The use of Semi-Structured Interviews for the Characterisation of Farmer Irrigation Practices

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Comments from Reviewer #1

1- The merit of semi-structured interviews over conventional methods should be crystal clear. It is not at this stage. With the information provided in the paper, I still believe that the data obtained can be collected using simple questionnaires.

We are sorry that we are unable to convince the reviewer, but have put further effort in highlighting a number of instances where important insights into water use in the study region were gained through use of SSI's that would not have been possible with questionnaires. Allowing the interviewees to expand on the issues which are of most importance to them forms a central part of the approach outlined, and would not be possible when using simple questionnaires.

In addition, it is worth noting the practical issues with questionnaires such as distributing and subsequent collection, as well as literacy levels which are quite low in the study region.

2- What is the main reason of the conflict between modelled and reported results in two regions (Fig 7)?

This section is intended to highlight the variance between results produced by models and values reported by farmers in the same region. The values reported by water users provide a more accurate representation of water use in the region as they take account for the local environmental and social characteristics. Large scale models, which are typically used in such applications, do not take these variables into account and often are driven with lower resolution data. This accounts for the variance between modelled outputs and field level reported values.

3- Citations of references in the text should be unified. I can distinguish at least three different ways that references are cited in the text. See e.g. Lines 62 and 63 vs. 70 vs. lines 88 and 89.

All citations were rechecked for consistency before re-submission

Comments from Reviewer #2

Review of resubmission - **The Use of Semi-Structured Interviews for the Characterisation of Farmer Irrigation Practices.** J. O'Keefe et al.

I have reviewed the revisions provided by the authors in response to the comments of 2 anonymous and 2 named referees.

I address the responses in turn:

Referee 1

S3.1.1 helps explain the method more fully in terms of the interview design and the supplementary information sets out the questions asked. S. 3.1.4 sets out inclusion/ exclusion criteria and s 3.1.5 follows through with the interview approach. This is a reasonably comprehensive description. The verification point remains live, but caveats have been provided ll 485-495 that embrace this point explicitly. I am satisfied that this goes sufficiently far to address the concerns expressed.)

S 4.3. The approach, combining modelled and field reported data, helps understanding of the issue and adds useful observations from climatic information. However, I was not happy with the both the content and layout of figure 7. I am not sure whether a comparison is possible between a modelled data series that ends in 2012 and field reported data for the following year, 2013. Were climate data not available to model 2013 as well? If these data can be included it would allow a direct comparison with the field data, but at the moment this is not possible. The figure itself needs a clean- up (e.g. a clear background, pref. no gridlines) and a (brief) better explanation (what do the components of the box and whisker plots mean, are they interquartile range and extremes?, etc. at editors discretion),

The modelled results cover a 64 year period from 1948 to 2012, and are compared with reported applied irrigation water volumes from 2013. The model used was driven using the best available data set for the region, which stops 1 year before the field work was carried out. While the modelled results should ideally cover the reported data, we feel it is still relevant for comparing to reported values, particularly as the variance in the modelled outputs is quite low in comparison to the reported values. To aid comparison we have plotted the mean of annual modelled irrigation requirements. The aim of this plot is to highlight the sometimes significant differences between modelled results, and what takes place in the field.

We have also amended the plot as per the reviewer's suggestions, and added a clearer explanation of the plot contents.

The inter-regional contrast in terms of model/ field data variation also merits perhaps a sentence or two more of comment.

We have added some additional information to help explain the potential differences between both districts (Lines 453 to 456).

3) The authors have set out uncertainties in more detail than in the previous version. While this section is useful, it might help also for the authors to set out whether the ‘propensity to please’ has been found in any previous studies and may be a culturally-specific phenomenon to either or both regions. Other than that, I feel this section addresses the reviewer’s concerns.

Social desirability response bias is not a culturally-specific phenomenon and is an important consideration when obtaining or analysing reported information. We have extended our explanation of this in the text and added an example of its presence, highlighted in both Indian and American cultures (Lines 487 to 489).

4) See 2) above, which covers the same issue.

5) I’m satisfied that this new section adds a helpful amount of qualitative information and addresses the reviewer’s concerns.

6) Agreed and this is also helpful additional material which addresses the concerns. Query necessity of use of colour in fig 3 and 4 - editor’s discretion perhaps?. The green won’t reproduce on a print palette very clearly and may end up masking the black circles

Agreed; we have amended the figures to re-print more clearly.

Referee 2 –

7) The new section referred to here is section 4.2, in which the qualitative information is set out. I examined this section carefully to see if the specific points raised by the reviewer were met. Although they are met in a largely qualitative sense, and I think the reviewer may be alluding to a need for more quantitative information to be elicited on payments and response to prices, I think on balance however this additional section meets the requirements set out by the reviewer.

8) The section 5 recommendations for future work are rather brief but sufficient in that they follow on from the description of the limitations of the work.

9) See response to reviewer in comment 3) above, which addresses this issue, in my view satisfactorily

10) See response to reviewer in comment 1) above, which, together with the supplemental information, addresses this issue satisfactorily.

11) See response to reviewer in comment 3) above, which addresses this issue, in my view, satisfactorily

12) Section 4.2 appears adequately to address the concerns raised here

13) Subject to the issues raised in my observations above on the response to reviewer 1 comment 2), the authors have responded to the points raised. There may however be scope to expand a little

further on this particularly implications for hydrological modelling, climate change, etc., in section 5, (which as noted above is a little brief), by way of suggestions for further work.

We have expanded Section 5 to address this.

K. Waylen

- Inappropriate reference to qualitative.

The authors have left this in. In my view it's a debate about semantics and not substance. I don't think the paper falls down on this basis. The new section sets out the interview findings. I can't see how this can be anything other than qualitative, so would struggle to suggest any alternative presentation. Reviewer accepts that revision of claims made would be sufficient and this is carried out through s.4.2.

- Sampling not aiming to achieve representativeness.

I think section 2.2 (and incidentally 2.3) are very general sections and do not set out methodology specific to the study. At very least, they need a good proof read for grammar (participants which – (who?)). S. 2.2. needs to set out exactly what 'purposive' means in this context and how participants were selected. If it was more opportunistic. I would suggest a way forward would be to integrate the general section s. 2.2 with the specifics of what was actually done in the study (s.3.1.1. to 3.1.4) to make an integrated methodology section that is clear on how the sampling was carried out and any issues of bias that could be raised.

One of the aims of this paper was to describe a methodology which could be used by hydrologists and engineers to efficiently collect information in data scarce regions. For that purpose, sections 2.2 and 2.3 is intended to be more general in nature, as it was felt that integrating it directly with the case study would reduce the perceived applicability to other situations.

We have added a more comprehensive description of purposive sampling (lines 134 to 137) and have rechecked all grammar and referencing throughout.

- Reviewer suggests that this work should not be presented as qualitative.

See above

- Approach more consistent with quantitative positivistic sciences

Agree that this has been addressed – see above.

- Survey administered face to face = better description

- these seem like SSIs to me, based on the template the authors have provided.

- Care with claims made for methods/ limitations , individual impacts, characteristics of farms, etc.

This is addressed adequately in the revised draft s.4.2

K. Holstead

- ‘Grounded theory’

these concerns have been addressed by removal of reference to the term

- No room for new concepts / reference to coding

Agree that s. 4.2 addresses the issue raised here

- Reflexivity and Rationality

Agree that revised draft addresses these concerns

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Abstract

~~Generating~~For the development of sustainable and realistic water security, generating information on the behaviours, characteristics and drivers of users, as well as on the resource itself~~,~~ is ~~vital in developing sustainable and realistic water security options~~essential. In this paper we present a methodology for collecting qualitative and quantitative data on water use practices through semi-structured interviews. This approach facilitates the collection of detailed information on actors' decisions in a convenient and cost-effective manner. ~~The interview is~~Semi-structured interviews are organised around a topic guide, which helps lead the conversation in a standardised way while allowing sufficient opportunity for relevant issues to emerge. In addition, ~~semi-structured interviews~~they can be used to obtain certain types of quantitative data. While not as accurate as direct measurements, ~~it~~they can provide useful information on local practices and users' insights. We present an application of the methodology on farmer water use ~~on~~in two districts in the State of Uttar Pradesh in North India. By means of 100 farmer interviews, information was collected on various aspects of irrigation practices, including irrigation water volumes, irrigation cost, water source and their spatial variability. ~~A statistical analysis~~Statistical analyses of the information, along with ~~some~~ data visualisation is also presented~~, which highlights~~; indicating a significant variation in irrigation practices both within and between~~ the~~ districts. Our application shows that semi-structured interviews are an effective and efficient method of collecting both qualitative and quantitative information for the assessment of drivers, behaviours and their outcomes in a data scarce region. The collection of this type of data could significantly improve ~~insight~~insights on water resources, leading to more realistic management options and increased water security in the future.

1 INTRODUCTION

The interactions between humans and water resources are often poorly understood; an issue which can be reflected in the decisions behind water resource planning. While some anthropogenic influences, such as greenhouse gas emissions and land use change, have been incorporated in much of the current modelling and decision making framework, less work has been ~~done~~carried out on the human~~ – ~~-water interface (Nazemi & Wheater, 2015). This shortfall is seen as a major challenge in Earth System Modelling (GEWEX, 2012) and consequently decisions on water resource management. Given that human induced issues of water scarcity affect many parts of the world (Döll, *et al.*, 2014; Famiglietti, 2014; Rodell, 2009; Voss, *et al.*, 2013; Wada, *et al.*, 2010), there is a need to understand anthropogenic~~–~~ - hydrological linkages in order to better manage water resources in the future. Socio-hydrology provides a means of supporting sustainable societal development in a changing environment (Montanari, 2015). Indeed, the significance of including so-called soft data has been well documented (see Siebert, 2002; Fenicia *et al.*, 2011). Winsemius, *et al.*, (2009) ~~argues~~argue the

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importance of including qualitative information to improve model realism, and while this may lead to reduced model efficiency, it can help produce a more realistic representation of catchment behaviour. Making use of this "experimental common sense" (Döll & Siebert, 2002) is an important step in more accurately representing anthropogenic water use in models~~ and while~~. While this paper is primarily concerned with data collection, the importance of obtaining and using soft, qualitative data is implied. Globally, irrigation water consumption accounts for some 70% of total groundwater and surface water withdrawals (Wisser~~,~~ *et al.*, 2008). This figure has increased dramatically over the last sixty years, largely as a result of population growth, market expansion and technological advances in water abstraction. Consequently irrigation water use needs to be explored in more detail than non-irrigative demand (Nazemi & Wheater, 2015).

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Representing water use~~ however~~ presents many challenges, much of which stem from a lack of data (Gao *et al.*, 2012; Portmann *et al.*, 2010). This often leads to oversimplification, either in resolution (Döll & Siebert, 2002) or in user behaviour, which can subsequently be reflected in model outputs. For example, irrigation water requirements are often calculated based on the ideal crop water requirement (Allen *et al.*, 1998; McKenney, 1993) giving a false representation of what is actually taking place on the ground~~,~~; as users will often over or under irrigate depending on prevailing social, economic or environmental conditions. Large scale model outputs or data representations also provide excellent tools for examining water use or resource trends (Döll, 2002; Rodell, 2009)~~,~~. While such approaches are useful as an overview of large scale issues, they are inadequate for developing realistic solutions at ~~any~~a meaningful, implementable level. The data collection methods described in this paper are aimed at providing information for more local scale models and decision making, particularly in instances where such information is scarce. This dearth of information includes both quantitative and qualitative data. In order to come up with suitable options for the use of water, it is important to generate information at a realistic spatial resolution, not only on the water resource itself, but also on the behaviours, characteristics and drivers of its managers and users.

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In social sciences and healthcare the collection of both qualitative and quantitative information through interviews is relatively common practice (Barriball & While, 1994; Ellis & Chen, 2013; Fallon, 2008; Gibson, 1998), however such methods are less used in the fields of earth and engineering sciences. For the purposes of data collection for hydrological studies little guidance exists. In both a time and resource constrained setting the use of semi-structured interviews provides an efficient and effective method for qualitative and quantitative data collection. This is particularly true of data scarce regions, as in our case study, where ~~little~~limited field level information exists. According to ~~(~~Calheiros~~,~~ (2000), using an ethnographic methodology is useful in instances where the theory is incomplete, the phenomena are observable and important at a local level. For the most part little room exists for the inclusion of "non-experts" into the application of scientific research methods (Calheiros, 2000). The incorporation of local knowledge however can have many advantages, including better defining the research questions and raising locally important, as well as unimportant, factors. Unlike a structured interview which contains a series of set questions asked the same way to all interviewees, a semi-structured interview is organised around a topic guide. The topic guide ensures the main points of interest are satisfied during the interview (Mason, 2002), while still allowing the overall direction to be shaped by the participants own understanding, so called experiential or traditional knowledge, of their environment. This naturally highlights issues

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which are of most importance to the interviewee and allows room to incorporate new themes. Semi-structured interviews can quickly produce rich and detailed data sets (Fallon, 2008) offering an accurate assessment of the characteristics of individuals and phenomena. Importantly it can also shed light on the drivers of these events and the motivations behind user decisions, providing a valuable contribution to earth systems modelling. Semi-structured interviews allow for the collection of qualitative and quantitative information efficiently and ~~cheaply~~cost effectively, in an unobtrusive and open manner. While qualitative approaches such as semi-structured interviews are widely recognised and regularly applied by social scientists working on water resources, they are scarcely used by natural scientists in the context of hydrology and modelling. In this paper we show how the method can be used for hydrological research, however, we see much greater scope for interdisciplinary dialogue on semi-structured interviews and its broader relevance in addressing hydrological model uncertainties. Aspects of the approach reported herein may differ from traditional methods (see Burnard, *et al.*, 2008; Creswell, 2009), for example; in terms of sampling. However, we believe semi-structured interviews provide ~~a potent~~an effective tool for data collection on water use. In this study, we applied this approach to two districts in the Northern Indian State of Uttar Pradesh to study irrigation water use and the results ~~will be~~are presented as a case study in ~~section~~Section 3, with the methodology used described in ~~section~~Section 2.

2 METHODOLOGY

2.1 Study preparation and interview design

The collection of qualitative and quantitative data in the field requires an understanding of the ~~relevant existing published research, as well as the~~ social nuances ~~which~~that exist in a study region~~.~~, as well as the relevant existing published research. This knowledge is essential in the planning phase, including ~~in~~ the design of the topic guide, around which the semi-structured interview is based (Ellis & Chen, 2013). The literature review and pre-fieldwork planning, which should also take practicalities such as logistics and cost into account, help define the main study area and the target interview participants. In this paper we treat the semi-structured interview purely as a tool for the collection of hydrological data in the field. Careful and consistent phrasing of questions in the interview is important and draws on the pre~~-field work~~fieldwork research as well as knowledge of the local characteristics. Questions should be unambiguous and easily understood by interviewees, related to their own experiences, ethically and culturally sensitive and ensure that they assist, rather than impede, the flow of information. In addition, the interviewer must ensure that the questions provide data which will address the research questions appropriately (Mason, 2002). Interviewees may not be able to give a direct answer to a technical question, however, skilfully crafted component questions can be combined to produce the required information (e.g. abstraction rates achieved via depth of water applied and irrigated area).

A significant advantage of semi-structured interviews is the opportunity for previously unknown information to emerge. ~~This~~Participants can ~~occur~~be regarded as experts by experience, therefore when ~~the interviewee is allowed~~ sufficient opportunity to speak freely ~~which, by making use of the fact that participant's are experts by experience, may result in the emergence of~~is provided; new and novel information~~.~~ can emerge.

This approach allows both quantitative and qualitative data extraction, for example the volume of water a farmer takes from a particular source and their reason for this. This approach can yield considerable benefits in terms of cost whilst ensuring a useful representation of parameters. Semi-structured interviews are traditionally comprised of open-ended questions. The collection of quantitative data, however, is best obtained through direct questions. For this reason the topic guide contains both. The topic guide for the semi-structured interviews, used in the case study ~~interviews contains~~, contain both open-ended and direct questions (~~can be seen in the~~see supplementary information~~ accompanying this paper).~~). While acquiring quantitative information in this manner is not as accurate as, for example, metered data~~ for example~~, we believe this approach can provide a useful representation of the important parameters and has a place in situations where other measures could be considered unacceptable to the sample, ~~of~~or unfeasible in the environment.

2.2 Sampling

Sampling comprises an integral part of study design. It allows us to select cases from a wider population, too big to be studied completely, enabling us to generalise the final research conclusions to an entire population, not just to the individual participants of a study (Flick, 2014). This is an important consideration when collecting information which could be used in policy, as any decisions arising from this data should be as applicable as possible to the wider population. ~~While the~~The sampling procedure traditionally adopted with semi-structured interviews does not aim to achieve a representative sample~~, it is felt that~~. However, seeking a representative sampling was a useful strategy for the purpose of the case study reported herein, in order to produce ~~results that can be generalised to a population larger than the sample.~~more universally acceptable results. This is achieved through a combination of sampling techniques. For example, purposive sampling provides a useful starting point by selecting participants ~~which are thought to be information rich.~~who are thought to be information rich. Purposive sampling involves the random selection of sampling units from a part of the population likely to contain the most information on the characteristics of interest to the researcher (Guarte & Barrios, 2006). Purposive sampling allows subjects to be selected based on their characteristics, and while this approach is often used to highlight and study extreme or deviant cases, it can allow the researcher to target sample populations which are likely to provide information of most relevance to the research questions. Once a sample group has been identified randomisation should take place to ensure a representative cross section of the study group is achieved. Prior to undertaking fieldwork it is necessary to set participant inclusion and exclusion criteria, as it is likely that potential interviewees who fall outside the research area interests will be approached. Inclusion and exclusion criteria help promote the best use of available resources.

2.3 Conducting the ~~Interview~~interview

~~Introducing~~Correct introduction of the study to potential participants is essential ~~in order to gain~~when gaining informed consent. This involves a clear and concise explanation of the purpose of the research, what the interview will involve and how you are going to use and store the information collected. It should also be highlighted that the respondent is under no obligation to answer any of the questions if they do not wish to (Mottram, 2011). This component of the research is important not only in creating the right kind of environment where the interviewee feels they can provide the information, but also in building good rapport with the individual (Rabionet, 2011). The subject of ethics is an important consideration when entering other peoples environments and collecting data on their livelihoods. While it is outside the scope of this paper to provide guidelines on ethics, it is strongly recommended that they are taken into account during the planning stage of the study.

~~Interviews~~Semi-structured interviews may need to be carried out via translator(s). Pre-project training should be provided to translators beforehand to ensure consistency in terms of interview style. In the field, interviews may be conducted in the presence of family members or neighbours. While for practical and cultural reasons it may not be possible to avoid this, care should be taken at all times to address the question to and receive the response from the designated participant, bearing in mind the potential impact others' presence may have on the answers received.

It is important that the interview is recorded in as much detail as possible, ideally through a mixture of field notes and a voice recorder. Again, consent should be sought from the interview participant prior to the recording of any conversation. GPS readings of where the interview takes place and any other pertinent locations, for example wells or canal access points, should also be taken, along with photos and samples where applicable. Data should be stored safely and securely following all applicable institutional guidelines. It should be made clear to the participants that their privacy and confidentiality will be maintained to the highest degree possible.

2.4 Data processing and analyses

Following the collection of data, all interviews should be transcribed verbatim. While time consuming, a full transcription is paramount in avoiding bias introduced through selective data extraction by the researcher, who may have particular themes or research questions in mind. It also ensures that all data remains available for further analyses, rather than what is of interest to the researcher at that time. Reading the transcripts results in various themes emerging from the text~~. From this~~; from which a thematic analysis begins. ~~These themes~~Themes are referred to as codes during the analysis. As the analysis progresses, commonality of codes across interviews may become apparent. However, thematic analysis allows new themes or ideas to constantly emerge. The use of qualitative data analysis software, for example RQDA (Huang, 2014) provides a useful platform for processing large amounts of qualitative data. ~~Here, words~~Words or sections from a discussion are coded, allowing the frequency and relationships across topics to be analysed (Barnes *et al.*, 2013). While the analysis of textual data can be a difficult process, it is made more straightforward using the appropriate software. It is also important to note that that such tools do not analyse the data, which is the task of the researcher, they only make the handling of such data more straightforward (Burnard *et al.*, 2008). This also allows information, both qualitative and quantitative, on each theme to be recalled easily. Once the data has been coded, the dominant themes can be identified. Overviews ~~on~~of the distributions of ~~the~~ variables within the database can also be produced. A significant portion of the data collected may also be quantitative and suitable for some statistical analyses and modelling purposes.

3 CASE STUDY – DATA COLLECTION

3.1 Study region: the Ganges Basin, North India

The ‘Green Revolution’ has led to enormous gains in agricultural productivity in India, largely through the use of more reliable seeds and improved irrigation technology (Singh, 2000). This has allowed India to become food self-sufficient (Jewitt & Baker, 2007) and has undoubtedly improved life for the majority of rural poor. The Indian green revolution has also received much criticism for its environmental and socio-economic impacts. This includes a reduction in India’s water resources while becoming one of the most intensely irrigated areas of the world (Rodell, 2009; Tiwari, 2009; Mueller~~,~~ *et al.*, 2012). However, to correctly investigate water security, field studies and an understanding of the often highly localised spatial variations in water abstraction need to be considered. While the large scale impacts on water resources are known, the factors influencing irrigation practices on a local level are much less ~~well~~ understood. In order to develop realistic and socially acceptable options for water use in the future, this local variability needs to be taken into account.

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Uttar Pradesh~~,~~ (UP), located on the plains of the Ganges Basin, is the highest producer of food grains and sugarcane in the country (Hagirath~~,~~ *et al.*, 2011) and the most densely populated (Government of India, 2011). Rice, grown during Kharif (the monsoon season from June to October~~)~~), and wheat during Rabbi (November to April~~)~~), are the two most dominant crops (Singh~~,~~ *et al.*, 2011). In the past, the dominant irrigation method in Uttar Pradesh has been via canal, much of which is supplied by the Ganges and Yamuna rivers. However according to Amarasinghe (2009), canal irrigation has declined by approximately 40% during the last four decades, with a thirteen fold increase in irrigation by tubewells.

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The following sections comprise a description of a case study in which data was collected through a series of semi-structured interviews. This was carried out in a data scarce region, with the collected information, through mapping and statistical analyses, used to gain a better insight into regional irrigation practices and the motivations of users. Based on irrigation water source information contained within the statistical abstract of Uttar Pradesh~~,~~ (Economics and Statistics Division, State Planning Institute, 2013), two districts, Jalaun ~~(~~, the highest user of surface water in the State~~)~~, and Sitapur ~~(~~, one of the highest irrigators in UP using groundwater, ~~the~~were chosen for investigation. The highest was not considered a viable option due to logistical constraints~~) were chosen for investigation.~~. A map of the study area, along with the interview locations, is presented in Figure 1.

3.1.1 Jalaun

Jalaun is located in the south central region of Uttar Pradesh, and is bounded by the Yamuna River to the north and the Betwa River to the east, covering an area of 4,565 km². It is home to over 1.5 million people (Economics and Statistics Division, State Planning Institute, 2013). Jalaun receives an average annual rainfall of 811 mm, about 70% of which falls during the monsoon season of June to August (ICRISAT-ICAR-IRRI, 2012). Approximately 139,000 hectares of land is irrigated per year using canal water, making it one of the highest users of this resource in the State. While canal water is generally applied through gravity flow along irrigation channels, groundwater is abstracted predominantly ~~using~~via diesel pumps. It was noted that there were approximately 10,421 diesel pump sets recorded in 2012 in the district, with electricity powering just 356 units. As there is no restriction on the number of wells that can be drilled or on pump specifications, it is likely that there are many more diesel pumps in use. The main crop grown in the district is wheat; with a total cropped area of 146,~~307ha~~307 ha. Jalaun is classed as one of Uttar Pradesh's 35 more deprived districts (Ministry of Panchayati Raj, 2014), and is known to be one of the more drought prone regions of the State (Avtar, Kumar, Singh~~,~~ *et al.*, 2011).

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3.1.2 Sitapur

Sitapur, also considered one of Uttar Pradesh's less developed districts (Ministry of Panchayati Raj, 2014), and is located to the north of the state capital Lucknow~~, and~~. It has a population of approximately 4.5 million (Economics and Statistics Division, State Planning Institute, 2013). The average rainfall in Sitapur is 903 mm~~,~~; 66% of which falls during the monsoon months (ICRISAT-ICAR-IRRI, 2012). On a district scale it is one of the largest irrigators in Uttar Pradesh and supplies its 374,445 ha of irrigated land largely using groundwater, with canal water only accounting for 17,914 ha. Using electricity for groundwater abstraction in this region is rare, and farmers predominantly use diesel pumps. As with Jalaun, lack of regulations and difficulty in counting wells ~~indicates~~indicate a larger number of pumps in use across the district. The main crops grown are rice, wheat and sugarcane, with most farmers carrying out a rice-wheat rotation on their land.

3.1.3 Interview design

The main focus of this study was to investigate farmer irrigation behaviour in the Ganges Basin of North India and to collect relevant quantitative, as well as qualitative information, all of which may be used for informing and driving models. Following a detailed literature review, a methodology employing semi-structured interviews was designed and a topic guide was organised around the following themes:

- Farm and Crop ~~information~~Information (farm size, soil type, crop type, crop calendar, yield)
- Irrigation Practices (number of irrigation events, irrigation volume, irrigation methods)
- Water Source (water source reliability, irrigation cost, irrigation method, influences on irrigation, presence of water market, power source, constraints)
- Other (perceptions of challenges faced, potential rationales, changes in water availability, livelihood sustainability)

The topic guide was designed to collect relevant information with as much flexibility as possible, allowing the interview to be shaped by the interviewees own understandings, the interests of the researcher, as well as any unexpected themes that emerge. The topic guide used during the interviews is presented (~~please~~ see supplementary information). While the contents of the topic guide are presented as questions, they were treated as prompts. This allows the conversation to progress with as much flexibility as possible while still keeping the interviews relevant ~~and~~ to the research questions. ~~While~~ However, while the aim is to highlight new data through open-ended questions and a fluid interview structure, some direct questions are included, for example relating to farm size or the depth of water.

3.1.4 Sampling

As described, field work was undertaken in two districts ~~which were~~, chosen based on their irrigation water source, with Jalaun the highest user of canal water in Uttar Pradesh, and Sitapur irrigating almost exclusively through groundwater. This initial targeted approach was deemed necessary to capture a representative sample of water users, including both conjunctive and groundwater only users producing as rich a ~~data set~~dataset as possible, whilst also considering logistics and other resource constraints, such as time and finances. Following the identification of the field work regions, a list of villages in each district was obtained (Government of India, 2011). These were randomized with 15 villages picked as data collection points. Between 3 and 5 interviews were conducted in each of the attended villages, with 50 farmers interviewed in each of the two districts. After approaching a potential interviewee, inclusion and exclusion criteria were used to determine whether or not the participant was suitable. Interview participant inclusion criteria were: (1) A farmer who grew wheat and/or rice, (2) irrigated their crops rather than depended on rain fed only, (3) The farmers land must be within approximately ~~5km~~5 km from the village centre and (4) must have the authority to answer the questions. Participants were excluded if they were: (1) too young or did not have the authority to answer the questions, or (2) if their land was too close to a previously interviewed farmer.

3.1.5 Data collection – conducting the interview

The field work team consisted of the researcher, a translator and a driver. All interviews were conducted through a translator. Potential interviewees were approached when seen in the field. No “gatekeeper”, such as a village head or government official was approached in order to facilitate meetings with participants as it was unnecessary, could have impeded the data collection and potentially impacted on the information received. Once a potential participant was identified, he was approached by the researcher and translator, who made an introduction, described the project, and asked if they would be willing to answer questions. It was made clear that the interviewee was under no obligation to take part if they did not wish to, and that all information collected would be treated in the strictest confidence. It was also highlighted that if participants had any questions they were free to ask. During the interview the participant was given as much opportunity as possible to expand on topics that were of most interest to them. All interviews were recorded using a ~~voice recorder~~dictaphone and field notes, with GPS readings of pertinent locations and photographs taken throughout.

3.1.6 Data processing and analyses

Once data collection was completed, all interviews were transcribed verbatim and uploaded to the qualitative data analysis package, RQDA (Huang, 2014) to allow for thematic ~~analysis~~analyses of the data. During the interviews and while reading the transcripts, a number of themes emerged as being important to the farmers; for example the cost of irrigation, the reliability of their water source, and the importance of conjunctive surface and groundwater use. These themes were coded to different sections from the transcribed interviews, allowing commonality of themes to emerge across interviews, yet also allowing unique perspectives to be highlighted. A significant portion of the data collected was quantitative. This allowed for statistical analyses of variables to assess differences in irrigation practices between and within the two districts. These included the volume of water applied (m^3/ha), the volume of water required to produce 1 tonne of wheat (m^3/t), the cost of wheat irrigation during the growing season (r/ha), the crop yield in tonnes per hectare (t/ha), the farm area (ha) and the cost of irrigation water per cubic meter (rupees/m^3). The cost of water in m^3 was calculated by taking into account the cost of irrigation and the volume of water applied per hectare. This case study analysis focuses on wheat. While both wheat and rice are grown in Sitapur, rice is not commonly cultivated in Jalaun, with only one farmer out of 50 interviewed growing the crop. The results of the analyses can be found in Figures 2 to 6, with a description of results below.

4 CASE STUDY - DISCUSSION AND RESULTS

4.1 Quantitative results

The results presented in Figure 2 and in the maps in Figures 3 and 4, show there is a significant variance in the irrigation practices of farmers in Jalaun and Sitapur. This can be seen in the volumes of irrigation water used (Figure 2A); with farmers in Sitapur applying on average 1,555 m^3/ha more than farmers in Jalaun. This is also reflected in the overall cost of irrigation with farmers in Sitapur paying on average over 7,000 rupees/ha/season more to irrigate their wheat crop than their counterparts in Jalaun (Figure 2B). This is despite the basic cost of water per cubic meter being largely the same; 3.58 r/m^3 in Sitapur and 3.84 r/m^3 in Jalaun (Figure 2, part F).

Sitapur is by area one of the largest irrigators in Uttar Pradesh, and for the most part ~~uses~~relies on water from the underlying aquifers. The primary method of abstraction is by diesel pump, which although reliable and versatile, is expensive, with farmers in Sitapur paying on average 12,782 r/ha/season to irrigate their wheat crop. Jalaun, however, is one of the highest irrigators using canal water in Uttar Pradesh, with the majority of farmers interviewed (33/50) making use of the resource, often in conjunction with groundwater. This provides a cheap, and sometimes free source of irrigation water (Figures 2C and Figure 3). In addition, farmers in Sitapur produce smaller yields than farmers in Jalaun, almost 2 t/ha less (Figure 2D). As can be seen in Figure 2B, and in Figure 4, farmers in Sitapur apply 1,017 m^3 of irrigation water with those in Jalaun using only 396 m^3 to produce a tonne of wheat.

When comparing tubewell users only in both districts further differences ~~emerge~~emerged. In terms of production efficiency farmers in Sitapur ~~require on~~required an average of 1,017 m^3 of irrigation water per tonne of wheat produced, ~~with~~while their counterparts in Jalaun applying 800 m^3 less (Figure 5B). When only tubewell users ~~are~~were taken into account, the price paid per m^3 of irrigation water was found to be very different. Farmers in Sitapur ~~pay on~~paid an average of 3.58 r/m^3 whereas farmers in Jalaun ~~pay~~paid significantly more; ~~on~~an average 8.71 r/m^3 (Figure 5D). The fact that farmers ~~apply~~applied less irrigation water in Jalaun however (Figure 5A), is reflected in the overall cost of irrigation by both groups (Figure 5C). Farmers in Sitapur ~~pay on~~paid an average of 1,167 r/ha more to irrigate their wheat crops despite the fact that the cost per cubic meter of water ~~is~~was less.

In Jalaun many of the interview participants had access to both tubewells, and the cheaper but less reliable, Irrigation Department supplied canal water. Conjunctive use of surface and groundwater is often promoted as a realistic option to solving groundwater overdraft caused by irrigation (Harou & Lund, 2008; Shah~~, Bhatt, Shah,~~ *et al.*, 2008) and developing an understanding of farmer behaviour in this type of environment is important when formulating solutions. To investigate irrigation behaviour between farmers who have a choice in their water source (canal and tubewell) and those who don't (tubewell only), a comparison of the data collected within the district of Jalaun was undertaken, the results of which can be seen in Figure 6. In terms of the volume of irrigation water applied, there was a statistically significant difference between both groups (Figure 6A), with farmers who ~~have~~had canal access, applying over 1,722 m^3 of water more than those who ~~rely~~relied on tubewells only. While more water ~~is~~was used by farmers who have access to canals to produce one tonne of wheat (Figure 6B), the difference between the two groups was not found to be statistically significant. The cost of irrigation water however, per m^3, was found to be significantly different between both users (Figure 6D); canal users ~~pay on~~paid an average of 2.09 r/m^{33}, whereas farmers who use tubewells ~~pay on~~paid an average of 8.71 r/m^3. As can be seen in Figure 6C, in terms of the overall price paid for irrigation by both groups, farmers who ~~have~~had access to canal water ~~are~~were applying more, and also ~~paying~~paid 7,805 rupees/ha/season less to irrigate their wheat.

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The data reported in this section provides an example of the type of information that can be collected using this methodology. While it reveals a considerable amount of detail on the irrigation behaviour of farmers in the region, it is envisaged that this information can be further utilised, particularly in the set up and driving of hydro-economic and groundwater models of the region.

4.2 Qualitative results~~:~~

The most commonly reported theme during the interviews was ~~that of~~ poor water availability. While no exact measurements were taken by respondents, a significant proportion in both districts reported that they had noticed water levels were ~~dropping~~falling. Among groundwater users, this was predominantly perceived to be as a result of overuse by other farmers and poor rainfall*:*

Farmer 1, Dafrapur, Sitapur. Translator: " Maybe because of many people extracting the water"

In some cases farmers reported that while they usually got water eventually, it was often too late to meet their crop water needs:

Farmer 1, Kishun Kheara, Sitapur. Translator: "always get but not always on time".

This problem is exacerbated as water levels decrease during the post monsoon season, causing farmers to rely on deeper tubewells, which are fewer in number, leading to a delay in access. ~~Interestingly, a significant~~A proportion of farmers in Sitapur~~, all of whom depend on groundwater,~~ highlighted that they had no issues with water supply~~. This was often as a result of having~~ when they had reliable access to a deep well, or ~~owning~~had land in an area with a high water table. ~~While farmers~~ Farmers in Sitapur are dependent on groundwater; however, many in Jalaun have access to both canal and surface water. Canals, while beneficial, particularly in terms of affordability, were perceived as unreliable, with the ~~irrigation department~~Irrigation Department supplied water often arriving late or early for irrigation. This ~~often~~sometimes forced farmers to turn to the more expensive groundwater where available, to ensure their crops were irrigated. Indeed in Jalaun, the lack of access to a reliable water source was deemed to be the main reason for ~~farmer's~~farmers' not growing rice, despite many saying that their soil was suitable:

Farmer 6, Barha Jalaun. Translator: "So he is telling me that he generally grows wheat, ….and don't grow rice because of lack of water, so soil is good for rice, but because of lack of water, they generally don't grow".

According to farmers in both districts, the lack of a dependable electricity supply was perceived as a significant barrier to accessing a sustainable source of water for irrigation. Electric submersible pumps allow for deeper water abstraction, and are generally considered to be a cheaper option for farmers than the common diesel pump. Indeed the introduction or improving of electricity in an area was seen as an obvious solution to water issues in both districts. The fact that this could lead to further drops in water levels was not mentioned by participants, highlighting the often myopic nature of farmers. Interviewees also singled out the Government for criticism, blaming them for poor infrastructure such as badly maintained wells, the poor electricity supply and corruption:

Farmer 2, Gulriha Sitapur. Translator: "He is saying GOV is not doing what they want here",

Farmer 1, Mania Sitapur~~;~~.
Interviewer: "And what do you think are the biggest problems you face at the moment?"
Translator: "Lack of fertilizer, lack of water lack of electricity everything, what they say first is everything! Major thing is [Government] corruption".

In Jalaun however, a number of farmers highlighted the benefits of some Government policies, particularly that of free, or cheap, canal water. While welcome, farmers saw this practice as a means ~~of securing votes~~ for local politicians to secure votes. As the participants were given freedom to elaborate where they saw fit, additional information emerged in a number of interviews. In Sitapur this included a system whereby access to water was shared between farmers who owned their own wells. This was outside the water market, a common method of irrigation water access in both districts, and was more prevalent in parts of Sitapur where farms were fragmented. The system allowed farmers to use tubewells owned by farmers neighbouring more distant pieces of their land, in return allowing their own well(s) to be used by others. Farmers would move their own pumps around to different wells as needed. A lack of labour was also highlighted as an issue for farmers. This emerged as an important reason why farmers did not use sprinklers for much of their wheat crop, and while most were aware of the potential benefits, particularly in Jalaun, implementation was curtailed by the lack of available labour. Climate, particularly the lack of rainfall emerged as a challenge for farmers; however a number of interviewees in Sitapur spoke of the onset of “westerly’s~~”,~~”; a drying wind which had a dramatic effect on crop water requirements:

Farmer 3, Lilsi, Sitapur. Translator: “Because of westerly’s, the wind can carry more and more moisture from the soil”.

Poor neighbour relations was also highlighted as a potential problem in accessing water when needed in both districts, but was more prevalent in Jalaun, particularly in terms of access to canal supply, with farmers further down the canal receiving less water. Interviewees also spoke of the damming of canals by farmers upstream as a problem in receiving water on time:

Farmer 4, Kusmra Bavani Jalaun. Translator: “… there is a conflict between the villages because the water distribution and what happens is that the upstream villagers they dam the canal as we have seen and they stop the water for 2 or 3 days”.

The perception among farmers in both districts was that irrigation water was not cheap. However, this did not appear to change their attitude to irrigation as a reduction in water could lead to a reduction in crop yield. It appeared that farmers were being as efficient as they could be, given the resources they had.

4.3 Comparison with modelled irrigation requirement results

Crop water requirements can be estimated ~~using a variety of~~through various algorithms, for example Hargreaves-Samani (Hargreaves & Samani, 1985) or Penman-Monteith (Allen~~,~~ *et al.*, 2005). These approaches are extremely useful as they can provide results without the need for field level measurements. It is ~~however~~ important however, to compare the modelled outputs to field data where possible as results can vary considerably. ~~Here we compare the~~ The reported volume of irrigation water applied by farmers to their wheat crop ~~with~~is compared to values obtained through modelling of requirements using Hargreaves-Samani’s (Hargreaves & Samani, 1985) potential evapotranspiration method, and the Terrestrial Hydrology Research Group at Princeton University’s global meteorological forcing dataset (Sheffield, 2006). The crop coefficients used in the calculation are provided by Choudhury *et al.* (2012), which are estimated through field experiments in North India. This data allowed for the modelling of wheat irrigation requirements from 1948 – 2012. The results are then compared with ~~the~~ irrigation ~~values~~volumes reported by farmers during field work undertaken in 2013. ~~The modelled~~All results ~~and the reported values~~ are presented in Figure 7. The

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model used the best available dataset for the region, and while the results do not overlap with reported values, the difference between modelled and information obtained in the field is clear.

The mean value reported by farmers in Sitapur is 40504,050 m³/ha of irrigation water applied during the wheat season. This is 368 m³/ha below the modelled 2012 result of 44184,418 m³/ha. The difference in Jalaun is more significant, with a mean reported values of 22832,283 m³/ha, 22532,253 m³/ha less the modelled result of 45364,536 m³/ha. The median reported value ofvalues for both districts isare also significantly lower than the modelled result, (Jalaun: 13901,390 m³/ha, Sitapur: 38003,800 m³/ha)), highlighting that the majority of farmers apply less water than would be predicted through modelling, showing the importance of using field collected information to address model uncertainties. The variance found between the districts is potentially due to differences in soil type with a higher proportion of sandy soil in Sitapur (Chauhan, 2009; Indian Council of Agricultural Research, 2010) requiring larger amounts of irrigation to maintain soil moisture. Rainfall rates are largely similar across both districts.

The data reported in this section provides an example of the type of information that can be collected using this methodology. While it reveals a considerable amount of detail on the irrigation behaviours, it is envisaged that this information can be further utilised, particularly in the set up and driving of hydro-economic and groundwater models of the region.

5 OPPORTUNITIES AND LIMITATIONS OF SEMI-STRUCTURED INTERVIEWS

The lack of reliable quantitative and qualitative information is a major barrier in developing realistic water security options. In data scarce regions of the world, information is typically downscaled from larger regional datasets; however this ignores the often significant spatial variability that exists on a finer scale. The use of qualitative, as well as quantitative information is essential in identifying the drivers behind water use practices, however the collection of this information is often expensive and time consuming. Semi-structured interviews provide a means of developing information rich datasets in a time and resource efficient manner. Direct contact with water users and the opportunity to allow themparticipants to expand on the issues of most importance to them provides a unique opportunity to develop an understanding of the human water interface in a given location.

Despite the usefulness of semi-structured interviews, we identify some limitations in both the data collected and the approach used. The information collected, while useful for informing large scale models, is most applicable to the scale at which it was collected, which ideally should coincide with a scale in which decisions on policy can be made and implemented; in this case district level. The type of data collected, both quantitative and qualitative, is useful for driving models, through numerical inputs and in setting rules; for example who has access to which water source and when. As can be seen in sectionSection 4.3, the differences between modelled outputs and collected field data can be significant. Incorporating field level information where possible is an important consideration for modellers in order to highlight bias and uncertainty. This also applies to water users and water managers, as the approach allows for more realistic conclusions to be drawn from model outputs. In the case studies, interviews took place from September to November. This snapshot of the farming year in Uttar Pradesh is during a time of peak water availability, as it is following the monsoon season. It is possible that this influenced farmer responses. In addition, out of 105 farmers approached, only 5 declined to be interviewed. While this high participatory rate made field work straightforward, it highlights a potential propensity for interviewees to please the interviewers~~ or provide~~, providing statements indicative of social desirability response bias (Collins *et al.*, 2005) ~~which may be reflected in the collected information.~~, which may be reflected in the collected information. This should be a consideration in all similar studies, and while it has been observed in Indian culture, social desirability response bias is not culturally specific (Hebert *et al.*, 1998) and should be considered at all stages of data collection and analysis. In the case study reported above, interviews required the use of translators. Shortfalls associated with using a translator(s) are described in ~~(~~Kapborga ~~and~~& Berterö (2002), however to limit the potential for discrepancy, training should be provided prior to fieldwork. It is also important to remember that in their environment the interviewee is the expert and should be treated as such. This also helps break down some of the barriers which may exist when a researcher and participant are from different cultures. It is important to take these factors into consideration at all stages of the research including subsequent analyses. While the case study sample size (*n*=50 per district) is small relative to the population [Sitapur = 623,000 farms, Jalaun = 253,000 farms (Economics and Statistics Division, State Planning Institute, 2013)~~,~~], we are confident that it presents a good representation of farming practices across the district as a whole. Verification of the objective accuracy of self-reported data is also an important consideration. Reported information can be triangulated with, if available, socio-economic data, outputs from other models, or ideally, field level monitoring of water levels, abstraction rates and surface water availability. While ~~checking the~~validation of collected data through objective measures is a necessary step in data collection, it is outside the scope of this paper. To address these shortcomings, further field work should be undertaken, focusing on different regions of Uttar Pradesh during more water scarce times of the year, and importantly gaining objective measures of the data reported herein, i.e. via direct observation and metering of the phenomena. This would help in quantifying the differences between modelled, reported and collected information, leading to more accurate hydrological model development and outputs, allowing for more realistic predictions to changes in boundary conditions, including those from climate change.

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6 CONCLUSIONS

~~Our~~Limits in our current ~~limited~~ understanding of the human~~ – ~~-water interface ~~is~~are a major ~~shortfall~~constraint in developing options for future water security. One of the major barriers in developing this understanding is a lack of suitable qualitative and quantitative data. In this paper we present a methodology to facilitate the collection of information for hydrological and engineering purposes in data scarce regions through semi-structured interviews. We use this methodology to investigate farmer irrigation practices in the Ganges basin of North India, collecting information from 100 farmers across two districts. Information was ~~collected~~obtained on topics such as irrigation water volumes, the cost of irrigation, water source and the drivers behind these practices. Statistical ~~analysis~~analyses of the data, along with some data visualisation is presented. Aspects such as a significant variability in water use practices, as well as insights ~~to~~into farmer behaviours~~,~~ and their environment are highlighted. ~~The semi~~Semi-structured ~~interview provides~~interviews provide a useful platform for the collection of qualitative and quantitative information simultaneously. This has clear benefits, including directly linking behaviours~~,~~ and their drivers~~,~~ to reported numerical values. Semi-structured interviews facilitate the collection of detailed information quickly, easily and relatively ~~cheaply~~cost effectively while ~~highlighting~~indicating themes which may not have been obvious beforehand, as well as ~~pointing out~~highlighting aspects of the study which may no longer be relevant. The data collected also lends itself to~~ more detailed~~ hydrological and hydro-economic modelling, as well as providing more realistic representations of user behaviour~~,~~; an essential component in model development. While some limitations do exist, we are confident that this approach can be employed by natural scientists as an effective and efficient method of collecting both qualitative and quantitative hydrological information for the assessment of drivers, behaviours and their outcomes in a data scarce region.

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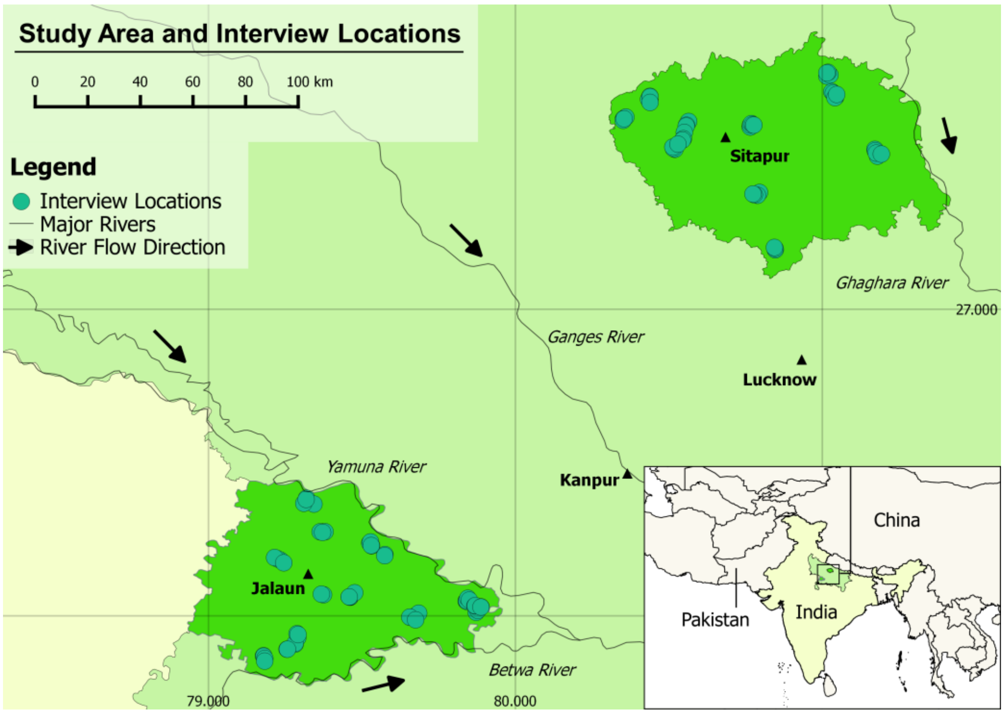
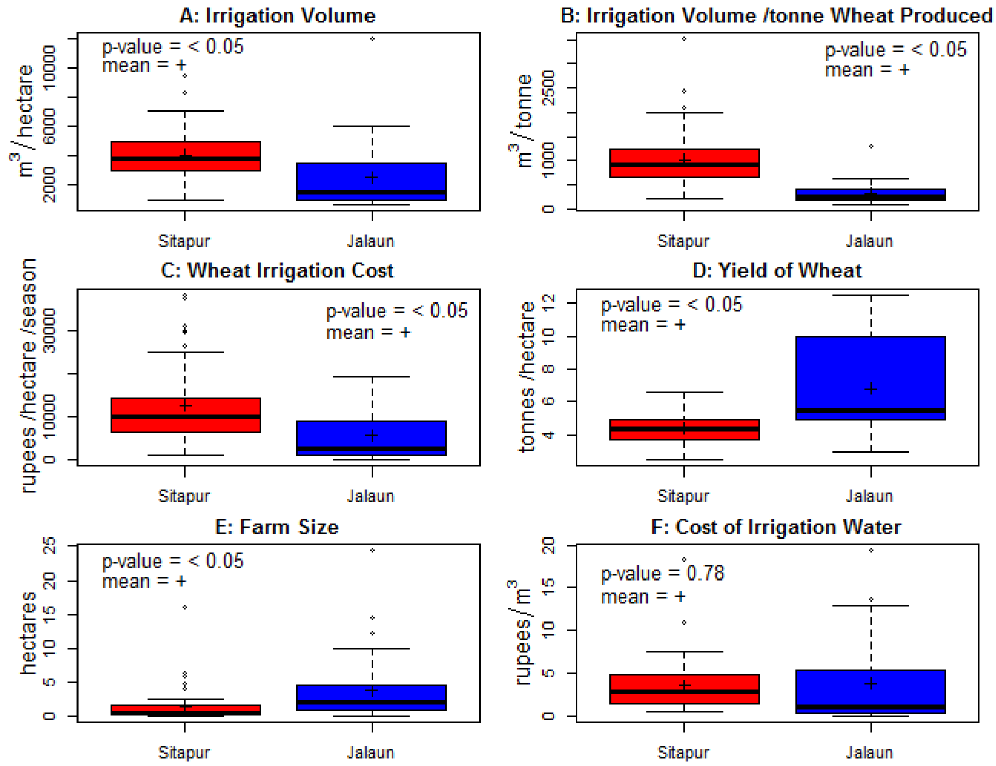
FIGURES



Study Area and Interview Locations
0
20
40
60
80
100 km
Legend
Interview Locations
Major Rivers
River Flow Direction
Sitapur
Ghaghara River
27.000
Ganges River
Lucknow
Kanpur
Yamuna River
Jalaun
Betwa River
79.000
80.000
China
Pakistan
India

Figure 1: Map of the study region including the locations of field interviews carried out.



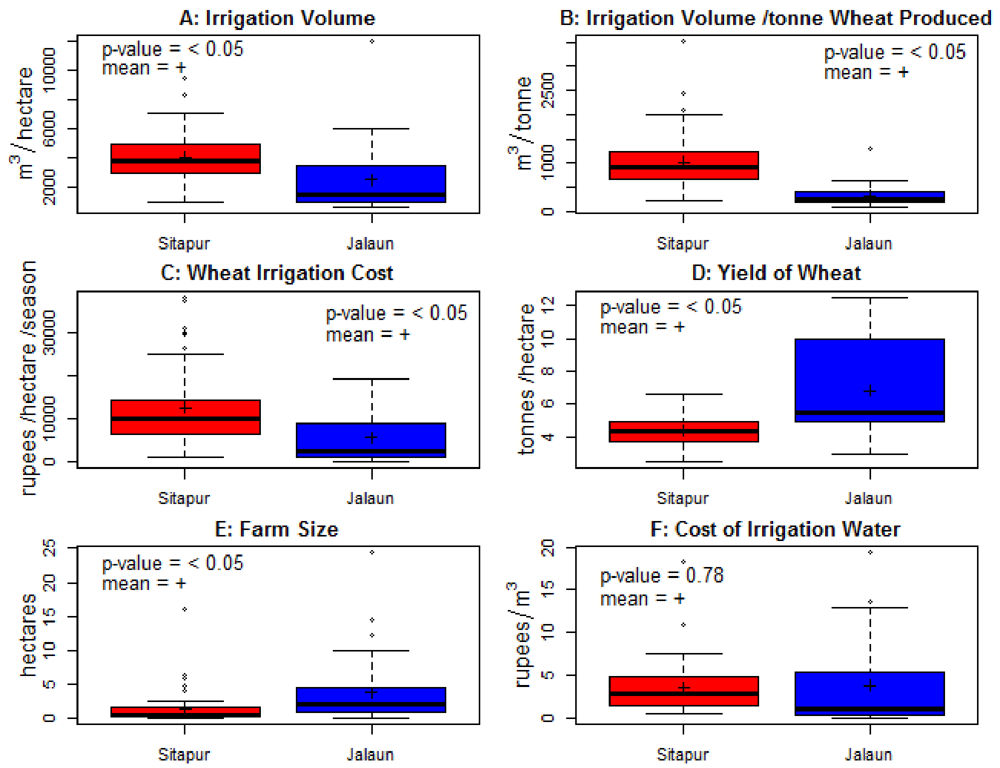
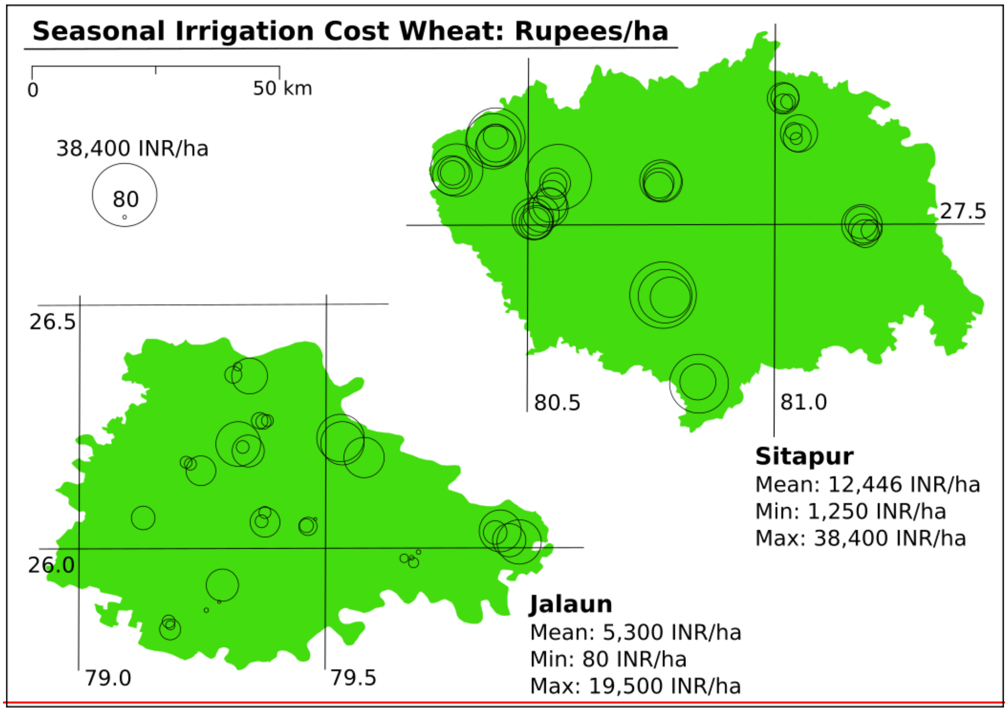
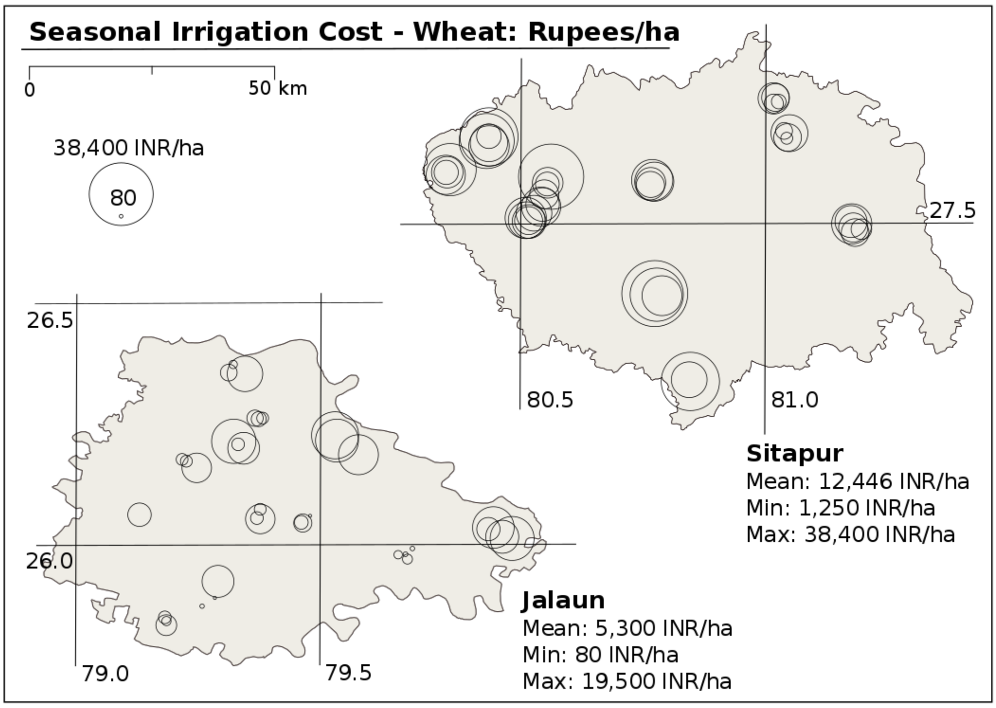


Figure 2: Differences in irrigation practices between the districts of Sitapur and Jalaun, Uttar Pradesh, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The P values give the chance of equal mean obtained from Student's t-test.


Seasonal Irrigation Cost Wheat: Rupees/ha
0
50 km
38,400 INR/ha
80
27.5
26.5
80.5
81.0
Sitapur
Mean: 12,446 INR/ha
Min: 1,250 INR/ha
Max: 38,400 INR/ha
26.0
Jalaun
Mean: 5,300 INR/ha
Min: 80 INR/ha
Max: 19,500 INR/ha
79.0
79.5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50 km
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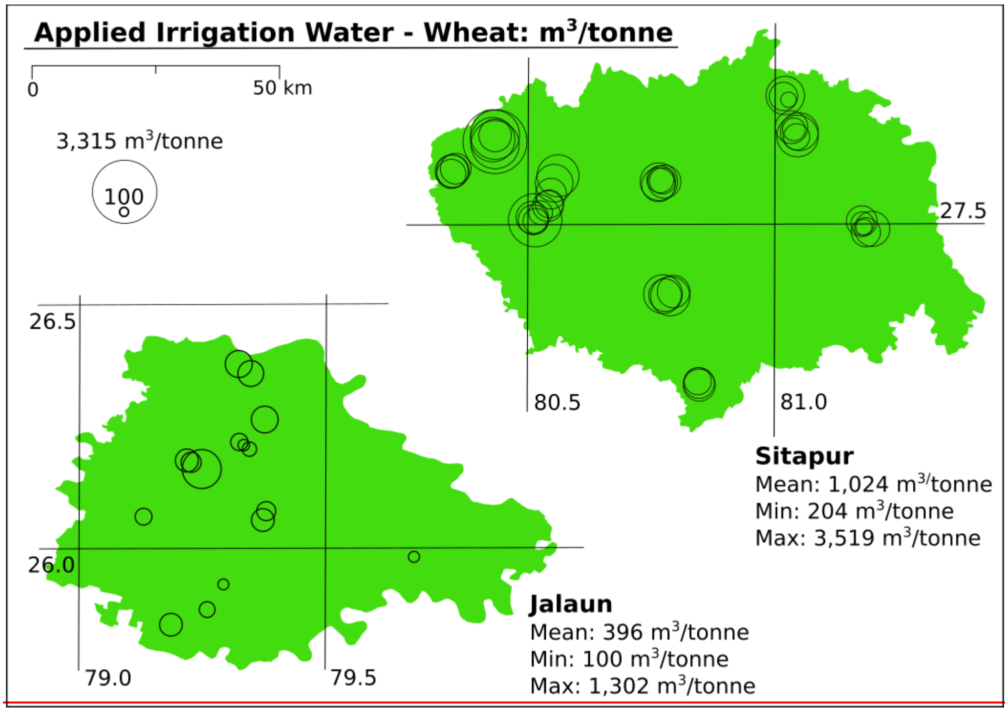
26.0
Jalaun
Mean: 5,300 INR/ha
Min: 80 INR/ha
Max: 19,500 INR/ha
79.0
79.5

Figure 3: Spatial variations in the annual price paid for the irrigation of wheat by farmers in Jalaun and Sitapur, Uttar Pradesh, North India



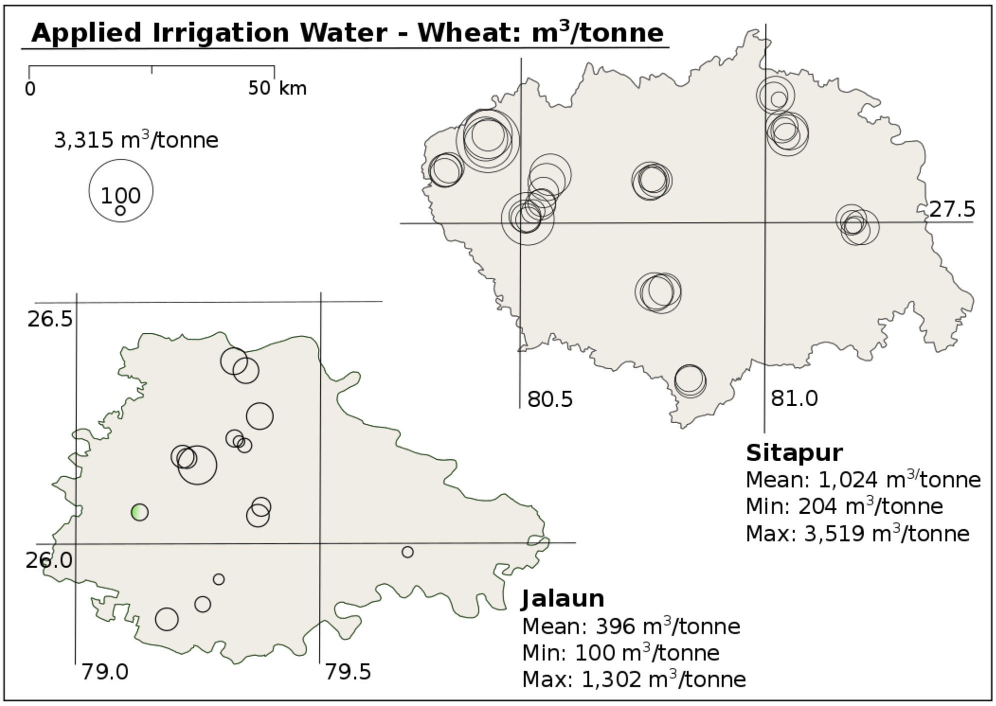
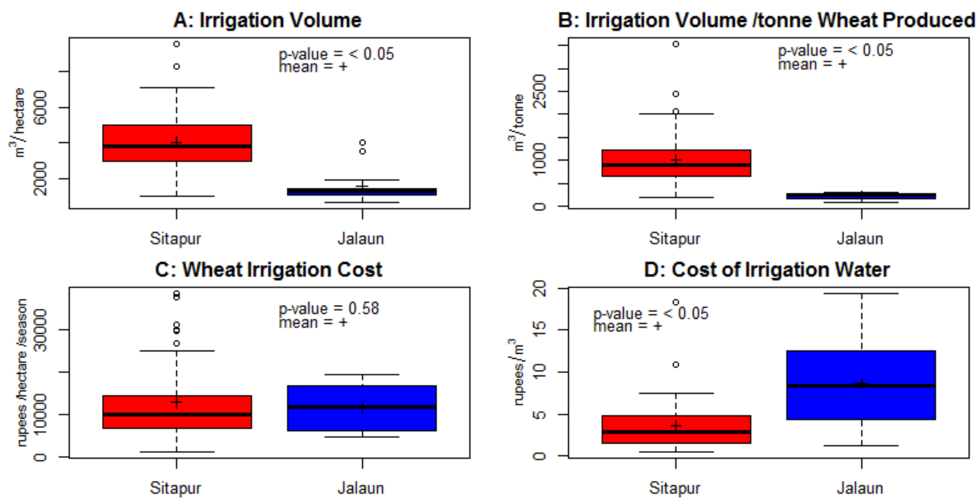


Figure 4: Spatial variations in the volume of water applied per tonne of wheat produced in Jalaun and Sitapur, Uttar Pradesh, North India.



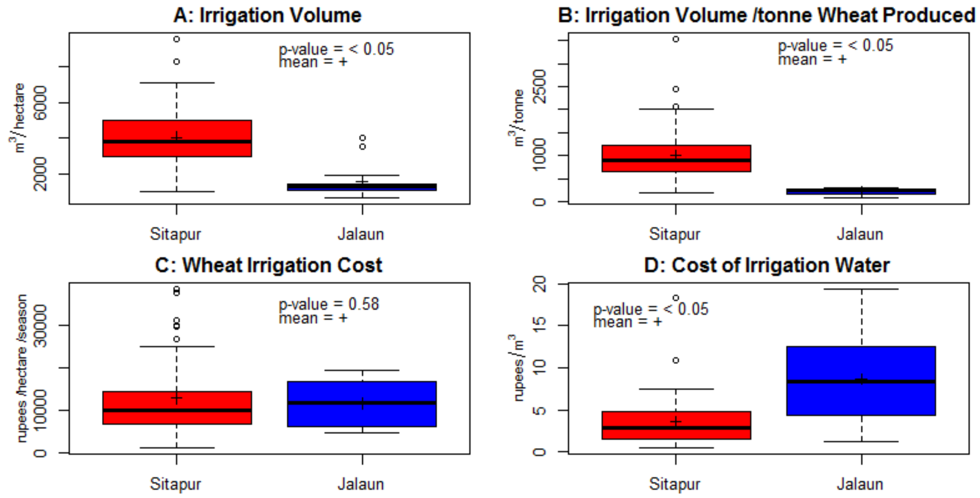
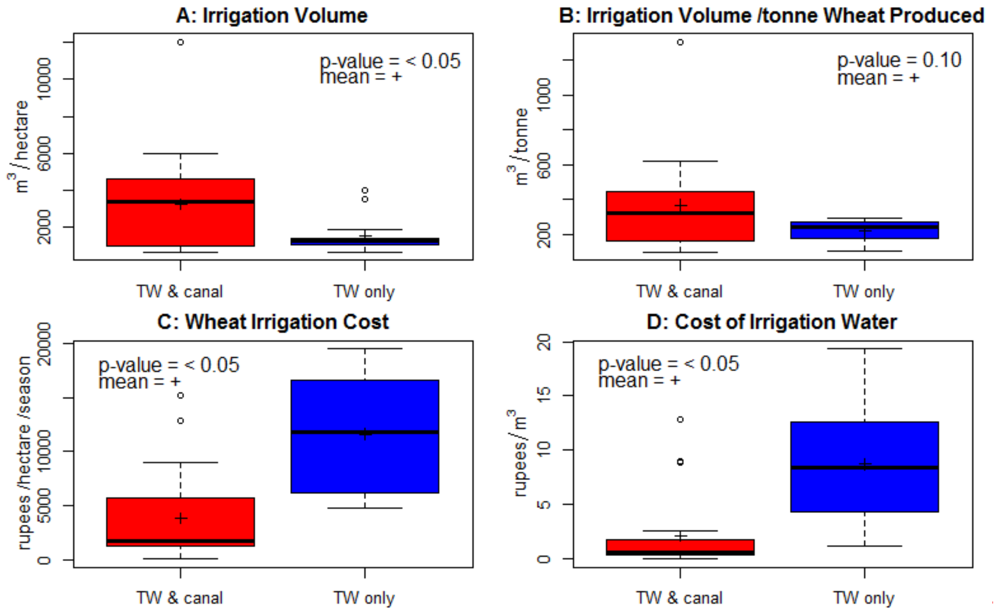


Figure 5: Differences in irrigation practices between tubewell only users in the districts of Sitapur and Jalaun, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The P values give the chance of equal mean obtained from Student's t-test.



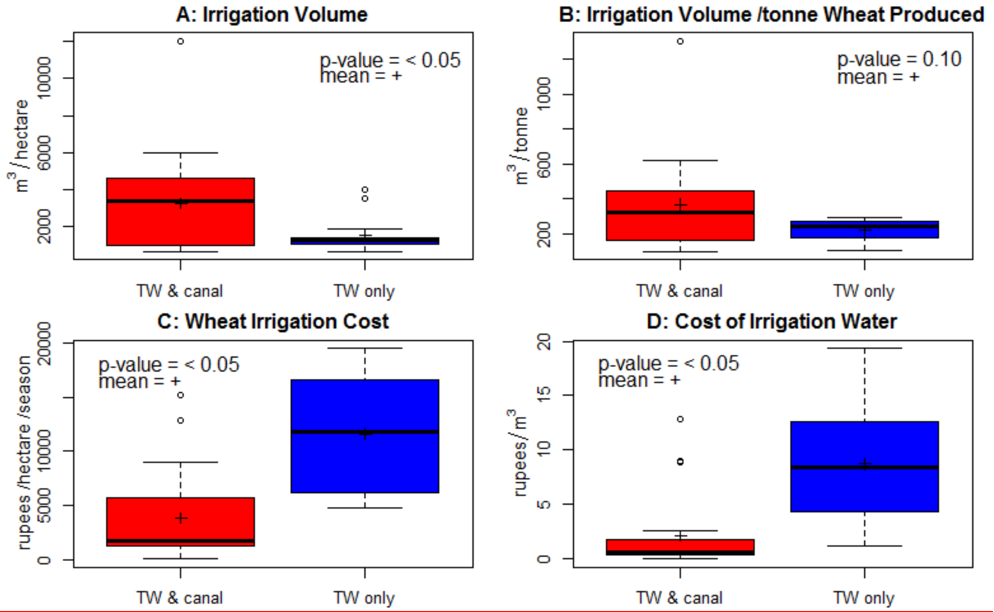
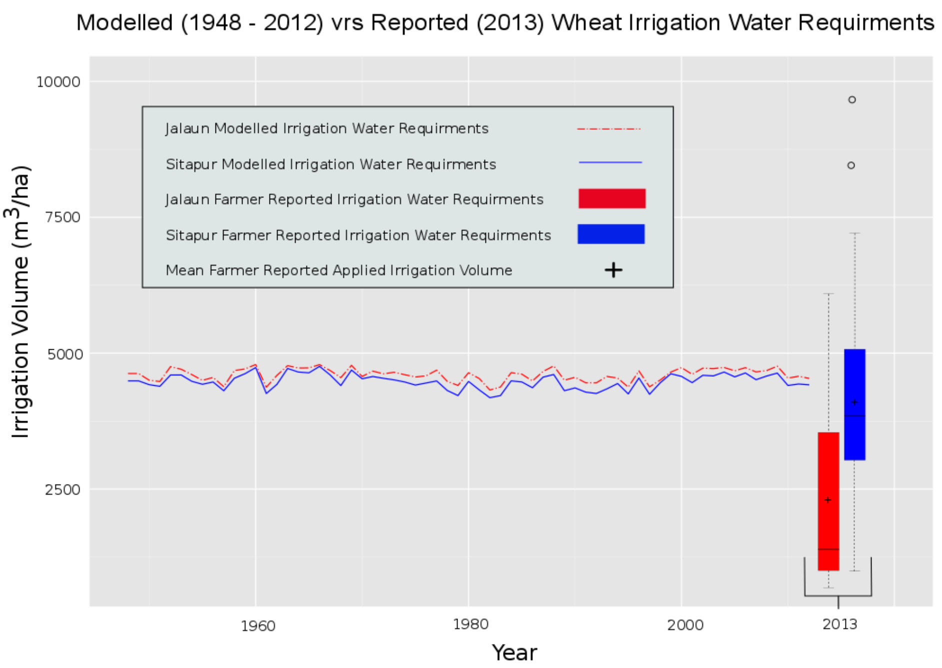


Figure 6: Differences in irrigation practices between tubewell/canal users and canal only users in the district of Jalaun, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The P values give the chance of equal mean obtained from Student's t-test.


Modelled (1948 - 2012) vrs Reported (2013) Wheat Irrigation Water Requirments
Jalaun Modelled Irrigation Water Requirments
Sitapur Modelled Irrigation Water Requirments
Jalaun Farmer Reported Irrigation Water Requirments
Sitapur Farmer Reported Irrigation Water Requirments
Mean Farmer Reported Applied Irrigation Volume
Irrigation Volume (m^3/ha)
10000
7500
5000
2500
1960
1980
2000
2013
Year

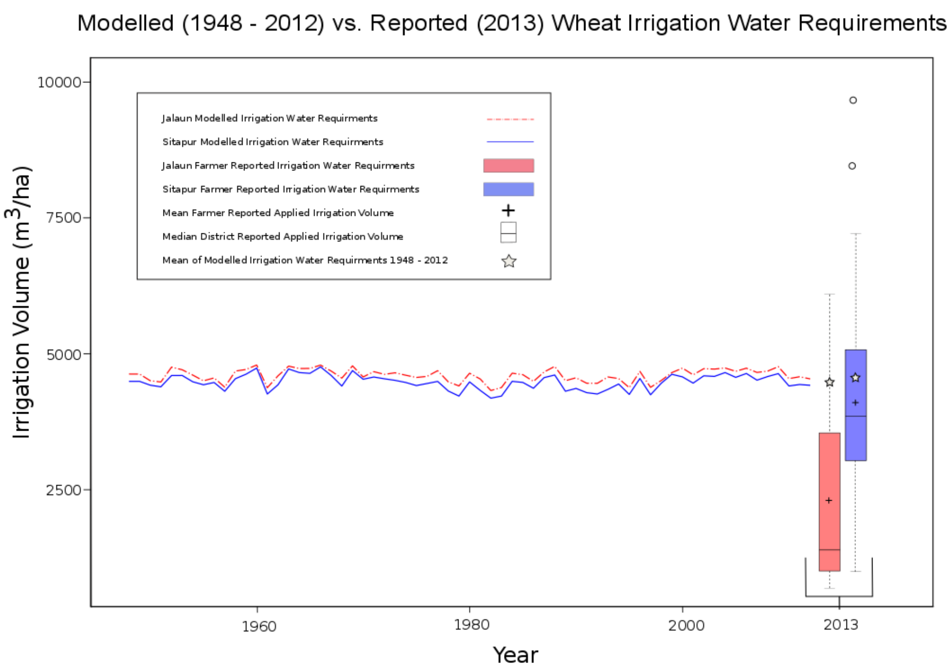

Modelled (1948 - 2012) vs. Reported (2013) Wheat Irrigation Water Requirements
Jalaun Modelled Irrigation Water Requirments
Sitapur Modelled Irrigation Water Requirments
Jalaun Farmer Reported Irrigation Water Requirments
Sitapur Farmer Reported Irrigation Water Requirments
Mean Farmer Reported Applied Irrigation Volume
Median District Reported Applied Irrigation Volume
Mean of Modelled Irrigation Water Requirments 1948 - 2012
Irrigation Volume (m^3/ha)
10000
7500
5000
2500
1960
1980
2000
2013
Year

Figure 7: Differences between wheat irrigation volumes reported by farmers (boxplots) and modelled irrigation water requirements (time series)). The mean modelled irrigation requirements from 1948 to 2012 are also shown (stars on boxplots) to aid comparison with 2013 reported information. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). Circles represent outliers; values which exceed 1.5 times the IQR.

SUPPLEMENTARY MATERIAL

Interview Topic Guide

Date/Time	Location (name & GPS)	Interviewee ID

Farm and Crops

- Farm area
- Can you tell me what types of crops you grow? Why do you grow these types? Crop yield
- How would you describe the soil here? Does it affect how you decide which crop type you grow?
- Can you tell me about your crop calendar? When do you sow/harvest crops? Why these times?

Irrigation Practices

- Can you tell me about your irrigation practices? What makes you decide to irrigate? How often? Why?
- How much water do you apply to your crops (depth)? Why this much water? Does this vary? Why?
- What makes you decide how much and how often you irrigate?
- Can you tell me about how you irrigate? (Irrigation method, time/ha, problems encountered)

Water source

- Where do you get your water from? (if multiple sources try to get % split)
- What makes you decide where you get your water from? (Cost, distance, availability?)
- Do you think it is cheap or expensive to irrigate your crops? (Cost of irrigating at beginning/end of wheat/rice season by source (canal & tubewell))
- Do you sell any of your water? (Price, number of customers)
- If using well: Can you tell me about the well you use? (May be well owner or water buyer. Depth, age, water level at beginning end of season, well yield)
- If using canal: Can you tell me about irrigating using the canal? (how often do you use it, reliability)
- How long have you used your current water source(s)? Before this where did you get your water?
- Are there any other ways of storing collecting water on your land?
- Do you ever have problems with getting water when you need it? (water level dropping too much, well interference, access to well due to waiting for turn)
- Do you think that where you get your water from changes the way you use it? (efficiency, volume, time)
- Can you tell me about the pump you use? (diesel, electric, power, cost to run, problems with use)

Other

- What do you think are the biggest challenges you face in farming? (water, labour, costs, access to resources)
- Have you noticed any changes in water availability? (Groundwater levels, canal reliability)
- Do you think the current farming practices can last? Why?