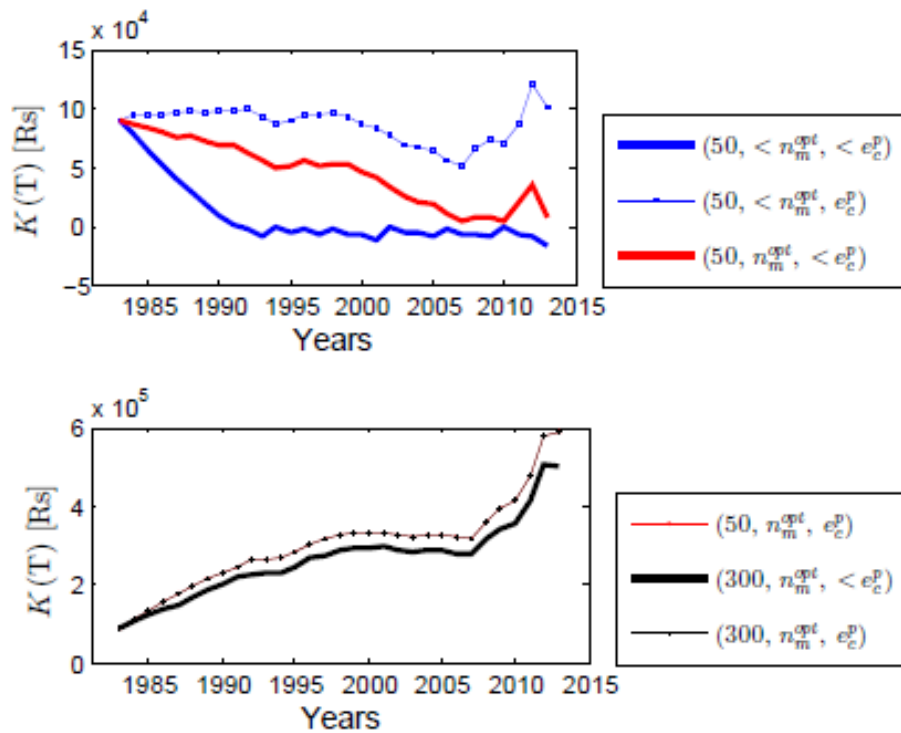


Figure A.2: These two graphs show six capital simulations of smallholders producing cotton. $(50, < n_m^{opt}, < e_c^p)$, represents a smallholder with 50mm storage, no optimal fertilizer conditions, and no irrigation. $(50, < n_m^{opt}, e_c^p)$, represents a smallholder with 50mm storage, no optimal fertilizer conditions, and irrigation. $(50, n_m^{opt}, < e_c^p)$, represents a smallholder with 50mm storage, optimal fertilizer conditions, and no irrigation. $(50, n_m^{opt}, e_c^p)$, represents a smallholder with 50mm storage, optimal fertilizer conditions, and irrigation. $(300, n_m^{opt}, < e_c^p)$, represents a smallholder with 300mm storage, optimal fertilizer conditions, and no irrigation. $(300, n_m^{opt}, e_c^p)$, represents a smallholder with 300mm storage, optimal fertilizer conditions, and irrigation. The simulations were done with a soil moisture balance running on a daily scale and precipitation and PET data from Aurangabad.

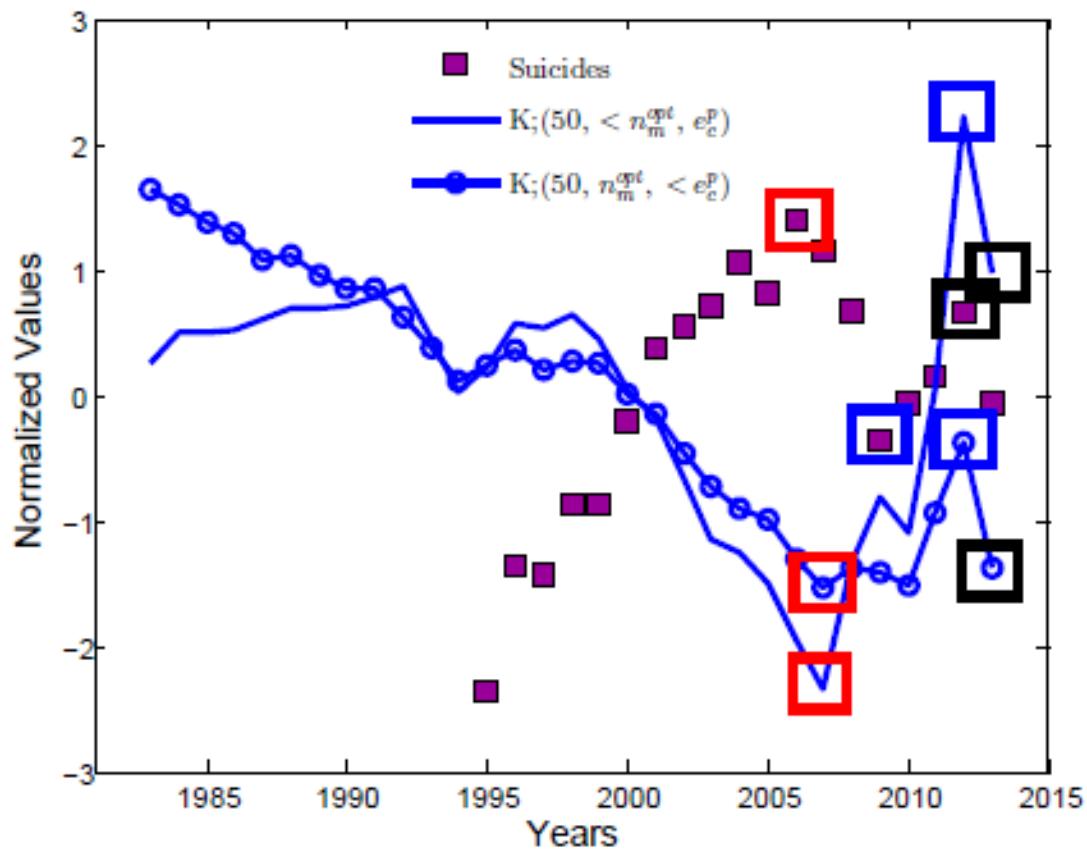


Figure A.3: The graph here displays two smallholder situations compared to suicide deaths in Maharashtra from 1995-2013, on a normalized axis. The graph tries to analyse whether the two peaks in suicide rates can be explained by the simulations. As one can see, the first peak coincides with a dip in the capital of these two farmers, however the second peak does not coincide, or there might be a delay of some kind.

B

The questionnaire

Questionnaire smallholder farming

Name interviewer:

Date:

Interview number:.....

Village name:.....

PART I. Household characteristics

1. Note gender of the interviewee 0 Female 1 Male
2. What is your age?
3. Are you the head of the family? 0 Yes 1 No
4. How many children do you have? B(oy)s G(irl)s
5. Did you follow education? 0 Yes 1 No
If yes, specify.....
6. How many livestock do you have? 0 None
.....
7. Since how many years do you practice farming? #
8. What legal land rights do you have? Landowner
 Land lease
 Other,
9. On how many acres do you produce crops? ha cropland
10. How much of the production is used for own consumption?
(on average) All / Half / Quarter/None
code: 1/0,5/0,25/0

PART II. Theme questions

PRODUCTION CHARACTERISTICS:

11. Do you have access to irrigation? **0** Yes **1** No

If Yes continue with questions. If No, move to capital characteristics

12. What is your main source of irrigation water?

| Season | Main source (see options beneath) | Distance to source (in km) |
|-------------------|--|---|
| Wet season | | |
| Dry season | | |

Options main source of irrigation water:

01 = piped water (specify) 04 = Other

02 = protected well

03 = canal

13. Do you receive any subsidies to irrigate? Or do you have to pay?

0 Yes **1** No

CAPITAL CHARACTERISTICS:

14. Is agriculture your main source of income? **0**Yes **1**No ,.....

15. What is the order of expenditure cuts you undertake when you have a negative end balance?

e.g. Selling off livestock, investment, school fees, interest payment on loans, tax on agricultural income, livestock costs, fertilizer costs, livestock cost and crop production labor.

1.
2.
3.
4.
5.
6.
7.

16. What assets do you own?

a. Radio **0** Yes **1** No

b. Mobile telephone **0** Yes **1** No

- c. Landline telephone **0** Yes **1** No
- d. Bicycle **0** Yes **1** No
- e. Vehicle **0** Yes **1** No
- f. Television **0** Yes **1** No
- g. Other,

17. Alternative off-farm employment options:

- a. Are there any off-farm labor alternatives in your vicinity?

0 Yes **1** No

- b. Do you make use of them regularly?

0 Yes **1** No

- c. Under what on-farm circumstances do you switch to these alternative employment options?

.....

18. Do you have any loans at the moment?

(for what are they used)

0 Yes, **1** No

If yes, specify.....

.....

19. Are credits easily accessible to you?

0 Yes **1** No

Specify.....

.....

20. Do you receive subsidies?

0 Yes **1** No

If yes, specify.....

.....

21. How far away is the nearest market?

..... km

This questionnaire was provided by Agrowon and the database with answers to the following questions were given.

आत्महत्या केलेल्या शेतकऱ्यांचा तपशील

१. आत्महत्या केलेल्या शेतकऱ्याची माहिती : **Questions about name, age etc.**

नाव : _____ वय : _____
पत्ता : _____

२. एकूण जमीन : **Question about acre size**

३. एकूण कर्ज : **Question about loan height**

४. कर्जाचे स्रोत : शासकीय बँक, खासगी बँक, सावकारी कर्ज, इतर **Question about source of loan**

५. कर्जाचा तपशील : **If children had to leave school after death of family member**

२) कुटुंबाची माहिती : **Question if anyone was in service**

| | नाव | शिक्षण | वय | आत्महत्या कारणान्याशी नाते |
|----|-----|--------|----|----------------------------|
| १. | | | | |
| २. | | | | |
| ३. | | | | |
| ४. | | | | |
| ५. | | | | |
| ६. | | | | |

३. अशिक्षित किंवा मुलांनी चालू शिक्षण सोडले असल्यास कारण : **Other source of income**

If reported by the police?

४. कुटुंबातील सदस्य खासगी किंवा सरकारी नोकरीस आहे का? होय नाही,
असल्यास त्यासंबंधी थोडक्यात माहिती : _____

५. कुटुंबातील इतर काही उत्पन्नाची साधने : आहे नाही
असल्यास त्याविषयी थोडक्यात माहिती : _____

६. आत्महत्येबाबत पोलिस पंचनाम्याची प्रत्यक्ष नोंद आहे का? होय नाही

७. आत्महत्याग्रस्त शेतकऱ्याची प्रत्यक्ष माहिती : _____

८. पिडित कुटुंबाची माहिती देणाऱ्याचे नाव : **Some final notes.**

बातमीदाराचे नाव : _____

पत्ता : _____ मो. नं. : _____

सर्व्हेचे ठिकाण : _____ दिनांक : _____

MARATHAWADA TOTAL.

| वय | शेती | | कर्म | | कोणाचे कर्म | | शिक्षण सोले | | कोणाला नोकरी | | इतर उत्पन्न | | पोलिस नोंद | | | | | | |
|----------|--------|-------------|--------|-----|-------------|--------|-------------|--------|--------------|-------------|-------------|--------|------------|--------|-----|-------------|--------|------|-------------------|
| | पर्याय | Q-1 शेती | पर्याय | Q-2 | कर्म | पर्याय | Q-3 | पर्याय | Q-4 | कोणाचे कर्म | Q-5 | पर्याय | Q-6 | पर्याय | Q-7 | साधन आहे का | पर्याय | Q-8 | पोलिस नोंद आहे का |
| 15-20 | A | 14 0-1 AC | A | 155 | 0-50 K | A | 394 | A | 444 | banker | Y | 107 | Y | 38 | Y | 36 | Y | 1036 | Y |
| 21-25 | B | 80 1-1.5 | B | 128 | 51-1 LAC | B | 255 | B | 126 | | N | 959 | N | 1028 | N | 1030 | N | 30 | N |
| 26-30 | C | 115 1.5-2.5 | C | 208 | 1-1.50 | C | 92 | C | 66 | | | | | | | | | | |
| 31-35 | D | 176 2.5_5 | D | 321 | 1.51-2 | D | 91 | D | 123 | | | | | | | | | | |
| 35-40 | E | 163 5-7.5 | E | 117 | 2.1-2.5 | E | 24 | AB | 49 | | | | | | | | | | |
| 41-50 | F | 256 7.5_10 | F | 53 | 2.51-3 | F | 25 | AC | 48 | | | | | | | | | | |
| 51-60 | G | 170 10_12.5 | G | 22 | 3.1-3.5 | G | 14 | AD | 29 | | | | | | | | | | |
| 61-70 | H | 83 12.5_15 | H | 16 | 3.51-4 | H | 15 | ABC | 9 | | | | | | | | | | |
| 71 above | I | 9 15_17.5 | I | 6 | 4.1-4.5 | I | 7 | ABD | 7 | | | | | | | | | | |
| | | 17.5_20 | J | 6 | 4.51-5 | J | 12 | ACD | 2 | | | | | | | | | | |
| | | 20 above | K | 9 | 5.1-5.0 | K | 2 | BC | 25 | | | | | | | | | | |
| | | | | | 5.51-6 | L | 6 | BD | 12 | | | | | | | | | | |
| | | | | | 6.1-6.5 | M | 4 | BCD | 1 | | | | | | | | | | |
| | | | | | 6.51-7 | N | 3 | CA | 1 | | | | | | | | | | |
| | | | | | 7.1-7.5 | O | 2 | CD | 9 | | | | | | | | | | |
| | | | | | 7.51-8 | P | 1 | NP | 79 | | | | | | | | | | |
| | | | | | 8-9 | Q | 7 | | | | | | | | | | | | |
| | | | | | 9_10 | R | 1 | | | | | | | | | | | | |
| | | | | | 10 above | S | 3 | | | | | | | | | | | | |
| | | NA | NA | 2 | NO LOAN | NP- | 106 | | | | | | | | | | | | |

any body in service reported by police
 & ave school edu
 other income source

C

Parameters

C.1. Crop factors

The crop factors in Table C.1 were used for the simulations.

Table C.1: This table gives the crop factors used for each month

| | Sugarcane | Soyabean | Cotton | Sorghum | Peas (green gram) | Grass |
|-----------|-----------|----------|--------|---------|-------------------|-------|
| Januari | 1.05 | 0 | 0 | 0 | 0 | 0.75 |
| Februari | 1.05 | 0 | 0 | 0 | 0 | 0.75 |
| Maart | 1.05 | 0 | 0 | 0 | 0 | 0.75 |
| April | 1.05 | 0 | 0 | 0 | 0 | 0.75 |
| Mei | 0.8 | 0 | 0 | 0 | 0 | 0.75 |
| Juni | 0.6 | 0.5 | 0.4 | 0.7 | 0.5 | 0.75 |
| Juli | 0.6 | 0.8 | 0.7 | 0.95 | 0.725 | 0.75 |
| Augustus | 0.85 | 1.15 | 1.05 | 1.2 | 1.15 | 0.75 |
| September | 1 | 1.15 | 0.8 | 1.05 | 1.1 | 0.75 |
| Oktober | 1 | 0.5 | 0.8 | 0 | 0 | 0.75 |
| November | 1.05 | 0 | 0.8 | 0 | 0 | 0.75 |
| December | 1.05 | 0 | 0.65 | 0 | 0 | 0.75 |
| sources | FAO | FAO | Pande | FAO | FAO | FAO |

C.2. Parameters for comparative assessment

The comparative assessment was performed over the regions Marathwada and Desh. Different input data was used for the simulations in the different districts. In Table C.2 one can find the calculation of different soil storages. Meteorological products used, are described in the methodology. Crop specific parameters use can be found in Table C.3. The same crop factors are used as described above. The simulations were done for un-irrigated conditions and fertilizer use was applied according to fertilizer use found in literature of the region.

C.3. Parameters for historical assessment

The same parameters as in the comparative assessment were used. These include crop factors, initial values and other crop related parameters. We manipulated the code such that the farmer shifts in 1992 from cereals

Table C.2: These soil storages were calculated with the help of the maps from (WRIS, 2016a) where you can calculate the percentages of different soil depths in different regions.

| MARATHWADA | Osmanabad | Aurangabad | Jalna | Nanded | Latur | Parbhani | Bid |
|-----------------------------------|-----------|------------|--------|--------|---------|----------|------|
| Average Soil Depth [m] | 0.24 | 0.72 | 0.78 | 0.54 | 0.17 | 0.70 | 0.32 |
| AWSC [mm/m] | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Estimated soil water storage [mm] | 48 | 145 | 155 | 108 | 34 | 140 | 64 |
| DESH | Kolhapur | Pune | Sangli | Satara | Solapur | | |
| Average Soil Depth [m] | 0.49 | 0.44 | 0.59 | 0.59 | 0.32 | | |
| AWSC [mm/m] | 200 | 200 | 200 | 200 | 200 | | |
| Estimated soil water storage [mm] | 98 | 88 | 118 | 118 | 64 | | |

Table C.3: This table presents some of the crop specific parameters used. All other parameters have remained as described by Pande and Savenije (2016).

| Parameter [unit] | Definition | Cotton | Sugarcane | Sorghum | Soyabean | Rice |
|----------------------------------|----------------------------|---------------|------------------|----------------|-----------------|-------------|
| y^{max} [kg/ha] | Optimal yield | {1000, 2500} | 10^5 | 2810 | 2371 | 2000 |
| K_y [-] | Specific yield coefficient | 0.85 | 1.2 | 0.9 | 0.85 | 1.1 |
| n_m^{opt} | Fertilizer application | 125 | 500 | 27 | 40 | 56.6 |
| $w(T)^1$ [₹/year] | Loan | 25000 | - | - | - | - |
| r_w [₹/₹] | Interest rate on loan | 0.35 | - | - | - | - |
| Initial conditions [unit] | | | | | | |
| S(0) [mm] | Soil moisture | 0 | 0 | 0 | 0 | 0 |
| K(0) [₹] | Capital | 90,000 | 90,000 | 90,000 | 90,000 | 90,000 |
| L(0) [amount] | Livestock | 2 | 2 | 2 | 2 | 2 |
| G(0) [kg] | Grass biomass | 6 | 0 | 0 | 0 | 0 |
| F(0) [kg] | Soil fertility | 500 | 0 | 0 | 0 | 0 |
| All other parameters | Pande and Savenije (2016) | | | | | |

to another crop. We did use multiple sources for the crop prices, as there is no consistent dataset available for the crops under study. Additional prices were retrieved from VDSA (2011), as explained in the methodology.

C.4. Crop growth parameters

C.4.1. Initial canopy size and Canopy growth coefficient

In the methodology we describe the crop growth development with the following two equations:

$$C = C_0 \exp^{dG} \quad (C.1)$$

$$C = C_{max} - 0.25 \frac{(C_{max})^2}{C_0} \exp^{-dG} \quad (C.2)$$

Where:

C is canopy cover at time t [fraction ground cover]

C_0 is the initial canopy size at $t=0$ [fraction ground cover]

C_{max} is the maximum canopy cover [fraction ground cover]

d is the day of the growing season [day or growing degree day]

G is the canopy growth coefficient [increase of fraction ground cover per day or growing degree day]

These equations are obtained from Aquacrop and try to incorporate the effect of soil moisture deficit on the crop growth. The crop growth development model needs a few parameters in order to start the calculations. These parameters are crop specific and need to be calculated accordingly. To obtain the right parameters for the crop growth formulas for cotton the following steps were undertaken.

From the Aquacrop calculation manual we know that at the end of the crop development $C = 0.98C_{max}$ and the maximum canopy cover under optimal conditions is 1 (for cotton after 80 days). If we incorporate this knowledge into Equation C.2 we get:

$$-0.02 = \frac{-0.25}{C_0} \exp^{-dG} \quad (C.3)$$

$$\frac{2}{25} C_0 = \exp^{-dG} \quad (C.4)$$

C_0 and G remain unknown, however we still have Equation C.1 and from FAO's description we know that at the beginning of the crop development (for cotton after 30 days) the $C = 0.1$. If we substitute C_0 in Equation C.4 with the right growing degree days that are specific for cotton, we get:

$$\frac{2}{25} 0.1 \exp^{-30G} = \exp^{-80G} \quad (C.5)$$

$$\frac{0.2}{25} = \exp^{-50G} \quad (C.6)$$

$$\ln \frac{250}{2} = -50G \quad (C.7)$$

$$\ln \frac{250}{2} = 50G \quad (C.8)$$

$$G = \frac{1}{50} \ln \frac{250}{2} = 0.097 \quad (C.9)$$

So now we have a value for the canopy growth coefficient G for cotton, that will get affected by a soil moisture deficit as explained in chapter 2. Now we can fill in the values in Equation C.1 to obtain the right value for C_0 .

$$C_0 = 0.1 \exp^{-300.097} = 0.0055 \quad (C.10)$$

C.4.2. Remaining parameters

[tbph]

Table C.4: These are the remaining parameters that were used to calculate the crop growth development. Most parameters are obtained from FAO's Aquacrop model.

| Parameter | Value | Unit | Explanation |
|----------------------------|-------|------------------------|---|
| Plant date | 158 | Day of the year | - |
| Initial stage | 30 | days | - |
| End crop development stage | 80 | days | - |
| Field capacity | 49 | % of available storage | http://jocpr.com/vol8-iss1-2016/JCPR-2016-8-1-153-160.pdf |
| Wilting point | 3.9 | % of available storage | http://jocpr.com/vol8-iss1-2016/JCPR-2016-8-1-153-160.pdf |
| p_{lower} | 0.2 | [-] | Soil water depletion threshold for canopy expansion, lower threshold. |
| p_{upper} | 0.7 | [-] | Soil water depletion threshold for canopy expansion, upper threshold. |
| Water productivity | 1.5 | kg/ha and per mm | - |
| Harvest Index | 30 | % of total yield | - |
| Soil evaporation factor | 0.6 | [-] | - |
| $D_{t,T}$ | 2 | mm/day | Interception threshold |
| k | 3 | days | The maximum number of days during which field capacity can be exceeded after high infiltration rates Makurira et al. (2011). |

C.5. Adjustments pan evaporation

As the pan evaporation showed overestimations, the daily values were adjusted with the help of satellite data from Zomer et al. (2008). To maintain the daily variance recorded by the weather station, the pan evaporation was multiplied by the fraction of $\frac{P_{anevaporation}[mm/month]}{P_{otentialevaporation}[mm/month]}$ for every day in every corresponding month. Such that the total pan evaporation does not exceed the total potential evaporation per month observed by the satellite product. This resulting evaporation is used as a "reference evaporation" for the daily calculations in the simulations.

C.6. Elaboration discussion

As was explained in the methodology the crop development is approximated with an exponential growth and an exponential decay function, see equation 2.10 and 2.11. The G is the canopy growth coefficient [day^{-1}] determines the development of the growth function and can be adjusted by experienced water stress. The water stress is currently the only factor influencing the function, hence responding heavily on water stresses. Also, the relation between soil moisture status and water stress factor influencing the canopy growth coefficient might be adjusted to concave instead of linear to create a more realistic growth curve. The latter was also noted by Farahani et al. (2009) when they tried to parameterize Aquacrop to cotton development in Northern Syria.

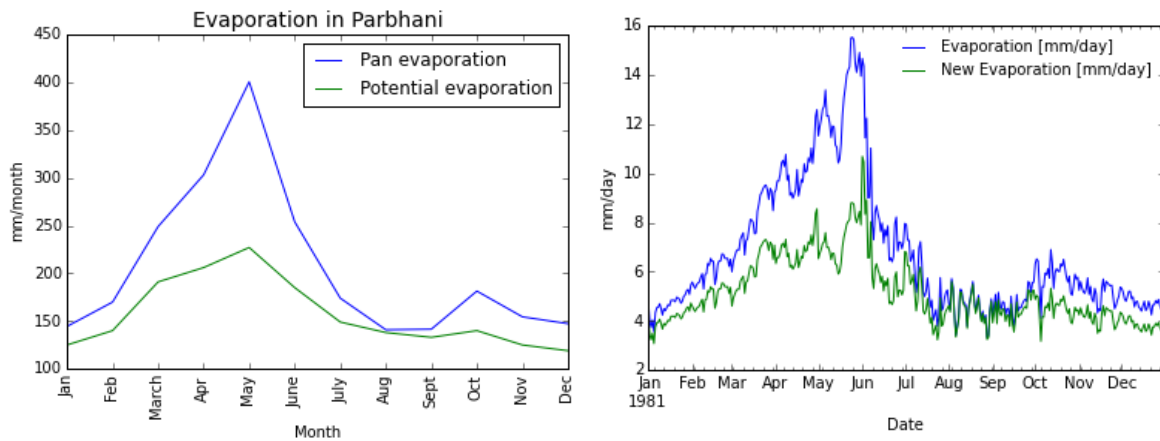


Figure C.1: The left graph shows the difference between average potential evaporation obtained from Zomer et al. (2008) and pan evaporation from a weather station at the University campus in Parbhani. The pan evaporation is overestimated and is therefore adjusted. The satellite product used is per month, whereas the pan evaporation recorded daily values. The result of these adjustments can be seen in the right graph, new evaporation.

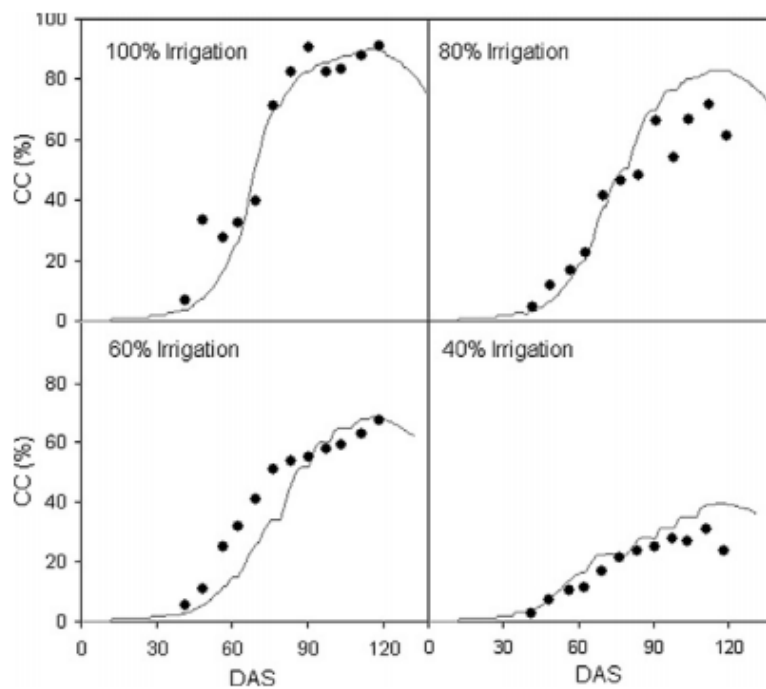


Fig. 3. Measured and simulated canopy cover (CC) under four irrigation treatments in 2006. DAS is days after sowing.

Figure C.2: This graph shows one of the graphs presented by Farahani et al. (2009). Under non-optimal conditions there is a significant yield reduction. The canopy cover does not even cross 40 percent. A similar reduction to optimal conditions for Marathwada was also applied to estimate fraction-wise the effect of non-optimal conditions on yield. This was done to make a comparison for the simulations already done, so that the interpretation of the results are legitimate.

D

Dry spell analysis

Beneath are the steps undertaken to make the dry spell analysis. The dry spell analysis is done over three months: June, July and August, and comprises 92 days. These months are very determining for the success of the smallholders: most farmers start sowing their crops in June and the determining crop development happens in the first months after. The following explanation is based on the lecture notes of Savenije (2006).

First we need to find the number of days within the chosen length (in this case 92 days) on which a dry spell of duration t can start:

$$n = 92 + 1 - t \quad (\text{D.1})$$

The total number of starting days is:

$$N = n \times T \quad (\text{D.2})$$

Where:

N number of starting days

n number of days on which a dry spell of duration t can start

T the length of the rainfall dataset [years]

the probability that a dry spell starts on a certain day within the season is defined by:

$$p = \frac{I}{N} \quad (\text{D.3})$$

The probability q that a dry spell of a duration longer than t does occur at a certain day in the season:

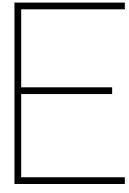
$$q = 1 - \frac{I}{N} \quad (\text{D.4})$$

The probability Q that a dry spell of duration longer than t does not occur during an entire season:

$$Q = \left(\frac{I}{N}\right)^n \quad (\text{D.5})$$

The probability P that a dry spell of a duration longer than t does occur at least once in a growing season:

$$P = 1 - \left(\frac{I}{N}\right)^n \quad (\text{D.6})$$

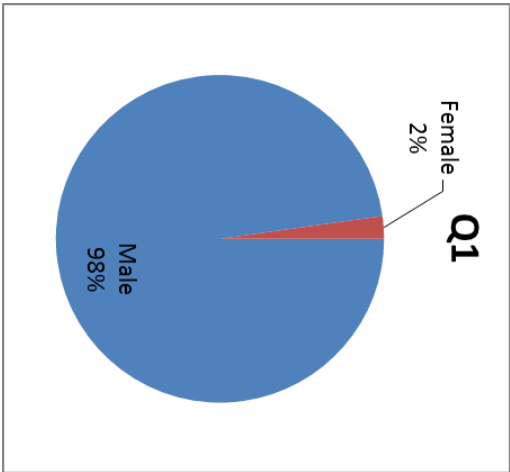


Outcome surveys

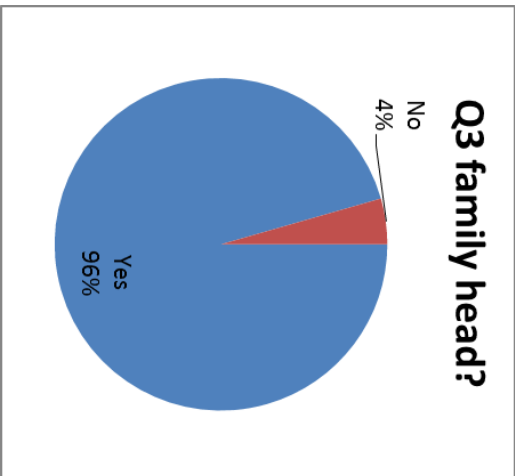
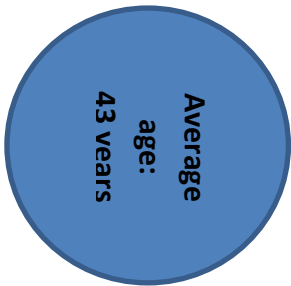
E.1. Outcome survey farmers Marathwada

SMALLHOLDER SURVEY OUTCOMES

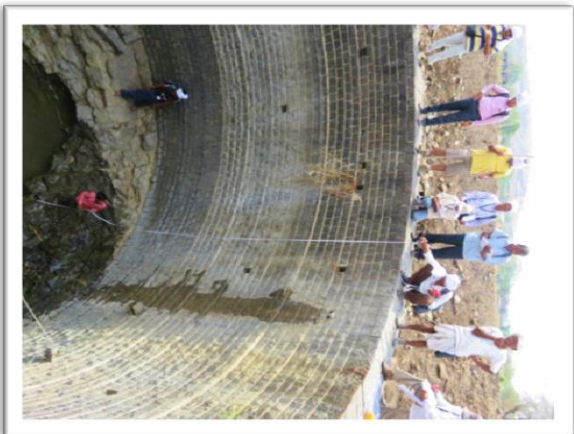
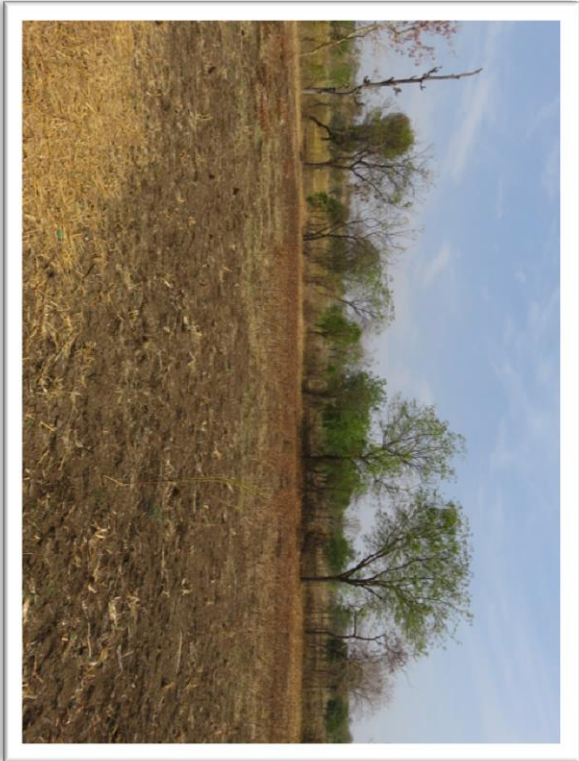
- Total interviewees: 45
- Six different villages throughout Marathwada

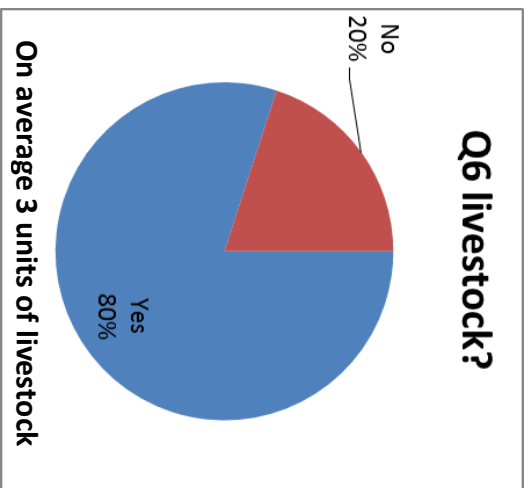
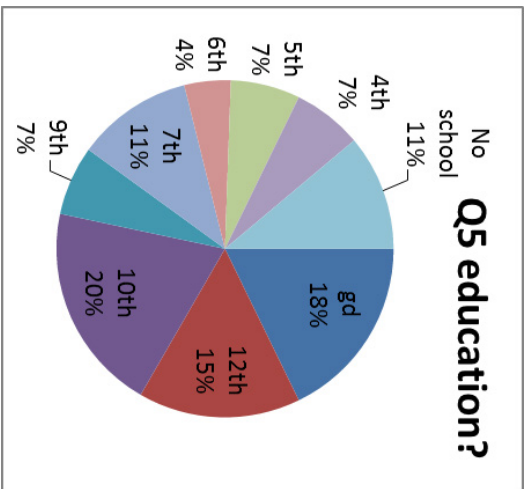
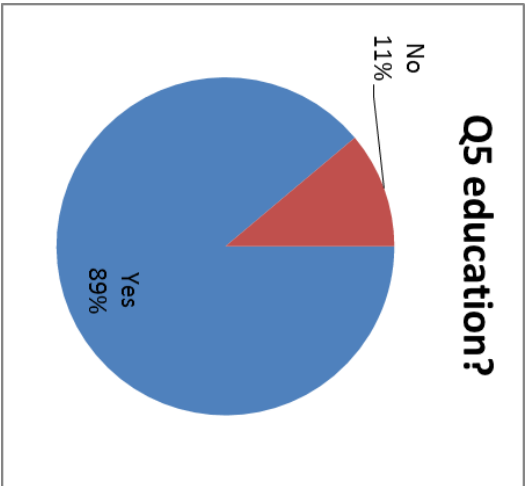


Q2: age?



Q2: children?

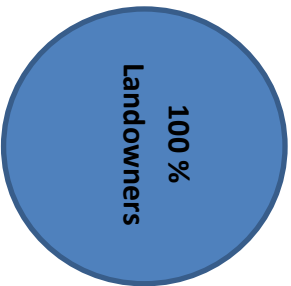




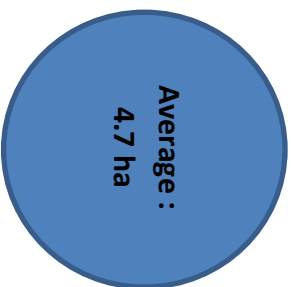
Q7: experience?



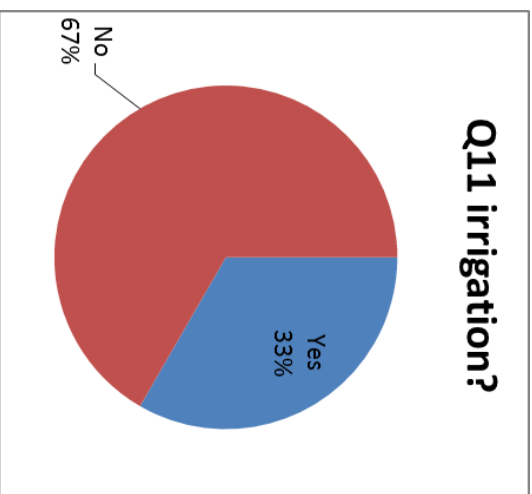
Q8: land rights?



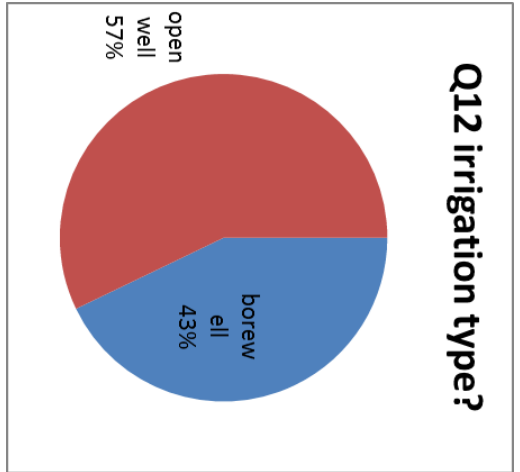
Q9: holding size?



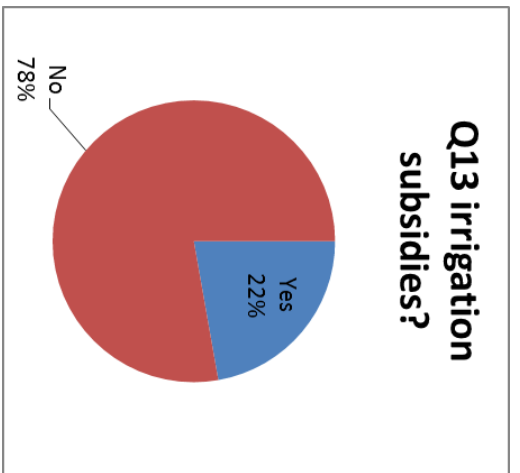
Q10: consumption?



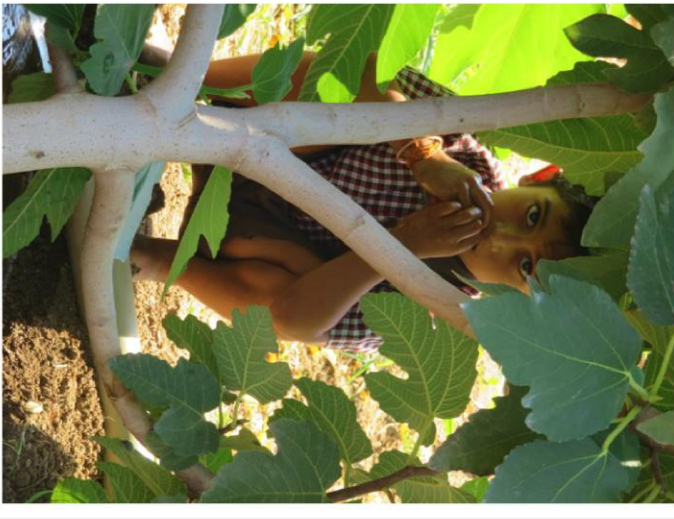
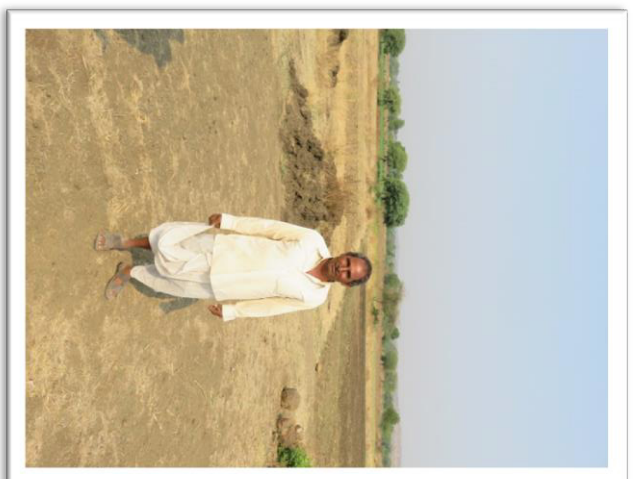
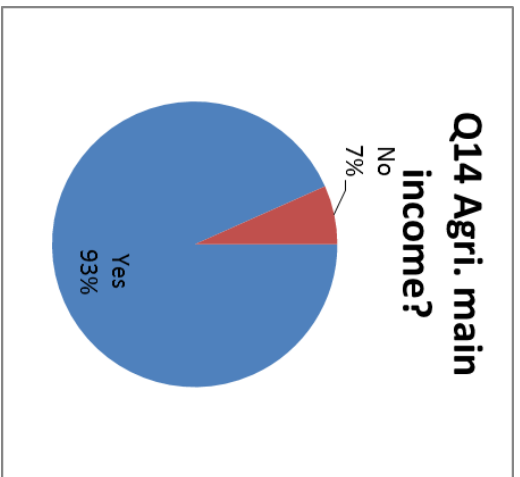
Q12 irrigation type?



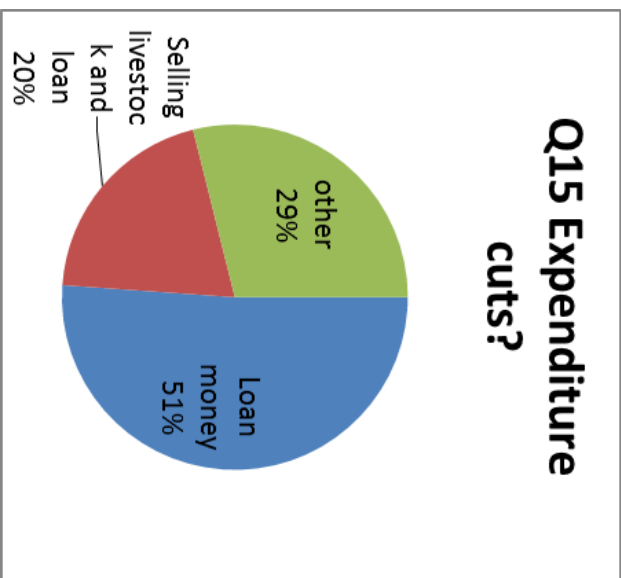
Q13 irrigation subsidies?



Q14 Agri. main income?

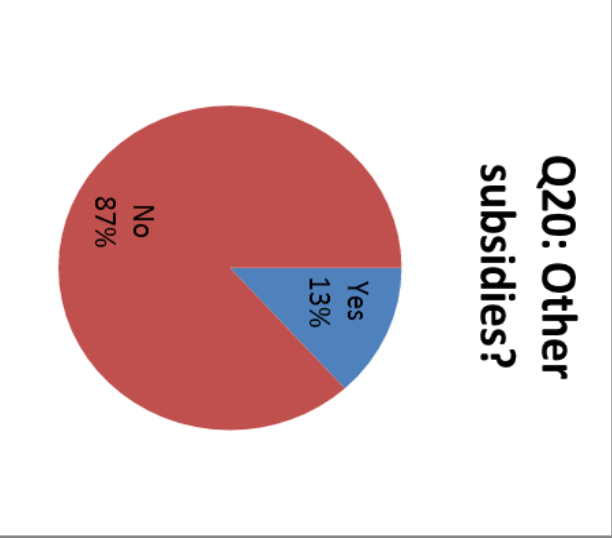
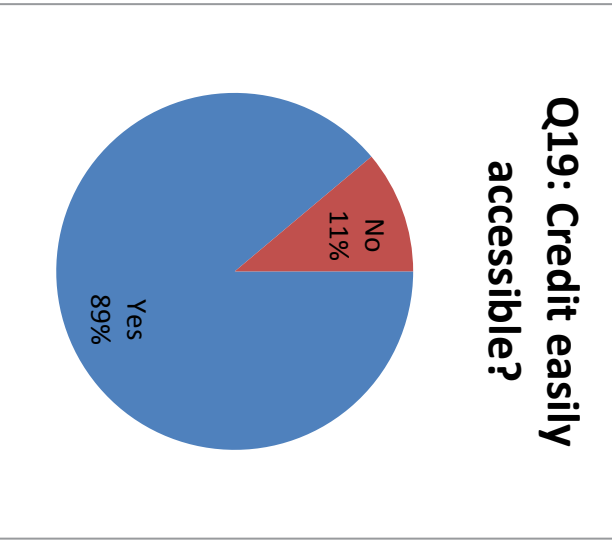
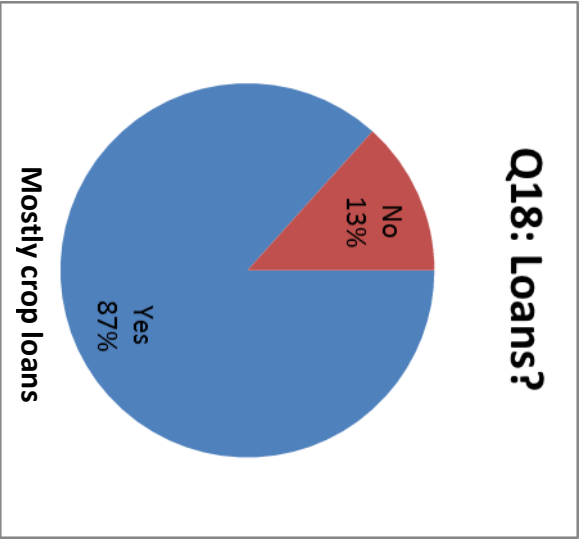
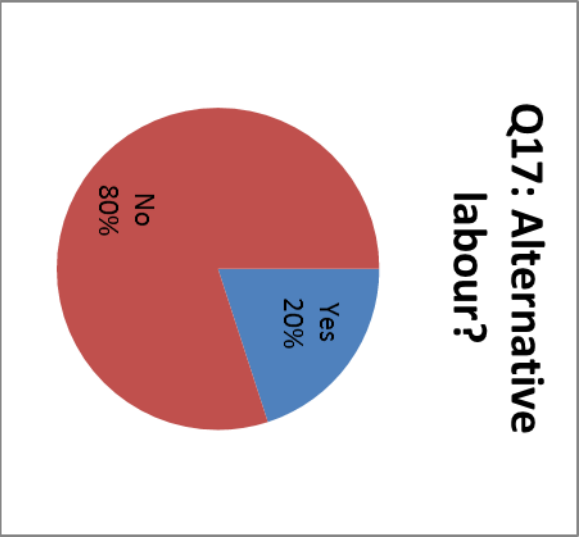


Q15 Expenditure cuts?



Q16: Assets owned?

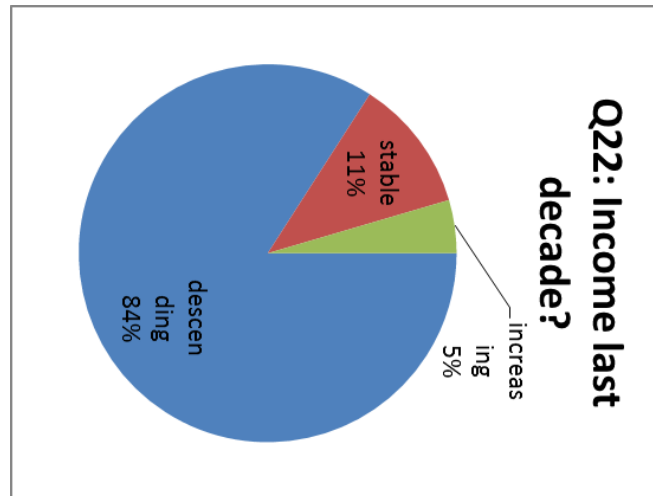
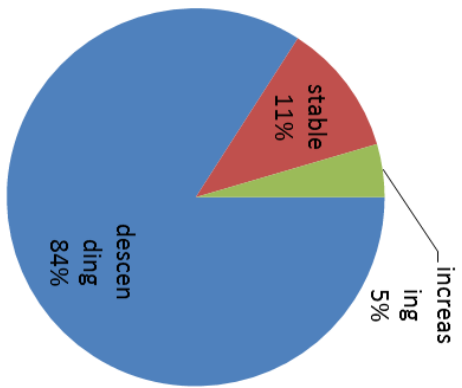
| | | |
|----------------------------------|-------|-------|
| a. Radio | Y: 16 | N: 29 |
| b. Mobile | Y: 42 | N: 3 |
| c. Landline | Y: 18 | N: 27 |
| d. Bicycle | Y: 18 | N: 27 |
| e. Vehicle (e.g. scooter) | Y: 20 | N: 25 |
| f. Television | Y: 34 | N: 11 |
| g. Tractor | Y: 6 | N: 39 |



Q21: market distance?



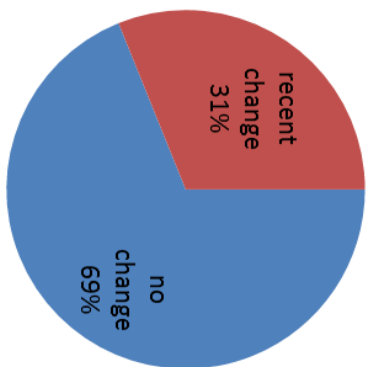
Q22: Income last decade?



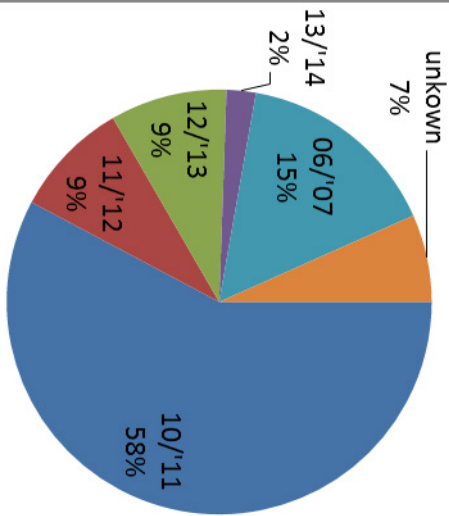
Q23: cropping pattern?



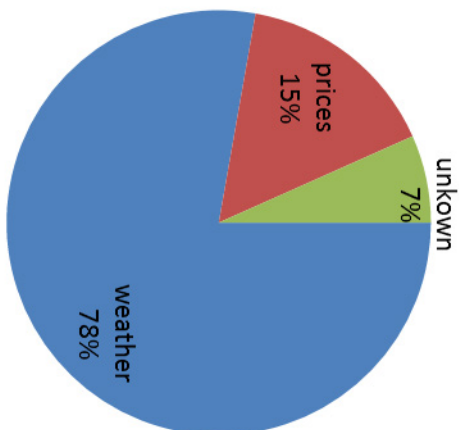
Q24: Cropping pattern change?



Q25: Good year?



Q25: Why?



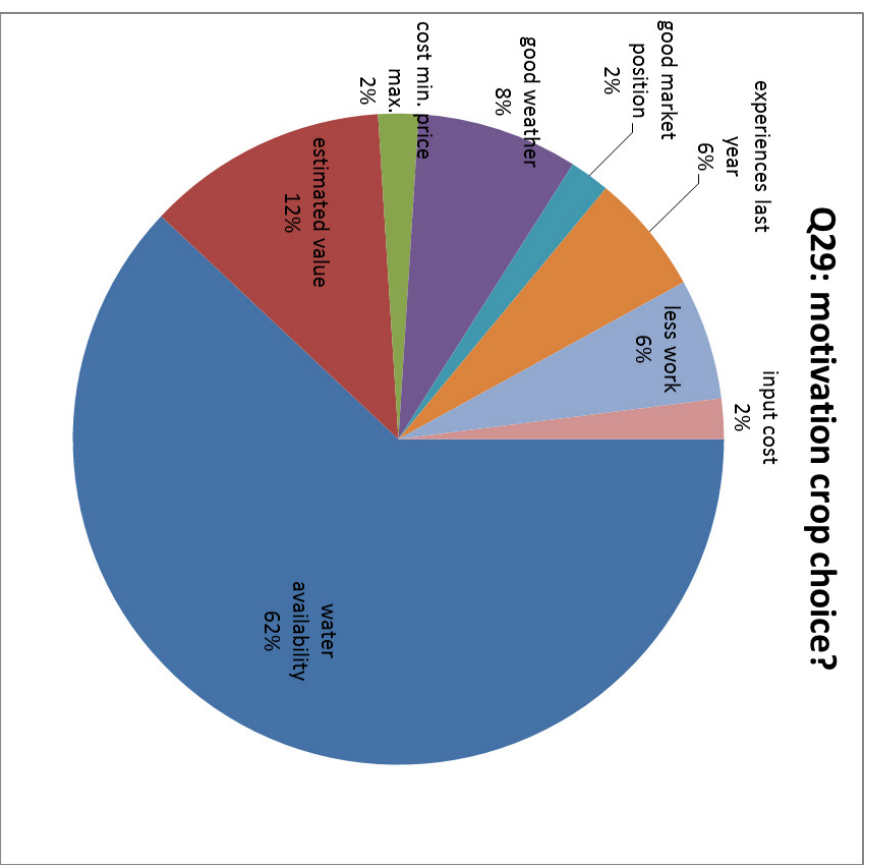
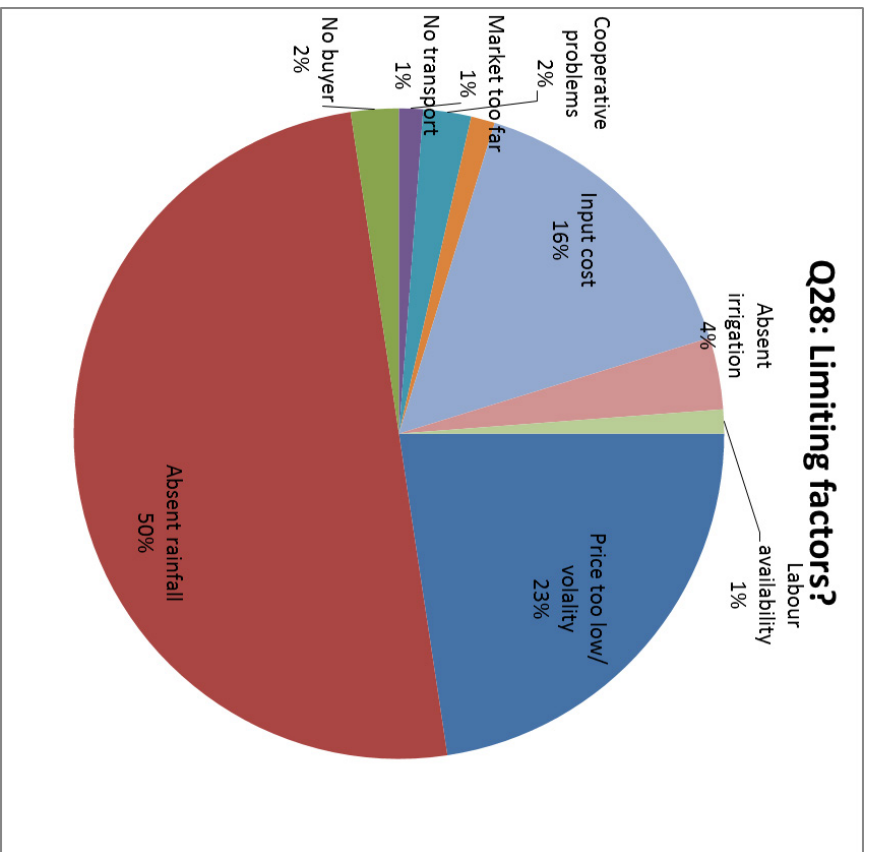
Q26: Bad year? And why?

All farmers agreed on that the last two years were the worst years so far, because of the drought.

Q27: Sequence of risky crops?

All farmers identify cash crops as most risky, than pulses, than cereals. And in a few cases farmers observe pulses as less risky.





Notes/remarks

- Cash crop requires less labor
- Moneylending is a problem and sensitive subject
- People prefer sugarcane if water is available
- Farmers do not feel supported by the government

- Some incident with corruption in seed trade and credit
- The severely distressed farmer sells off his land
- Farmers are aware of the risks of growing cash crops, but see no alternative!
- Soil depth is not limiting

I was also interviewed during my visit in Ellora. The locals became increasingly more interested in what this white girl was doing in their fields. The interviewer did not speak english very well so it was a tough conversation. During the interview I mentioned that sugarcane should not be stimulated in this region and their governments should encourage rainwater harvesting, in stead of endlessly tapping groundwater...

संमिश्र

दुष्काली अभ्यास दौरा

एनजीओच्या माध्यमातून मराठवाड्याच्या मदतीसाठी पुढाकार

मराठवाड्यात बोअरवेलसह उसाच्या पिकावर बंदी हवी

प्रतिनिधी | वेरूळ

मराठवाड्यात तीन ते चार वर्षांपासून पाऊस कमी पडत आहे. त्यामुळे पाणीपातळी खालावली असून यास आपणही मोठ्या प्रमाणावर जबाबदार असल्याचे मत नेदरलँड येथील विद्यार्थिनी नाजा यांनी व्यक्त केले. त्यांनी मराठवाड्यातील दुष्काली भाग असलेल्या लातूर, नांदेड व परभणीचा दौरा करून पाण्याच्या नियोजनाविषयी अभ्यास केला. यात मराठवाड्यात बोअरवेलसह ऊस या पिकावर पूर्णतः बंदी घालावी, असेही त्यांनी सुचवले आहे. गुरुवारपासून त्यांनी वेरूळ परिसरात पाहणी सुरू केली असून विविध ठिकाणच्या पाण्याच्या स्रोताविषयी जाणून घेतले. दरम्यान, प्रतिनिधीने त्यांच्याशी संपर्क साधला असता त्यांनी आपले मत मांडले.

नाजा डेन बेस्टन (२५) या नेदरलँड येथील असून डेल्स युनिव्हर्सिटी ऑफ टेक्नॉलॉजी विद्यापीठामध्ये वॉटर मॅनेजमेंट या विषयावर पोस्ट ग्रेज्युएट करीत आहेत. पाणी व्यवस्थापनात कामाची आवड असल्याने त्यांना मूळ भारतीय दिल्ली येथील रहिवासी असलेले, पण सध्या नेदरलँड येथे प्रोफेसर असलेले संकेत पांडे यांच्याशी त्यांनी विचारविमर्श केला. त्यांच्या वाचनात मराठवाड्याचा अग्रलेख



वेरूळच्या विहिरीच्या पाण्याच्या परिस्थितीची पाहणी करताना विद्यार्थिनी.

आल्याने येथील पाणी प्रश्नावर अभ्यास करून येथील नागरिकांना काय मदत करता येईल यासाठी त्यांनी २० फेब्रुवारीपासून मराठवाड्यातील कटकळंबा (नांदेड), लातूर, परभणी या परिसरास भेट देत पाहणी केली. आता त्या वेरूळ परिसरात अभ्यासासाठी आल्या असून त्यांनी गुरुवारी वेरूळ येथील येळगंगा नदी, परिसरातील विहिरी, श्रीसंत जनार्दन स्वामी आश्रम परिसराची पाहणी करीत श्री श्री १००८ महामंडलेश्वर स्वामी शांतीगिरी महाराज यांच्याशी पाणीप्रश्नावर चर्चा केली. नाजा यांना शेख सादिक शेख

युनुस हे परिसराची माहिती देत आहेत. याआधी नाजा यांनी रशियामध्ये एक वर्ष विविध समस्यांवर काम करीत सेवाभावी संस्थांच्या माध्यमातून मदत उपलब्ध करून दिली आहे.

नाजा यांनी 'दिव्य मराठी'शी बोलताना सांगितले की, मी जेव्हा मराठवाड्याची चर्चा केली. त्या वेळी पाण्याची बिकट परिस्थिती असल्याचे कळले. त्या मुळे देश-विदेशातून येणारे लोकही येथे येण्यास कचरतात. येथे काय मदत करता येईल, याकरिता अभ्यास म्हणून मी भेट दिली. येथे खरोखरच बिकट परिस्थिती आहे. काही ठिकाणी

पंधरा दिवसांनंतर पिण्यास पाणी मिळत असल्याचे समजले. अनेक शेतांना भेटी दिल्या असता श्रीमंत लोक खोलवर बोअरवेल घेऊन उसासारखे पीक घेत असल्याचे आढळले. गरिबांच्या विहिरींना पाणी नाही. सध्या पर्जन्य कमी असल्याने पाणीपातळी खालावत असून बोअरवेल यास जादा प्रमाणात कारणीभूत असल्याने मराठवाड्यात बोअरवेलसह उसाचे पीक घेण्यावर पूर्णतः बंदी घालावी. कापूस, सोयाबीन, द्राक्षे यांचेही प्रमाण कमी व्हावे. रेन वॉटर हार्वेस्टिंगचे प्रमाण वावे. पाणीपातळी वाढवण्यासाठी बोअरवेलद्वारे पावसाचे पाणी जमिनीत सोडावे.

नदी, नाले, ओढे यांचे खोलीकरण करणे. हे खोलीकरण करताना कमी उंचीचे बांधारे बांधणे, जेणेकरून पाणी वाहते राहिल. यालगतच्या शेतकऱ्यांनी आपल्या शेतात छोटी-छोटी तळी उभारावीत, जेणेकरून प्रवाहही थांबणार नाही व पाणीपातळी वाढेल असे सुचवले. मुख्यतः पाण्याचे स्रोत परिसरात प्लास्टिक बंदी हवी. सध्यातरी असे वाटत असून आणखी काही दिवस या विषयावर अभ्यास करून हा अभ्यासक्रम भारत देशासह नेदरलँड व इतर देशांतील सेवाभावी संस्थांना दाखवून मराठवाड्याच्या पाणीप्रश्नावर मदत करण्यासाठी प्रयत्न करणार असल्याचे सांगितले.

E.2. Summary Interview and Outcome survey Agrowon

The outcomes of Agrowon were given by two journalist (Niranjan Chhanwal and Ranjit Khandare) controlling the database of 1060 filled-in questionnaires. The outcomes were unfortunately not covering the hydrological situation of the farmers, but contained some interesting information about the farmers under distress in Marathwada. Almost all affected families in Marathwada were covered by the Agrowon's reporter network. The questionnaires were documented by 40 different reporters all over Marathwada. Beneath a summary of what Niranjan and Ranjit told me about the rural situation.

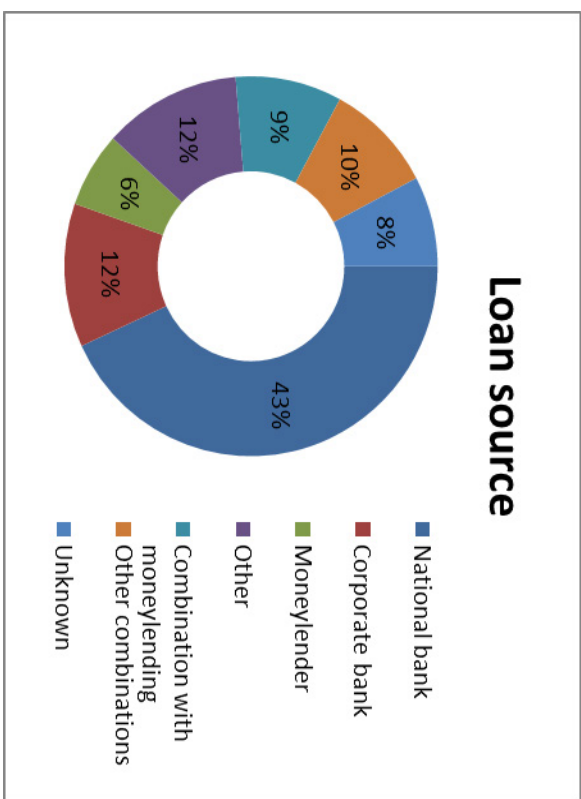
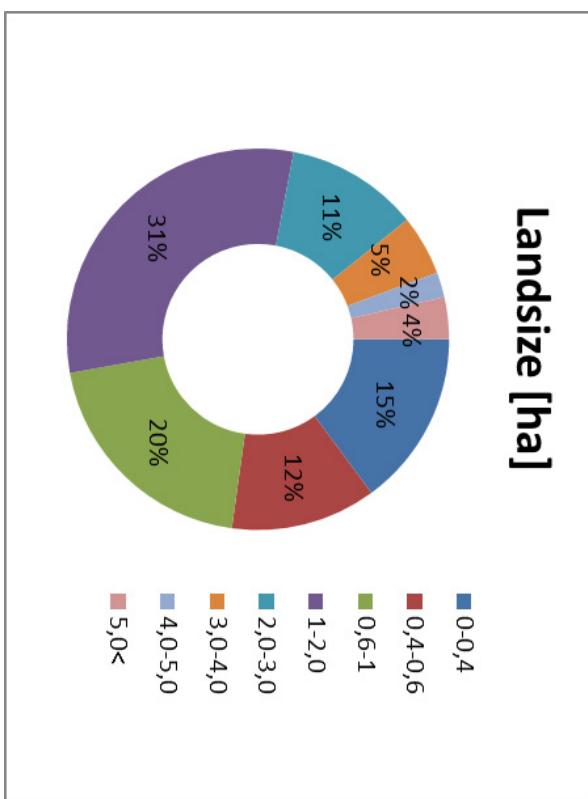
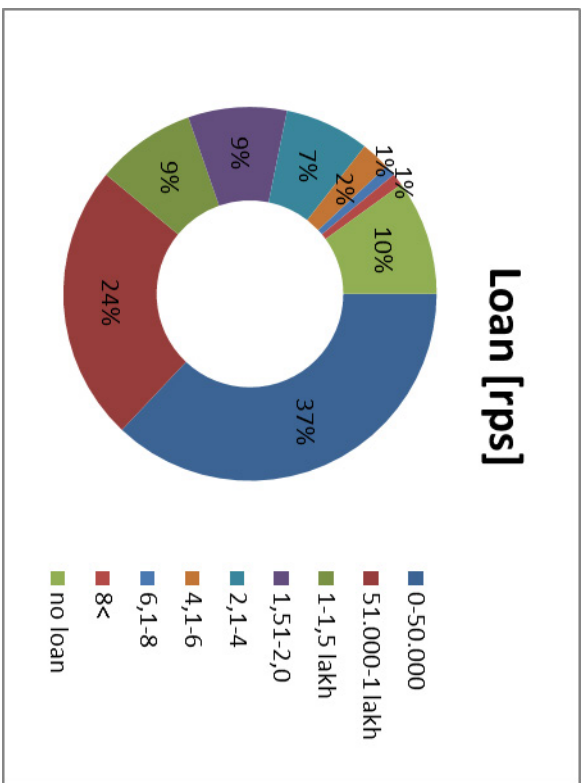
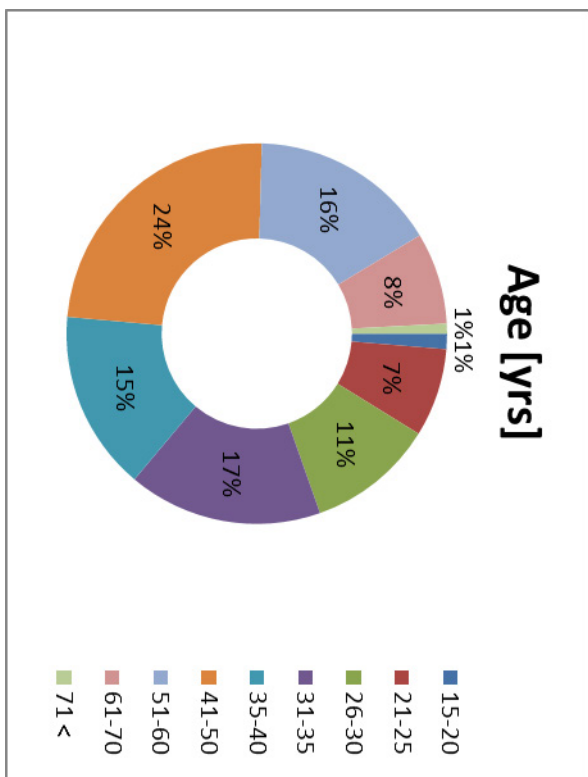
The reporters told me that the farmers that committed suicide can be assumed to have no access to irrigation. The farmer suicide story is a sensitive subject. The ruling party in the state is already there for ten year and did not directly have a beneficial effect on the farmers. In 2009 there was a loan clearance applied by the government, but this was not beneficial for the farmer, more for the banks that supplied the loans. It is currently not interesting for banks to create crop insurance to for farmers. This should be encouraged by the government. The interest rate with a corporate lays around 17-18 percent per year, while a moneylender can ask the same per month.

There are many factors bothering the livelihoods of farmers in Marathwada. No crop insurance, crop failures, no alternative income, pressure from moneylender or other debt sources. Even though abolished, there is still the problem of Dowry¹ which creates significant stress to a farmer's family. 50.000-1 lakh ₹ are not unusual Dowry-amounts, but a farmer's yearly income in a good rainy season lies only around 30-40.000 ₹.

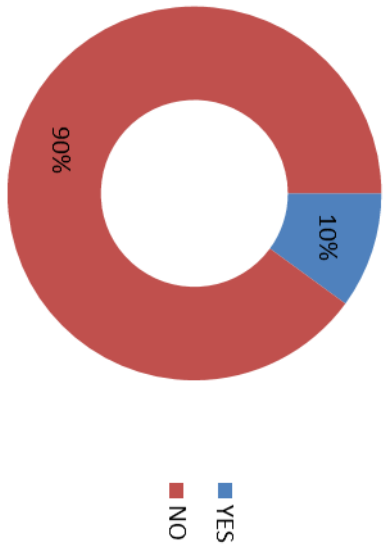
Because of the immediate need of money most farmers cannot stock their yields and need to sell immediately, even though the prices might not be preferable. The reporters explain that the governmental support is near to absent and most farmers are just left alone in their misery. Most farmers try to diversify to spread chances on yield. However, due to plots becoming smaller and smaller over the years, as inherits need to be divided over the family, there is not much diversifying possible.

Niranjan and Ranjit believe the solution lies in irrigation plans subsidized by the government that implements rainwater harvesting techniques. Crop insurance should also be improved. More water-tankers should be reached out to the rural inhabitants. Groundwater restoration should take place. They also mention one good thing: one of the ruling parties is setting up a place where 100-200 couples can get married together, which go without costs for the families. .

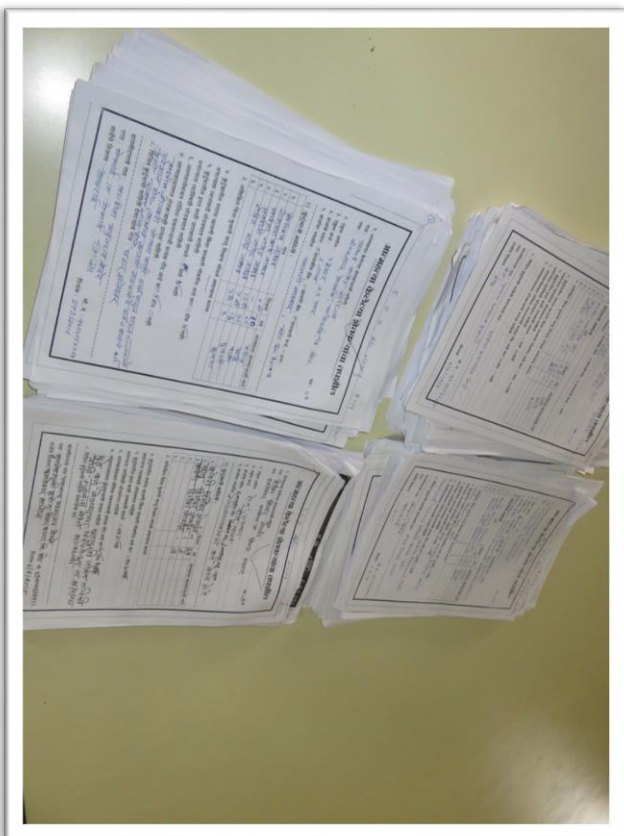
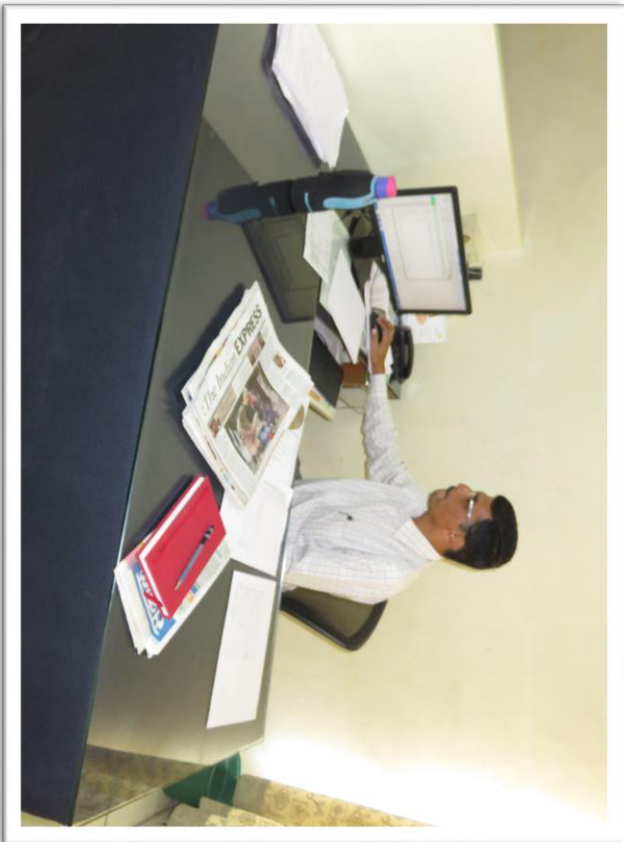
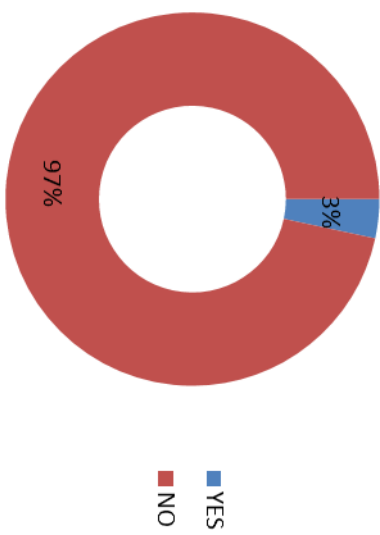
¹Dowry is a marriage settlement: an amount of money of property that should be given by the bride's family to the groom's family. Thus gives financial pressure to the bride's family.



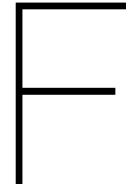
Children had to leave school?



Other income source?



These pictures were taken at Agrowon's office in Aurangabad. The left picture shows the managing journalist, controlling the data. On the right side the collected surveys conducted by Agrowons reporter network.



Success story

During a stop in Aurangabad, Marathwada I got the chance to go into the field with Madhuri Gavit and Prakash Chole, both working in the Dr Hedgewar hospital in Aurangabad. Good health care in Maharashtra is mostly available in private hospitals, communal hospitals are seldom able to give good health care. Therefore Dr. Hedgewar was founded by seven young doctors, end of the 1980s, to reach out to the (medical) needs of the (poor) rural people. They opened with help of donations and still function like this today, their expenses are covered by donations from society. Besides a blood bank and several centres and clinics, they also reach out to the farmer with their NGO "Savitribai Phule Mahila Ekatma Samaj Mandal". With this initiative projects are started relating to improving the water availability in poor rural areas in Aurangabad district. They do this by developing multiple watershed and micro-irrigation projects. Two examples are shortly described beneath.

The project Tushar Samruddhi in the villages Shelud and Chartha (district Aurangabad) started in 2013 and is almost ended. The project focused on Enhancement of 'agro based livelihood' through 'watershed plus' initiatives for irrigation and drinking water purposes. By redirecting runoff into reservoirs, deepening, obstructing and widening parts of the Dudhana River the rainwater is harvested in a natural way, Figure F.1 gives a few pictures from parts of the river. This project is half funded by the NGO fun and the other half by the government. A farmer living nearby the project shares his experiences:

"Myself Mr. Pandharinath raosaheb Chaudhari residing at Shelud Tq. and Dist. Aurangabad would like to share my experiences about my farming activities. I had only five acres of land. Due to drought I was able to cultivate only one acre of the land and remaining land was laying unused. Expenses for cultivation of one acre land was too high, literally I could not save even 10 thousand rupees after one season. Fertilizers, pesticides, labour, transport and unassured market prize were the big problems I was facing.

As soon as Tushar samruddhi project came in our village my life has changed. Due to deepening and widening of Dudhana River enough water was stored and percolated up to 700 meters around the banks of the river. Previously my tube well used to lift the water for only one hour but today it lifts water for six hour in a single day. The ground water table has increased drastically and we have enough surplus water in our farms. This year I started to cultivate Pomegranate in three acres of my land and bajra, maize and cotton in remaining three acres. I am getting 300-400 crates per acre. This gives me 5 to 6 Lakh rupees per year. This has changed my overall lifestyle. My children are going to good school where they can get quality education. They are getting good facilities. Today also I have enough water in my field due to that I could sow early before the arrival of monsoon." This story would be a complete success story if the farmer also produced sustainable crops for the region, but this can only be encouraged with the help of the government.

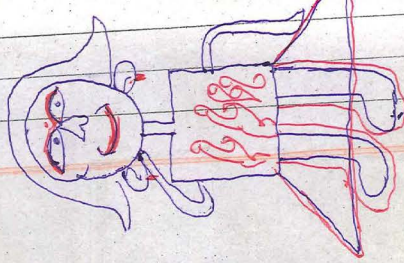
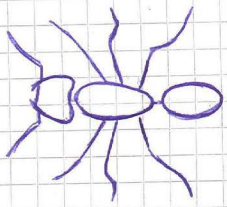
Another farmer story is from the village Donwada (Aurangabad district) where we met a farmer, Mr. Mukale, and his family. Mr. Mukale realized with the help of the NGO and other farmers in the village a large pond. The right picture of Figure F.2 shows the results of the realized farm pond by communal efforts. The water availability increased significantly, however these last two years were still hard, according to Mr. Mukale. Another positive notion to this story is that the Dr Hedgewar hospital also sponsored a life-threatening illness of one of his daughters. During the time of the drought she was under treatment, but thanks to this initiative she is now almost cured.



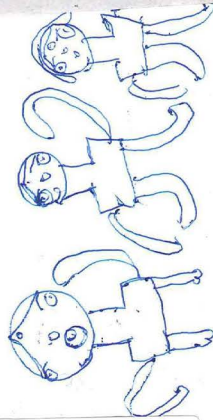
Figure E1: Pictures of some runoff interventions. Environmental flow was guaranteed, but a few changes were applied to the Dudhana River. Obstructions and deepening of the Dudhana River was realized, which resulted in significant enhancement of the water availability to local communities. Other runoff dispersion techniques also changed the situation. The pictures were taken by Prakash.



Figure E2: This pictures were taken in March 2016, while it is summer the reservoir still contains water. The left picture shows a local farmer, and family, in front of their house.



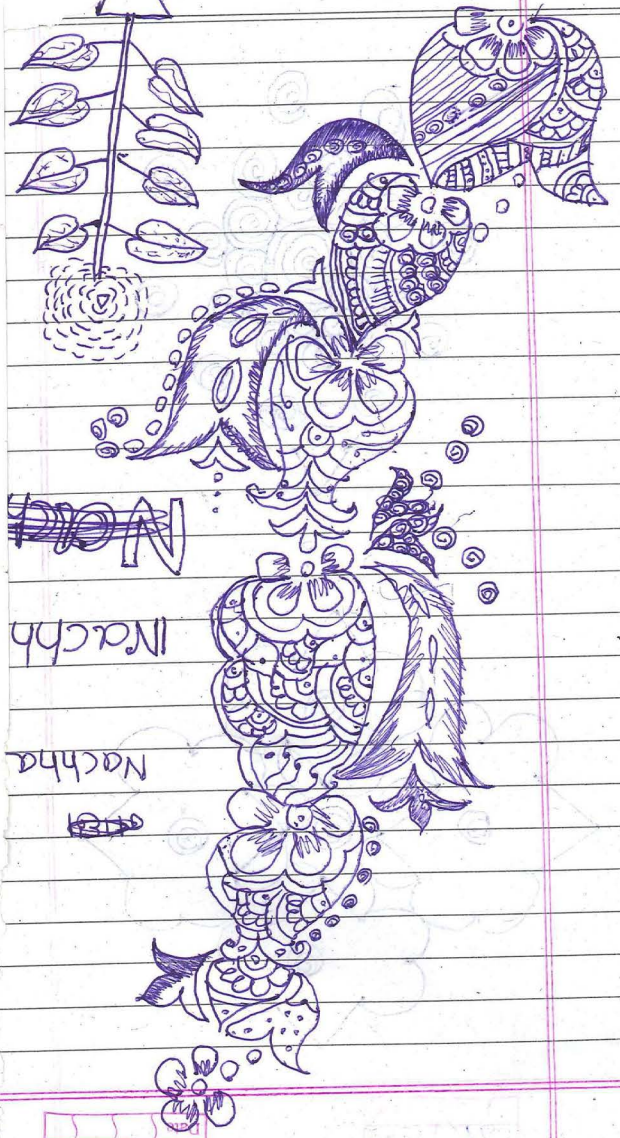
अरु



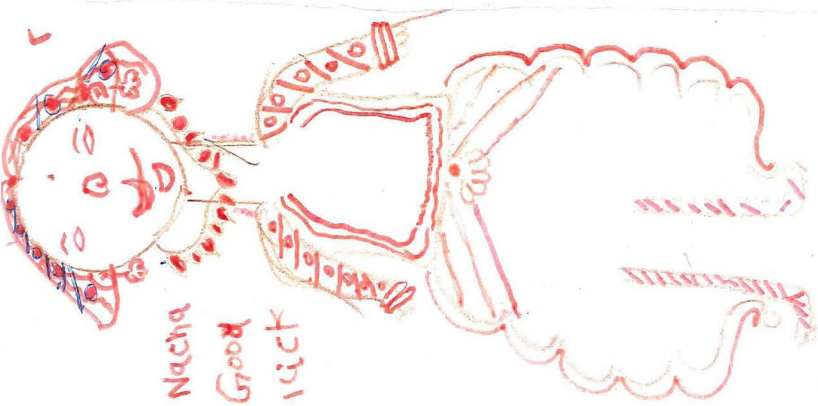
I am Sunil an song
 fuzzy wuzzy caterpillar
 in the garden creeps
 makes himself a chrysalis
 and soon falls fast asleep
 Fuzzy wuzzy caterpillar
 wakes up by and by
 to find he has wings at last
 changed to a butterfly.
 - Sunil More
 class 4th
 Address: Katakaba
 M: 962 322 6913



Nacha
Good
luck



Nacha
Nacha
Nacha



Nacha
Good
luck

These drawings were made by children from a village called Katkalamba (Nanded district). The front was made from collected newspapers from Agrowon about the farmer distress.

