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

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From Anonymous Referee 1: Comments

I read hess-2015-254, "The use of Semi-Structured Interviews for the Characterisation of Farmer Irrigation Practices", by J. O'Keeffe and colleagues with a great interest. The paper promotes using semi-structures interviews for obtaining various data on irrigation practice directly from farmers. These data can be then used for decision making as well as informing hydrology/water resource system models (and ultimately Earth System models) for understanding the extent of human-water interactions in time and space. This is quite important considering the lack of measured data on irrigation water use and the fact that current estimations contain various sources of uncertainty, which are often large in their quantity. The paper is well-written and certainly within the scope of HESS; however, the paper suffers from several, some rather major, deficiencies, which should be improved prior to the final publication in HESS. Below I try to briefly elaborate on these limiting points – please consider these comments as positive. I believe there can be a good paper in here. First, although authors provide quite an extended description of "semi-structured" interviews, it is not very clear how this mechanism was applied in this particular case. Authors should provide information on how the farmers were approached, interviews were guided, and more importantly, how the truthfulness of the information obtained can be verified independently using e.g. local observations etc. I suggest, therefore, that Section 3.1.3 is extended to provide enough description for interested readers to replicate such procedures in other cases. Second, the results are rather raw considering the arguments made in the introduction. Section 3.2 briefly presents few statistics and discuss their variability between and within regions. This is totally fine but is not enough considering the motivation highlighted in Section 1. In particular, how can such information be used in large-scale models instead of bottom-up and top-down estimations? Please elaborate on that. Third, what are the sources of uncertainty in the information obtained from these interviews and how can these uncertainties be quantified and taken into account in modeling and/or decision making applications? Without such information, it would be very hard to convince modelers and decision makers to use such data. Forth, how can these data be compared with various top-down and bottom-up estimations? Data on global, nationwide and regional water use are available through various sources (e.g. FAO-AQUASTAT), which can be downscaled based on various proxies to the regions considered in this paper. Alternatively, various algorithms are available to estimate the irrigative water demand (and with some assumption water use), e.g. the difference between PET and ET. These estimations should be compared with the data obtained from interviews. Fifth, what sort of qualitative data are obtained in here? All variables mentioned in Section 3.1.4 and 3.1.5 are purely quantitative and I am wondering what are the merits of semi-structured interviews in here? I am not a social scientists and my knowledge on qualitative methods are rather minimal, however, I think all the information obtained in here can be obtained using simple questionnaires with exact questions and exact answers. So there is no room for "previously unknown information to emerge". Regarding this, I think authors should take into account the short comments made earlier on their paper. I also have two minor comments: First more information is required for RQDA software and how it can be used to process the information obtained from interviews. I suggest a stand-alone subsection for this. Also the quality of Figures 3 and 4 should be improved. Many thanks for your attention and best of luck with revising the paper!

Responses to Anonymous Referee 1:

1

Description of semi-structured interview but not clear how mechanism was applied. Authors should provide info on how farmers were approached, interviews were guided and more importantly how info can be verified.

Extend 3.1.3 to provide enough description for interested readers on interview logistics (how farmers were approached etc. and the truthfulness of info collected)

- ***In section 3 we have added additional detail on how the mechanism was applied. This involved rewriting section 3.1.3, adding a separate sampling section (3.1.4) and a section on conducting the interview (3.1.5) to provide more detail on how potential interviewees were chosen, approached in the field and how the interview itself was carried out.***
- ***In section 5 (lines 488 to 495, revised version) we state the importance of the verification of the collected data, particularly highlighting the use of objective measures such as onsite monitoring of water levels. We recommend this as a future research goal as its implementation was outside the scope of this paper.***

2

Results are a bit raw considering the claims in section 1. How can this info be used in large scale models instead of bottom up top down approaches? Please elaborate

- ***The aim of the collected information is to provide insights which aid decision making. For this reason it is not particularly aimed at large scale models, but models with resolutions which are suitable for making relevant policy decisions. We highlight large scale models to emphasise that while they are excellent in providing an overall view of phenomena on a large scale, they lack much of the detail necessary to provide meaningful insights for policy design. Both the quantitative and qualitative data collected however can, and will be used to drive certain models; however it is outside the scope of this paper to demonstrate that. We address these concerns in the introduction (page 2, lines 51-56, revised version).***
- ***In section 4.3 we highlight the differences between importance of incorporating field collected data in modelling by comparing farmer reported irrigation volumes with outputs generated climatic data and the Hargreaves-Samani method for evapotranspiration calculation.***

3

What are the sources of uncertainty from/in interview data and how can these uncertainties be taken into account in modelling/decision making applications – it will be very hard to convince modellers to use this data otherwise.

- ***A number of uncertainties, including those gained through social desirability response bias, the time of the year in which the interviews were conducted (monsoon or dry season) and the sample size is highlighted in section 5.***
- ***These can be accounted for by obtaining information from as large a sample size as possible, examining trends within areas and identifying outliers.***
- ***We also highlight in section 5 approaches for reducing uncertainty such as triangulating collected information with other sources including socio-economic data, outputs from other models and in particular field level monitoring of the variables where possible. We stress that some of this is outside the scope of this paper.***
- ***While we acknowledge that some uncertainties still exist in the collected data, we are confident that they still provide a realistic and useful representation of the phenomena in the region.***

4

How can these data be compared with bottom up top down estimation? E.g. aquastat, various ET/PE estimation methods and irrigation calculation algorithms to estimate irrigation water demand? These should be compared with interview data.

- ***In section 4.3 we compare the farmer reported irrigation volumes with modelled irrigation water requirements using Hargreaves-Samani method for evapotranspiration calculation. This is also represented graphically in figure 7.***

5

What sort of qualitative data was obtained? Most of what is shown here could be done with simple interviews with exact questions and answers, no room for previously unknown data to emerge – for this take into account the previous comments.

- ***Section 4.2, which focuses specifically on the qualitative information which emerged during the interviews, has been added. This included some of the more prevalent themes which emerged during the interviews such as water availability issues, a lack of a reliable electricity source, problems with the government, climate, farmers perceived reasons for water level depletion and their suggested solutions. Additional information, including the presence of a water sharing system, the problems associated with obtaining farm labour and how that affects irrigation methods, and the damming of canals by farmers is also described.***
- ***The topic guide used during the interviews can also be found in the supplementary information.***

RQDA subsection and improve figures 3 &4

- ***We have provided some additional detail on RQDA within section 2.4. We also refer the reader to the documentation of this software programme in the text.***
- ***Figures 3 & 4 have been improved.***

From Anonymous Referee 2: Comments

The authors have generated an interesting paper that aims to demonstrate the value of semi-structured interviews in water resource management research. In many ways this is a methods paper - that describes in detail how semi-structured interviews can be utilised by natural scientists or engineers researching water management issues. This is a very worthy cause, as many different research methods and approaches have specific value and raising the awareness in the research community of the diversity of approaches is essential. The authors attempt to illustrate their arguments for the value of semi-structured interviews with a very interesting case study from India on irrigation practices. My concern with the paper is that the authors do not provide particularly convincing arguments from their case study for the advantages/benefits/strengths of semi-structured interviews compared to other traditionally social science approaches more commonly used by natural scientists working in water management such as surveys and questionnaires. The data presented in the paper is focussed around quantities of water used, sources of water, crop yields and pricing of water (for which semi-structured interviews are unlikely to be the optimal data collection approach). This quantitative data is traditionally obtained highly efficiently and accurately using surveys. The benefits of surveys for such data collection include being that multiple researchers can conduct the fieldwork (if done in person) with less concern that differences in the data set collected will result. In other settings, remote methods such as telephone interviews and online surveying can highly efficiently collect this information. The authors rightly note that the strengths of semi-structured interviews are in the rich diversity of information that is provided to the researcher by the interviewees, which enables the researcher to identify factors that would not have been revealed through a structured interview/survey. To support this argument I would expect the authors to present data showing what topics/items/issues they discovered that they did not already know when they went into the field. This is most likely to be based on qualitative data, that explores the underlying factors (such as beliefs, strategies and constraints) driving irrigation practices. This is alluded to in the paper but not substantiated with data. For example, why is there such diversity in price paid for water between different users of canal water in the same area? How does this affect a farmer's decision to use tubewell water? How reliable is water at certain critical times of the year and how does this affect farmer's decision making on water use and source? What factors appear to be most critical for farmer decision making on water use and crop scheduling - is economics and water pricing the dominant factor or do other issues such as water rights and institutional support play a role? It would also be very interesting if the authors could expand on how this information can be translated into research recommendations for scientists concerned with modelling water resource management, policy makers planning water supply, and farmers attempting to manage their available resources. The economics, geography, anthropology and sociology literature has made attempts to address these types of questions in water management settings and this paper should tap into this body of work in its analysis of the (undoubtedly) rich data that has been collected by the authors. By bringing in more qualitative data the authors will be able to more convincingly argue the value and worth of semi-structured interviews to the research community - and particularly natural scientists/engineers who rarely consider the critical need for such research approaches. At the same time, the authors should ensure that they fully address some of the concerns and challenges that researchers often have with data derived from semistructured interviews. Several are touched upon (e.g. translators, representation and reliability). But there is considerable scope for more comprehensively discussing these concerns, again using the wealth of social science literature from human geography, development studies and anthropology. For example, data quality concerns (have interviews revealed the "truth" and what is the "truth" when in most situations there is no one correct answer, rather all answers are biased and reflect the context in which they are given), consistency concerns (did all interviewees provide data on all the same topics and if not is this because the issue is irrelevant for them or was it simply overlooked during the interview?), representativeness concerns (how relevant, in this case study, is it that the sample "represents" the wider/entire community? How have interviewees been selected?). I would suggest the authors consider shortening the introduction and methods sections by referring the reader to key texts on setting up and conducting semi-structured interviews (for example "Doing Development Research", edited by Desai and Potter (2006)). They should, however, explain how they selected farmers for interviews (i.e. randomly encountered in the sampling regions or through a "gatekeeper"), and consider including the semi-structured question sheet and perhaps an interview transcript (as supplementary material or an appendix) as this would be of interest to a reader unfamiliar with semi-structured interviews. The paper should also be balanced by some discussion of the limitations and challenges of working with data derived from semi-structured interviews and the arguments annulling these concerns or strategies adopted to address them. Most critically, to make this a paper illustrating the use of semi-structured interviews (as a mixed-methods approach) the authors should include data that would not have been possible to collect via surveys, such as the underlying factors driving irrigation practices. If they could then discuss, or even better demonstrate, how these mixed qualitative/quantitative findings could be integrated into hydrological modelling and water management planning the paper would be of great value to the community.

Responses to Anonymous 2:

7

Authors don't present convincing arguments for the benefits of SSI compared to other more commonly used methods – eg surveys and questionnaire

The authors highlight this in a way of collecting information that would have been possible to collect in other ways. To support this I would expect data presented on topics that they did not know of in the field (how farmers pay for irrigation, their reaction to price, why is there such a reaction to price, how does it affect farmers decisions to use TW water…)

- ***Please refer to comment 5 above.***

8

How can this research be translated into research recommendations for scientists – tap into economics, sociology, geography literature

- ***Gaps in the research include quantifying the difference between results provided by farmers and more objective measures and how to best use this information for modelling and decision making.***
- ***We make some recommendations for future work in section 5.***

By bringing in more qualitative data the authors will be able to more convincingly argue the value and worth of SSI's, particularly to natural scientists/engineers

- ***Please refer to comment 5 above.***

9

Authors should address some of the concerns and challenges with dealing with data from SSI's - again use sociology, development studies, anthropology. (E.g. data quality concerns; have interviews revealed the truth and what is the truth when in most situations there is no correct answer…consistency concerns…representativeness concerns)

- ***Some of the concerns with the methodology and data obtained through semi-structured interviews is addressed in section 5. This includes problems associated with its collection, such as the propensity for interviewees to please the interviewer, and the data itself including how it can be triangulated with other data sources.***

10

Explain how you picked farmers, consider including a semi-structured interview topic guide and transcript

- ***We have extended the description of how data collection was undertaken by expanding the interview design section (3.1.3), and the data processing and analyses section (3.1.6), as well as including sections on sampling (3.1.4) and on conducting the interview (3.1.5)***

11

Paper should also be balanced by limitations and concerns of working with data derived from semi-structured interviews. How are these concerns addressed?

- ***We provide a description of the limitations of collecting data using this methodology in section 5, and how they may be addressed, for example through the collection of objective data such as monitoring of water levels and water abstraction rates.***

12

Most important to illustrate the importance of semi-structured interviews. Include data that would otherwise not be possible to collect via surveys, e.g. underlying factors driving irrigation behaviour

- ***We have added section 4.2 to specifically include some of the qualitative data obtained in the interview, including some of the perceptions farmers have to challenges such as falling water tables or issues with the government corruption. Additional information, such as the impacts of a labour shortage on irrigation methods, or different ways of obtaining water are also included.***

13

Show how this (or demonstrate how these mixed qualitative/quantitative findings) could be integrated into hydrological modelling and water management planning.

- ***In section 4.3 we compare field collected values with modelled outputs, highlighting the differences between the two methods and the importance of incorporating local knowledge where ever possible. While outside the scope of this paper, we also state that this information is useful in informing and driving models, through more realistic quantitative values, and model rules provided through qualitative data.***

K. Waylen kerry.waylen@hutton.ac.uk Received and published: 1 September 2015

Your work has collected some interesting information, but I believe you have made inappropriate reference to the work as "qualitative", and this weakens the credibility of the study. Qualitative scientific research has a different epistemological basis, and its relevance, credibility and quality are constituted quite differently to research that follows the quantitative paradigm. This affects everything from the research questions to the design and analysis of qualitative research projects. As an example, the issue of sampling: the sampling approach for semi-structured interviews does not aim to achieve a representative sample of a general population (e.g. using random sampling), instead a smaller number of in-depth carefully conducted interviews are carried out with interviewees usually purposively selected to understand key aspects of the range, whilst the resulting data would then be carefully analysed (not using statistics) to disentangle and explain the patterns between issues. So, I suggest this work must not be presented as qualitative. As far as I can tell you have used an approach to understanding the problem, sampling and data analysis that is consistent with the quantitative positivistic sciences: so I suggest you simply present it as such, and discuss the strengths and weaknesses of your work in these terms. (Linked to this, I suggest your data collection approach might better described as a survey administered in person/ face-to-face, rather than as semi-structured interviews.) Taking this approach won't preclude you from discussing any additional insights that you uncovered through the survey, or any issues that you can't analyse using statistics, but it will mean that they are better contextualised and you won't be judged as over/misclaiming by any social scientists who read your work. I hope that makes sense and is helpful, good luck with the work.

Main points and responses:

- Inappropriate reference to qualitative
  We have added section 4.2 which includes some of the qualitative data obtained in the interview, including some of the perceptions farmers have to challenges such as falling water tables or issues with the government. Additional information, such as the impacts of a labour shortage on irrigation methods is also included.

- Sampling for semi-structured interviews doesn't aim to achieve a representative sample for general population (eg as in random sampling)
  In this study we used semi-structured interviews as a tool for gathering qualitative and quantitative data. While the sampling is more consistent with quantitative methods we feel it was the best approach in this situation. To address this comment we have expanded section 2.2 to better explain the sampling structure.

- Reviewer suggests that this work **should not** be presented as qualitative
  Section 4.2 has been added to highlight the qualitative data that was obtained during the interview.

- Approach used more consistent with quantitative positivistic sciences
  This has been addressed in section 4.2.

- Better described as a survey administered face to face – Not SSI.
  Examples of data gained through employing a semi-structured approach which emerged during the interviews can be found in section 4.2, along with a more detailed description of how they were carried out in sections 2.1 to 2.4.

K. Waylen kerry.waylen@hutton.ac.uk Received and published: 3 September 2015

Hi Jimmy Thanks for the detailed response. I do appreciate that carrying out as well as reporting mixed methods can be challenging, and agree that your approach of face-to-face interviewing/surveying sounds generally appropriate way to explore the issues and get estimates of certain characteristics, given the situation you were working in. However, you need to be careful in the presentation and claims made for the methods (also in the description of limitations - e.g. using a translator is not a challenge inherent or unique to semi-structured interviews). Therefore I am glad that you will consider updating the presentation of the methods in any future iterations of the paper. I reiterate the specific suggestion to present this as a survey administered face-to face, rather than as semi-structured interviews. As you say, semi-structured interviews can be excellent for studying "the impacts of events on individuals" but I think you did not use your survey/interviews for this purpose? I saw you assess and report characteristics of farms and water management, but do not report any information that was not about these characteristics, which implies there was not much flexibility in the data collection and no exploration of perceptions and experiences, both of which would be expected if using s-s interviews. Good luck with the revisions Cheers Kerry

Main points and response:

- Be careful in the claims made for the methods
  We have added section 4.2 to describe the information collected through semi-structured interviews.

- Be careful in the claims made for the limitations (ie those claims with translators not unique to SSI)
  While not unique to semi-structured interviews, we believe highlighting shortfalls associated with the use of translators is an important point, particularly as the data scarce regions such as that in the case study will often require one. We have also expanded section 5 to incorporate additional limitations, as well as opportunities with both the methodology and the data collected.

- SSI excellent in showing impacts on individuals but you did not show this
  We have addressed this comment in section 4.2.

- You assess and report characteristics of farms and water management but nothing else. Implies there was not much flexibility in data collection

In section 4.2 we have included the qualitative data that was collected, and highlighted some of the data that was provided by allowing participants to lead the conversation. This includes problems with the government or neighbour relations, themes which emerged through the use of semi-structured interviews.

- No exploration of perception and experiences which are expected in SSI
  We have addressed this comment in section 4.2.

K. Holstead kirsty.holstead@hutton.ac.uk Received and published: 3 September 2015

Thank you for this interesting discussion so far. I second the concerns of Kerry. Your paper presents some interesting findings however I still have a number of major issues with the methodology, in particular how you used Grounded Theory for your analysis. The basis of Grounded Theory which you correctly pointed out is that it allows a researcher to let issues emerge from the data to develop a theory. However, since it appears you set out in the beginning to gather very specific data on the characterisation of farmer irrigation practices looking at volume of water applied amongst other variables, then this strongly suggests that you have not allowed for any emergence of new concepts and should not be labelled as such as this is misleading. I am particularly concerned as you noted that coding is "straight forward"; overall I feel that your analysis fails to deliver the reflexivity and rationality inherent to this approach.

Main points and response:

- Issue with grounded theory analyses – doesn't look like this was used as you set out with specific data in mind
  We have removed the reference on grounded theory analysis.

- Did not give other data a chance to emerge – no room for new concepts
  We have addressed this in section 4.2.

- Concern that the coding is "straightforward"
  In this section we were implying that the process of qualitative analysis is made easier by the use of software, not that it is an easy process. We accept that this was not well described in the text and have now made this clearer in section 2.4.

- This analyses fails to deliver the reflexivity and rationality inherent to this approach
  We believe we have addressed this in the revised version of the paper.

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~~**ABSTRACT**~~

Abstract

Generating information on the behaviours, characteristics and drivers of users, as well on the resource itself, is vital in developing sustainable and realistic water security options. 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 organised around a topic guide, which helps lead the conversation in a standardised way while allowing sufficient opportunity ~~to identify~~for relevant issues ~~previously unknown to the researcher~~to emerge. In addition, semi-structured interviews can be used to obtain certain types of quantitative data. While not as accurate as direct measurements, it can provide useful information on local practices and ~~farmers'~~users' insights. We present an application of the methodology on farmer water use on 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 of the information, along with some data visualisation is also presented, which highlights 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 on water resources, leading to more realistic management options and increased water security in the future.

1~~.0~~ 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 on the human - water interface (Nazemi ~~and~~& 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 ~~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). Water resource management can broadly be categorised into water demand and water supply decisions, which can further be split into irrigative and non irrigative demands . Indeed, the significance of including so-called soft data has been well documented (Nazemi and Wheater 2015)(see Siebert, 2002; Fenicia *et al.*, 2011). Winsemius, *et al.*, (2009). Globally, irrigation water consumption accounts for some 70% of total groundwater and surface water withdrawals argues the 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" (Wisser, *et al.*, 2008)(Döll & Siebert, 2002) is an important step in more accurately representing anthropogenic water use in models and 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 . 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 and Wheater 2015)(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. .

Representing water use however presents many challenges, much of which stem from a lack of data Consequently irrigation water use needs to be explored in more detail than non-irrigative demand (Gao *et al.*, 2012; Portmann *et al.*, 2010)(Nazemi & Wheater, 2015). This often leads to oversimplification, either in resolution .

Representing water use however presents many challenges, much of which stem from a lack of data (Döll and Siebert 2002)(Gao *et al.*, 2012; Portmann *et al.*, 2010) 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 (see . This often leads to oversimplification, either in resolution Allen *et al.*, (1998); (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 McKenney (1993)(Allen *et al.*, 1998;) 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. While such approaches are useful as an overview of large scale issues, they are inadequate for developing realistic solutions at any meaningful implementable level. 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.

In social sciences and healthcare the collection of both qualitative and quantitative information through interviews is relatively common practice (Barriball and While 1994; Ellis and Chen 2013; Fallon 2008; Gibson 1998)McKenney, 1993), however the methods employed are rarely used in the fields of earth and engineering sciences. 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 For the purposes of data collection for hydrological studies little guidance exists. In a time and resource constrained setting the use of semi-structured interviews provides an efficient and effective method of data collection. This is particularly true of data scarce regions. According to (Calheiros, 2000)(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 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.

In social sciences and healthcare the collection of both qualitative and quantitative information through interviews is relatively common practice , 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)(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. . 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.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 field information exists. According to 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 2002Calheiros, 2000), while still allowing the overall direction to be shaped by the participants own understanding, so called experiential or traditional knowledge, of their environment., 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 This naturally highlights issues which are of most importance to the interviewee and allows room to incorporate new themes.The use of semi-structured interviews is common in fields which have a strong social science component as the method quickly produces rich and detailed data sets offering an accurate assessment of the impacts of events on an individual (Fallon 2008Calheiros, 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 . Importantly it can also shed light on the drivers of these events and the motivations behind participant decisions,

~~providing a valuable contribution to earth systems modelling. The semi-structured interview allows information to be collected efficiently and cheaply, in an unobtrusive and open manner.~~

~~In this study we use grounded theory analyses developed by (Glaser and Strauss 1967)~~(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 which are of most importance to the interviewee and allows room to incorporate new themes. ~~. This inductive process allows the researcher to be guided by the analyses of data, developing a substantive theory through emersion in the collected information~~ Semi-structured interviews can quickly produce rich and detailed data sets ~~(Ellis and Chen 2013)~~(Fallon, 2008)~~. We propose a methodology for the collection of qualitative and quantitative hydrological data through semi-structured interviews. We apply this approach to two districts in the Northern Indian State of Uttar Pradesh to study irrigation water use and the results will be presented as a case study in section 3.~~

~~2.0~~ 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, 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 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 presented as a case study in section 3, with the methodology used described in 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 ~~subject, in conjunction with~~, as well as the social nuances which exist in a study ~~area~~region. This knowledge is essential ~~when designing~~in the planning phase, including in the design of the topic guide, around which the semi-structured interview is based (Ellis ~~and~~& Chen, 2013). The ~~pre-fieldwork~~ 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 research as well as knowledge of the local characteristics. Questions should be unambiguous and easily understood by interviewees, ~~be~~ related to their own experiences, ~~be~~ ethically and culturally sensitive and ensure that they assist, rather than impede, the flow of ~~the interview~~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 can occur when the ~~interviewer allows the~~ interviewee is allowed sufficient opportunity to speak freely~~,~~ which ~~can result in the acquisition of novel information,~~ , by making use of the fact that ~~the interviewees~~participant's are ~~"~~experts by experience~~".~~, may result in the emergence of new and novel information. This approach allows both quantitative and qualitative data ~~collection and has been demonstrated to~~ 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 ~~quality and~~ cost whilst ensuring a useful representation of parameters. Semi-structured interviews are traditionally comprised of open-ended questions. The collection of quantitative data ~~within a semi-structured interview~~ however is ~~better~~best obtained through direct questions. For this reason the topic guide contains both. The topic guide used in the case study interviews contains both open-ended and direct questions (can be seen in the supplementary information accompanying this paper). While acquiring quantitative information in this manner is not as accurate as 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 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 ~~the~~an entire population, not just to the individual participants of a study (Flick, 2014)~~. Sampling comprises an integral part of study design. In order to obtain representative data while making best use of available resources; a combination of sampling techniques can be employed.~~. 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 sampling procedure traditionally adopted with semi-structured interviews does not aim to achieve a representative sample, it is felt that 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. 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. 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 ~~may be~~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 the study to potential ~~interviewees forms an integral part of the program.~~participants is essential in order to gain 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 ~~conducting a semi-structured interview~~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.

~~In our case study, 100 participants were interviewed during the course of the field work. All interviews were carried out by the same interviewer. Apart from the rephrasing of a number of the questions to better target a particular aspect, or in order to make the question more understandable to the interviewee, the same topic guide was used throughout. As the interviewer did not speak the local language, in this case Hindi, it was necessary to employ translators to facilitate the interviews. Pre-project training should be provided before hand to ensure best practice is followed at all times. Interviews were often~~ Interviews may need to be carried 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.

~~During the interview it~~It is important that ~~all~~ the ~~information~~interview is recorded~~. While there are many ways~~ in as much detail as possible, ideally through a mixture of ~~doing this,~~field notes and a voice recorder~~ provides a reliable and unobtrusive way of recording all the information provided~~. Again, consent should be sought from the interview participant prior to the recording of any conversation.~~ It is also important that field notes are kept.~~ GPS readings of where the interview

~~took~~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. ~~The storage of data can also fall under the umbrella of ethics as the research project may involve the collection of sensitive information.~~ 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

Formatte

Following the collection of data, all interviews ~~were~~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, ~~not just~~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 a thematic analysis begins. These 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.~~

Field Cod

~~The first step in data analyses is the setting out of categories based on the collected material. Categories may include; water use, irrigation methodology, irrigation costs, crop information and participant livelihood. A coding guide is then produced whereby all information within each interview is highlighted based on the categories. This is straightforward to achieve using appropriate software which also allows information, both qualitative and quantitative, on each theme to be recalled easily. Once the data has been coded, overviews on the distributions of the variables within the data base can be produced. A significant portion of the data collected should also be quantitative and suitable for some statistical analyses and modelling purposes.~~

~~3.0~~ provides a useful platform for processing large amounts of qualitative data. Here, 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 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~~:~~

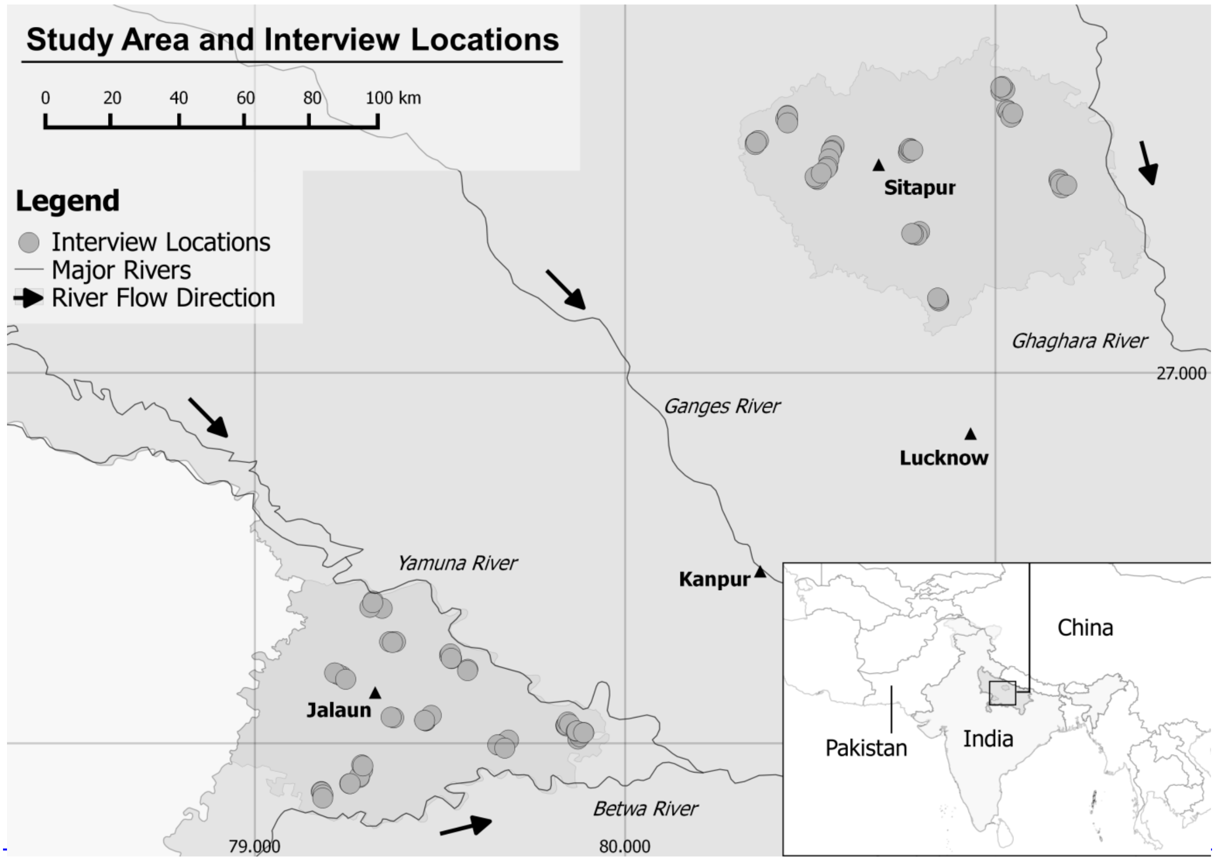
3.1~~.~~ Study region: the Ganges Basin, North India

The ‘Green Revolution’ has led to enormous gains in agricultural productivity in India~~. This has involved~~, largely through the use of more reliable seeds~~,~~ and ~~an embracing of~~ improved irrigation technology (Singh, 2000).~~The Green Revolution~~ This has allowed India to become food self-sufficient ~~and in doing so has raised Asian per capita food production by 27%~~ (Jewitt ~~and~~& Baker, 2007)~~. While it~~ and has undoubtedly improved life for the majority of rural poor~~, safeguarded livelihoods and kept food prices in check, the~~. The Indian green revolution has also received much criticism for its environmental and socio-economic impacts ~~including~~. This includes a reduction in ~~available~~India’s water resources ~~on its way to~~while becoming one of the most intensely irrigated areas of the world~~. Analysis of GRACE satellite data show a dramatic decrease in groundwater resources across North India~~ (Rodell, 2009; Tiwari, 2009; Mueller, *et al.*, 2012).~~Satellite data provides a useful method for assessment of changes in water resources, particularly in a data scarce region.~~ However, to correctly investigate water security ~~this needs to be coupled with~~, 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.

Uttar Pradesh, 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)~~. According to~~ . 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)~~, rice is the single most dominant crop in the state during Kharif (the monsoon season from June to October) and wheat during Rabbi (November to April).~~. 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.~~While the large scale impacts these practices have had 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.~~

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 ~~their~~the motivations of users. Based on irrigation water source information contained within the statistical abstract of Uttar Pradesh, ~~(Anon 2013)~~(Economics and Statistics Division, State Planning Institute, 2013) two districts, Jalaun (highest user of surface water in the

State) and Sitapur (one of the highest irrigators in UP using groundwater, 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.



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

~~***Jalaun***~~

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 ~~(Anon 2013)~~(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 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 are many more diesel pumps in use. The main crop grown in the district is wheat; with a total cropped area of 146,307ha. 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).

3.1.2 Sitapur

Sitapur, also considered one of Uttar Pradesh's less developed districts (Ministry of Panchayati Raj, 2014), is located to the north of the state capital Lucknow, and has a population of approximately 4.5 million ~~(Anon 2013)~~(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)~~. District wise~~. 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 ~~points towards~~indicates 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

~~A list of villages within each district was obtained from the State Census \citep{OfficeoftheRegistrarGeneralandCensusCommissionerIndia2011} and fifteen were randomly picked from each. A total of 100 farmers were interviewed, 50 in each district. As the~~The main focus of ~~the~~this study was to investigate ~~the variation in~~ farmer irrigation behaviour~~, data was collected under~~ 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:

- ~~1~~ Farm ~~*information (farm size, number of farm sections, soil type)*~~
- ~~2~~ and Crop information (farm size, soil type crop type, crop calendar, yield~~*, price received, crop constraints*~~)
- Irrigation ~~*information (water source,*~~ Practices (number of irrigation events, irrigation volume, irrigation methods)
- ~~3~~ Water Source (water source reliability, irrigation cost, irrigation method, influences on irrigation, ~~-~~presence of water market, power source, constraints)
- ~~*4 Aquifer and well information (depth of well, depth to water, pump type, water level fluctuations, cost, constraints, pump information)*~~
- ~~*5 Canal information (reliability of supply, method of water transfer, number of times used, cost, constraints)*~~

~~All interviews were conducted using a translator and all information was recorded using a voice recorder.~~

- 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 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 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 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 and field notes, with GPS readings of pertinent locations and photographs taken throughout.

3.1.6 Data processing and ~~***storage***~~analyses

Once data collection was completed, all interviews were transcribed verbatim and uploaded to the qualitative data analysis package, RQDA (Huang, 2014)~~. A~~ to allow for thematic analysis of the data. During the interviews and while reading the transcripts, a number of themes emerged as being important ~~in terms of irrigation behaviour and water use. These form the basis for all following analyses. They include the volume~~ to the farmers; for example the cost of irrigation, the reliability of their water ~~applied, variability in efficiency~~source, and ~~productivity, irrigation cost~~ the importance of conjunctive surface and ~~the variability in yield. Using these~~ groundwater use. These themes ~~as the focus, relevant data was~~ were coded ~~within each of the geo-referenced interviews~~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~~, and~~. This allowed for statistical analyses of ~~many of the~~ variables~~. 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.~~

~~***Data Analyses***~~

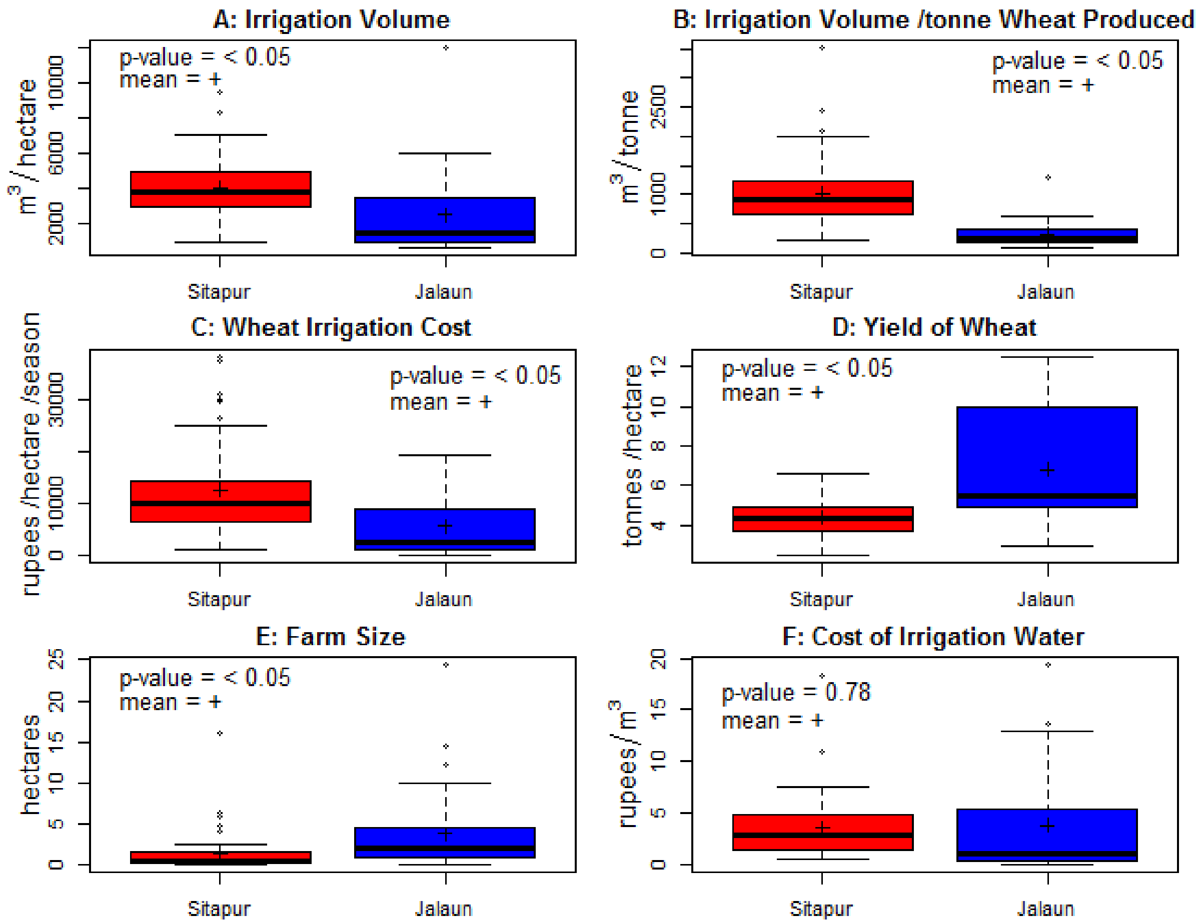
~~T-tests were carried out~~ to assess ~~the variance~~differences in irrigation practices between and within the two districts. These included the volume of water applied (m^3/ha), the volume of water required to produce 1 tonne of wheat (m^3/t), the cost of wheat irrigation during the growing season (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.

~~3.2 Discussion and Results:~~

4 DISCUSSION AND RESULTS

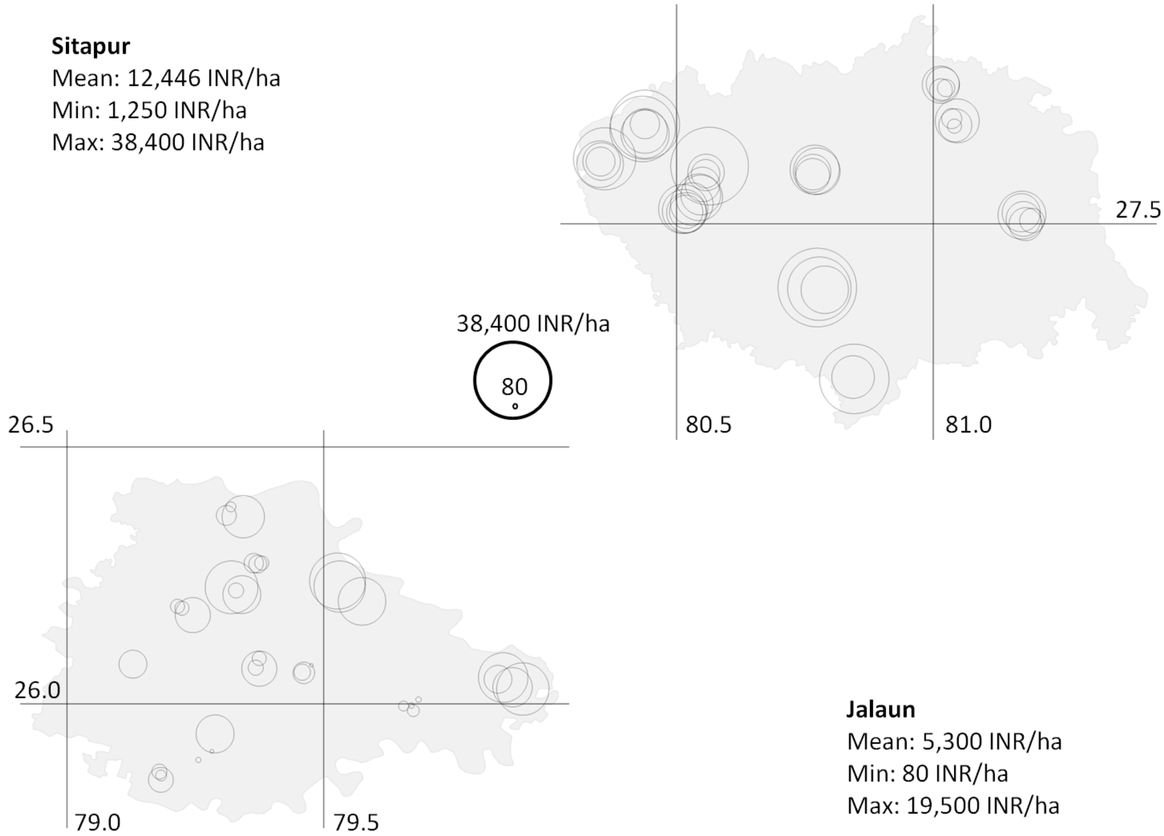
4.1 Quantitative results

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.



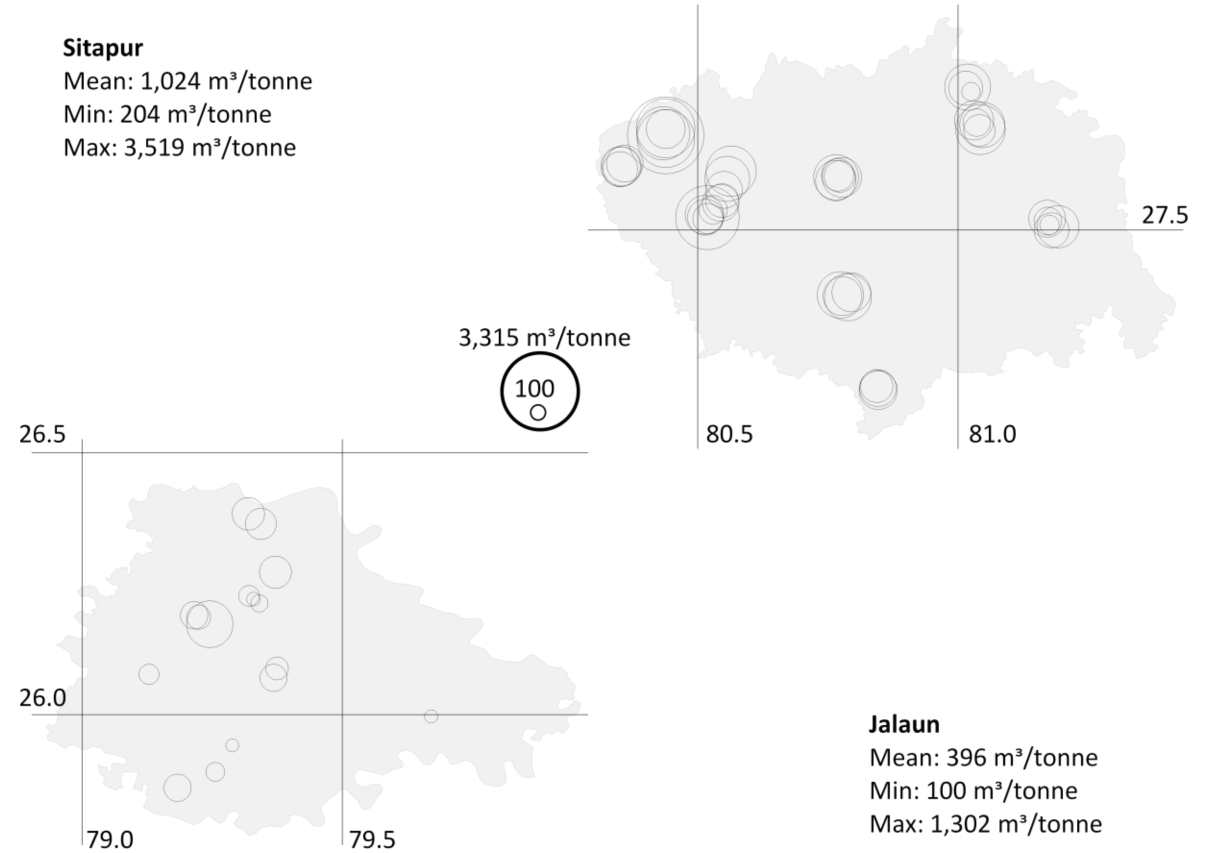
~~Figure 2: Differences in irrigation practices between the districts of Sitapur and Jalaun, Uttar Pradesh, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The P-values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

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).



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

Sitapur is by area one of the largest irrigators in Uttar Pradesh, and for the most part uses 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 (~~32~~33/50) making use of the resource, often in conjunction with groundwater. This provides a ~~cheaper~~cheap, and sometimes free source of irrigation water (~~Figure~~Figures 2C and ~~Figure~~ 3~~); normally in the region of 90 rupees/ha/season for wheat.~~). 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 ~~or~~of irrigation water with those in Jalaun using only 396 m^3 to produce a tonne of wheat.



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

When comparing tubewell users only in both districts further differences emerge. In terms of production efficiency farmers in Sitapur require on average 1,017 m³ of irrigation water per tonne of wheat produced, with their counterparts in Jalaun applying 800 m³ less (Figure 5B). ~~Unlike when doing a direct comparison of all farmers surveyed in both districts, when~~ When only tubewell users are taken into account, the price paid per m³ of irrigation water was found to be very different. Farmers in Sitapur pay on average 3.58 r/m³ whereas farmers in Jalaun pay significantly more; on average 8.71 r/m³ (Figure 5D). The fact that farmers apply less irrigation water in Jalaun however (Figure 5A~~)~~), is reflected in the overall cost of irrigation by both groups (Figure 5C~~), as farmers~~). Farmers in Sitapur ~~also~~ pay on average 1,167 r/ha more to irrigate their wheat crops despite the fact that the cost per cubic meter of water is less.

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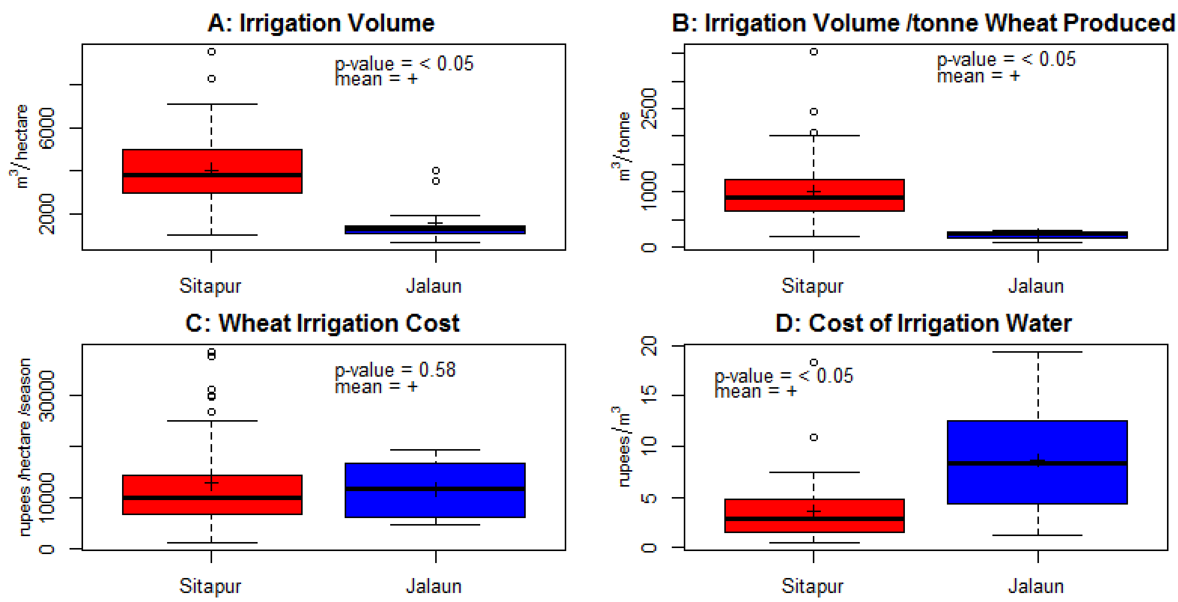
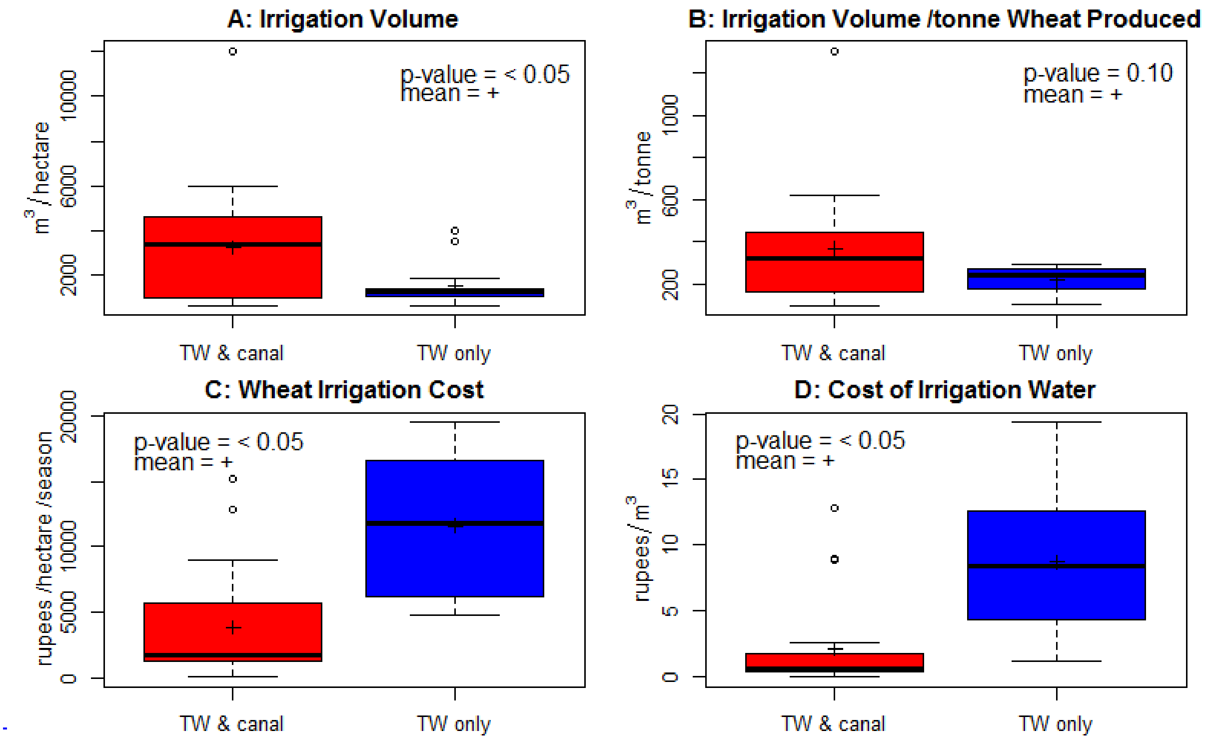


~~*Figure 5: Differences in irrigation practices between tubewell-only users in the districts of Sitapur and Jalaun, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR).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

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 ~~and~~& 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 ~~the scores for~~ both groups (Figure 6A), with farmers who have canal access, applying over 1,722 m^3 of water more than those who rely on tubewells only. While more water is 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 average 2.09 r/m^3 whereas farmers who use tubewells pay on average 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 access to canal water are applying more, and also paying 7,805 rupees/ha/season less to irrigate their wheat.



~~*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.*~~

The data ~~shown here~~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.

~~4.0 OPPERTUNITIES~~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. Among groundwater users, this was predominantly as a result 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 season, causing farmers to rely on deeper tubewells, which are fewer in number, leading to a delay in access. Interestingly, a significant 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 reliable access to a deep well, or owning land in an area with a high water table. While farmers in Sitapur are dependent on groundwater, 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 supplied water often arriving late or early for irrigation. This often 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 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. 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 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".

4.3 Comparison with modelled irrigation requirement results

Crop water requirements can be estimated using a variety of algorithms, for example Hargreaves-Samani (Hargreaves & Samani, 1985) or Penman-Monteith (Allen, *et al.*, 2005). These approaches are extremely useful as they provide results without the need for field level measurements. It is however important to compare the modelled outputs to field data where possible as results can vary considerably. Here we compare the reported volume of irrigation water applied by farmers to their wheat crop with 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 reported by farmers during field work undertaken in 2013. The modelled results and the reported values are presented in Figure 7.

The mean value reported by farmers in Sitapur is 4050 m^3/ha of irrigation water applied during the wheat season. This is 368 m^3/ha below the modelled 2012 result of 4418 m^3/ha. The difference in Jalaun is more significant, with a mean reported values of 2283 m^3/ha, 2253 m^3/ha less the modelled result of 4536 m^3/ha. The median reported value of both districts is also significantly lower than the modelled result, (Jalaun: 1390 m^3/ha, Sitapur: 3800 m^3/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.

5 OPPORTUNITIES AND LIMITATIONS OF SEMI-STRUCTURED INTERVIEWS

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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 ~~allowing~~the opportunity to allow them to expand on the issues of most importance to them provides a unique opportunity to develop an understanding of the human water interface in ~~that~~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 section 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, 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 statements indicative of social desirability response bias

~~Despite the usefulness of semi-structured interviews, we identify some limitations. In many cases interviews require the use of translators. Shortfalls associated with using a translator are described in (Kapborga and Berterö 2002)~~(Collins *et al.*, 2005)~~, however to limit the potential for discrepancy, training should be provided prior to fieldwork.~~ which may be reflected in the collected information. In the case study reported above, interviews required the use of translators. Shortfalls associated with using a translator(s) are described in ~~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 cultural barriers which may exist between a researcher and participant. Facilitating a suitable interview environment also forms part of the role of the translator or facilitator. 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 statements indicative of social desirability response bias (Collins *et al.*, 2005)~~(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 ~~be reflected in the collected information.~~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~~,~~ ~~(Anon 2013)~~(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 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 ~~will~~should be ~~needed~~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.

~~5.0~~6 CONCLUSIONS~~:~~

Our current limited understanding of the human - water interface is a major shortfall 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 on topics such as irrigation water volumes, the cost of irrigation, water source and the drivers behind these practices. Statistical analysis 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 farmer behaviours, and their environment are highlighted. The semi-structured interview provides 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 while highlighting themes which may not have been obvious beforehand, as well as pointing out aspects of the study which may no longer be relevant. The data collected also lends itself to more detailed hydrological and hydro-~~economical~~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

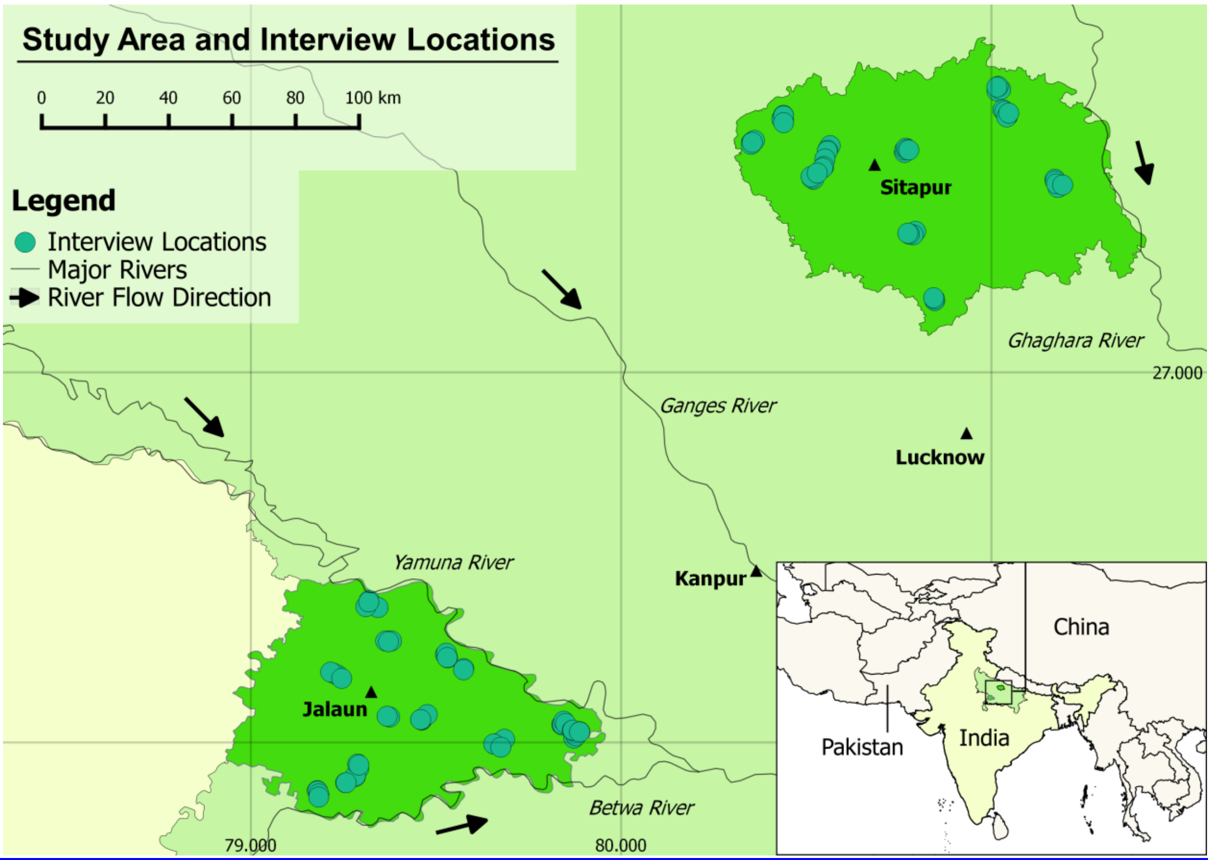

Figure 1: Map of the study region including the locations of field interviews carried out.

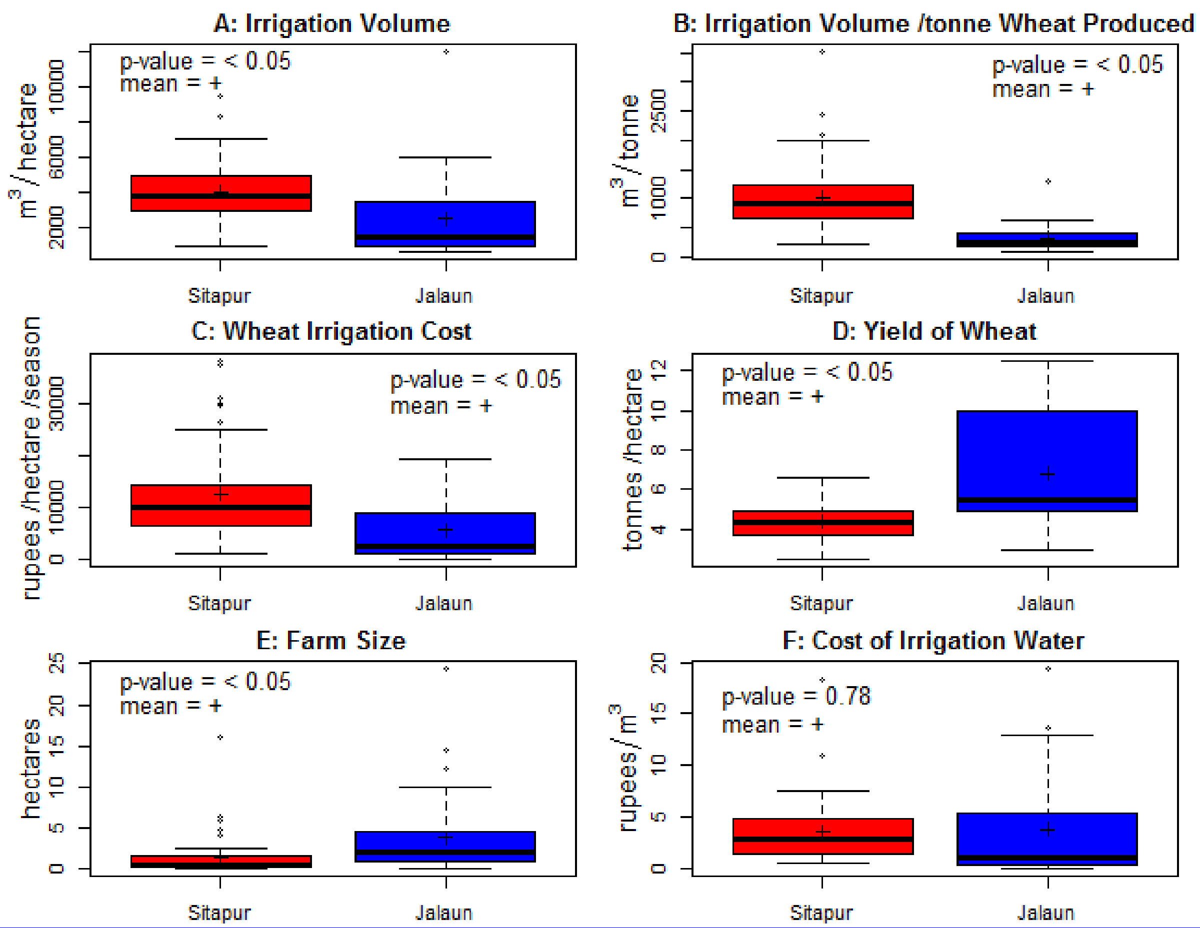

Figure 2: Differences in irrigation practices between the districts of Sitapur and Jalaun, Uttar Pradesh, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The P values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

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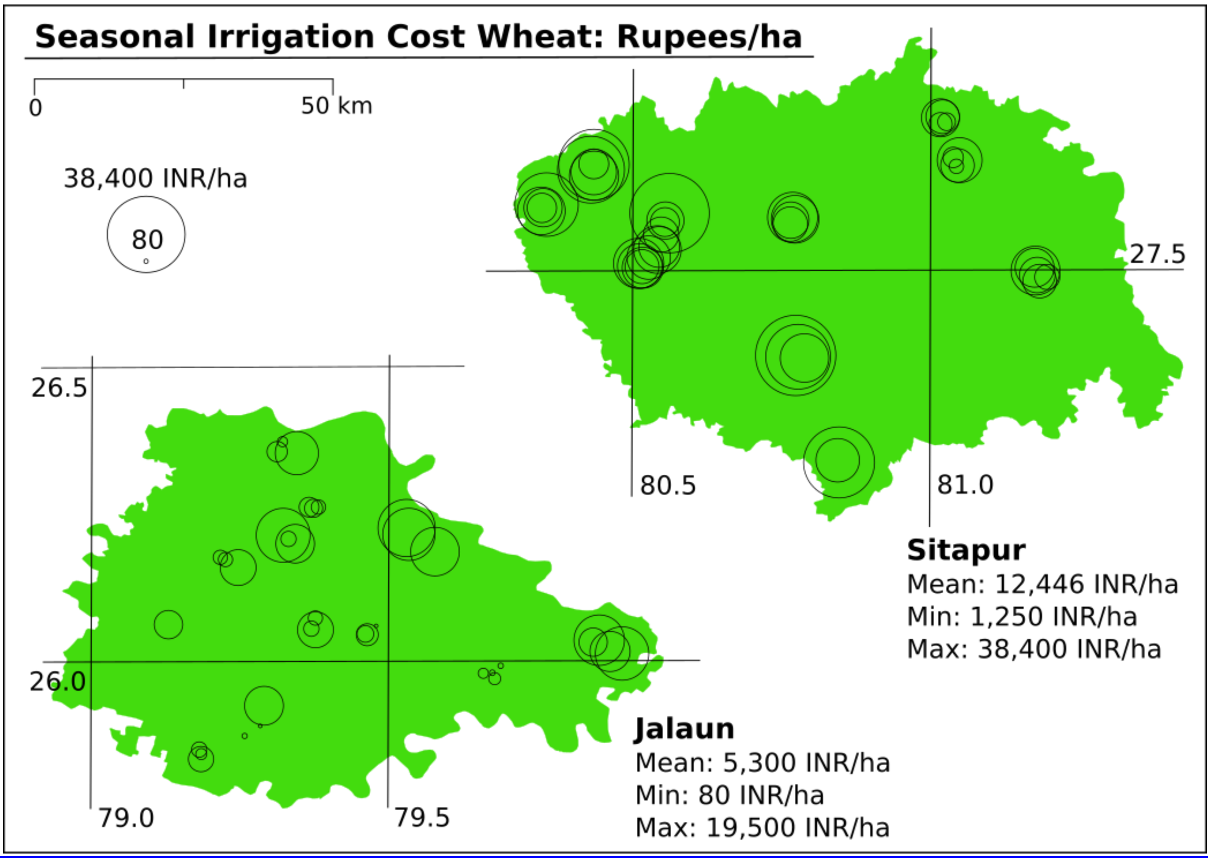

Figure 3: Spatial variations in the annual price paid for the irrigation of wheat by farmers in Jalaun and Sitapur, Uttar Pradesh, North India

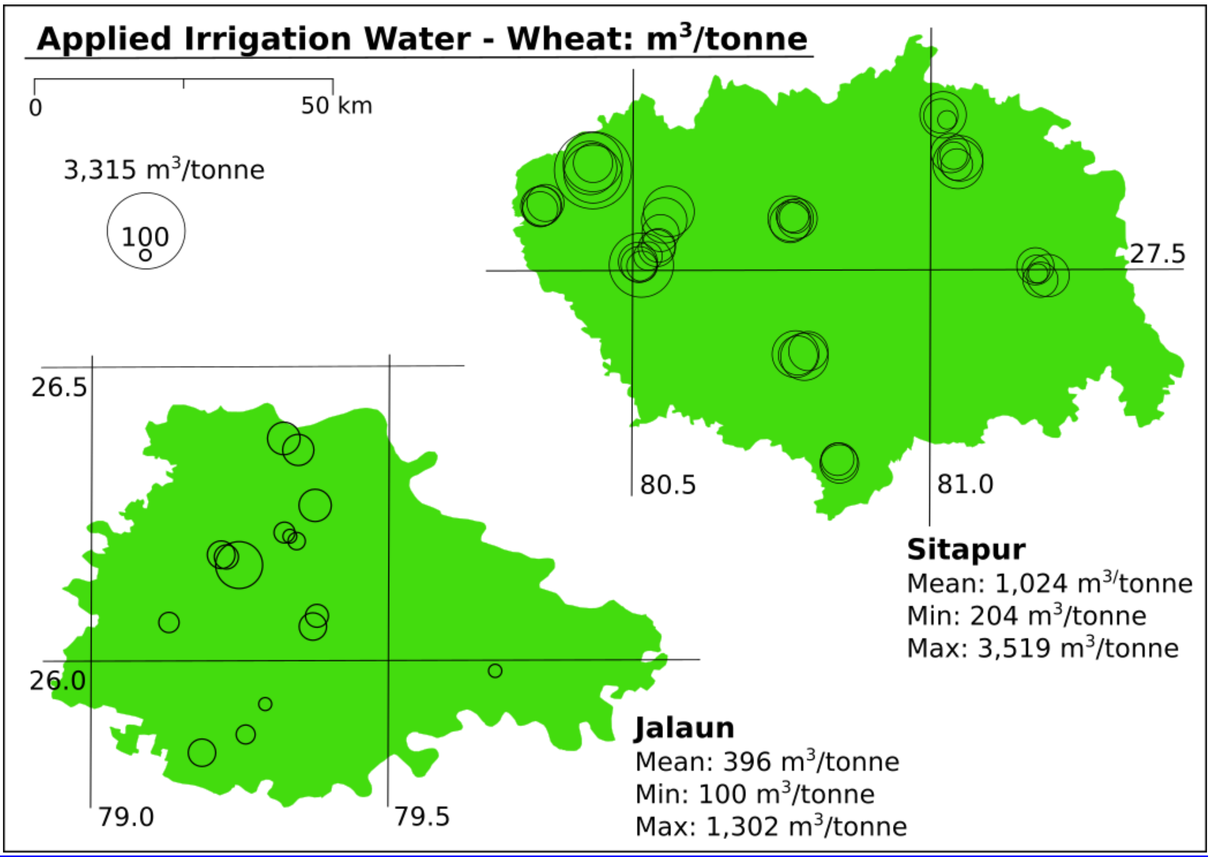

Figure 4: Spatial variations in the volume of water applied per tonne of wheat produced in Jalaun and Sitapur, Uttar Pradesh, North India.

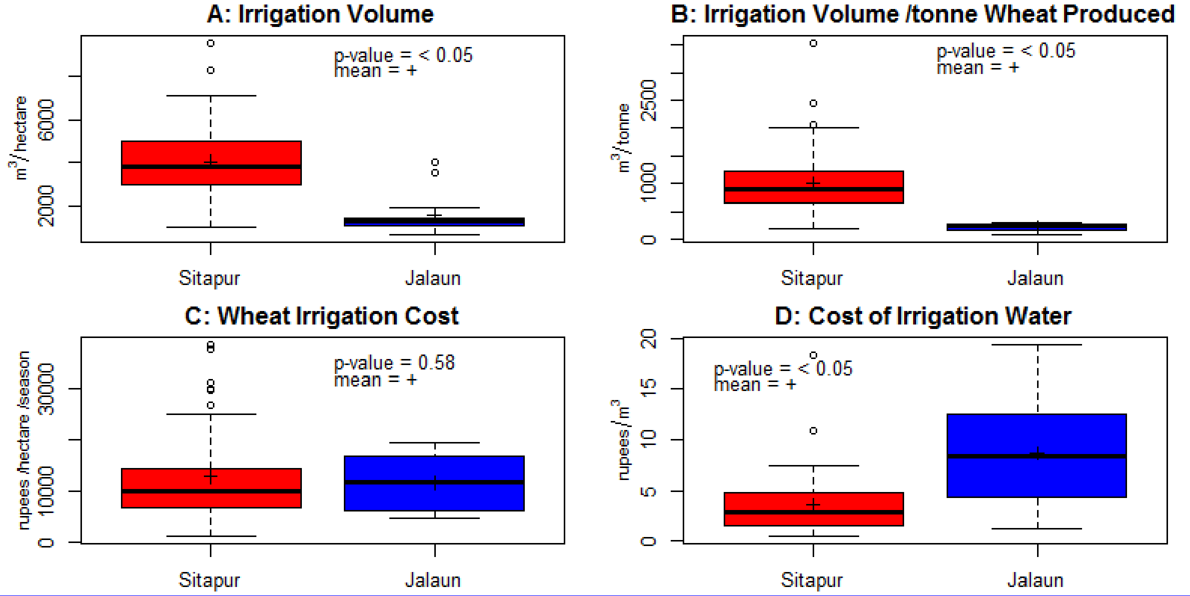

Figure 5: Differences in irrigation practices between tubewell only users in the districts of Sitapur and Jalaun, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range (IQR). The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

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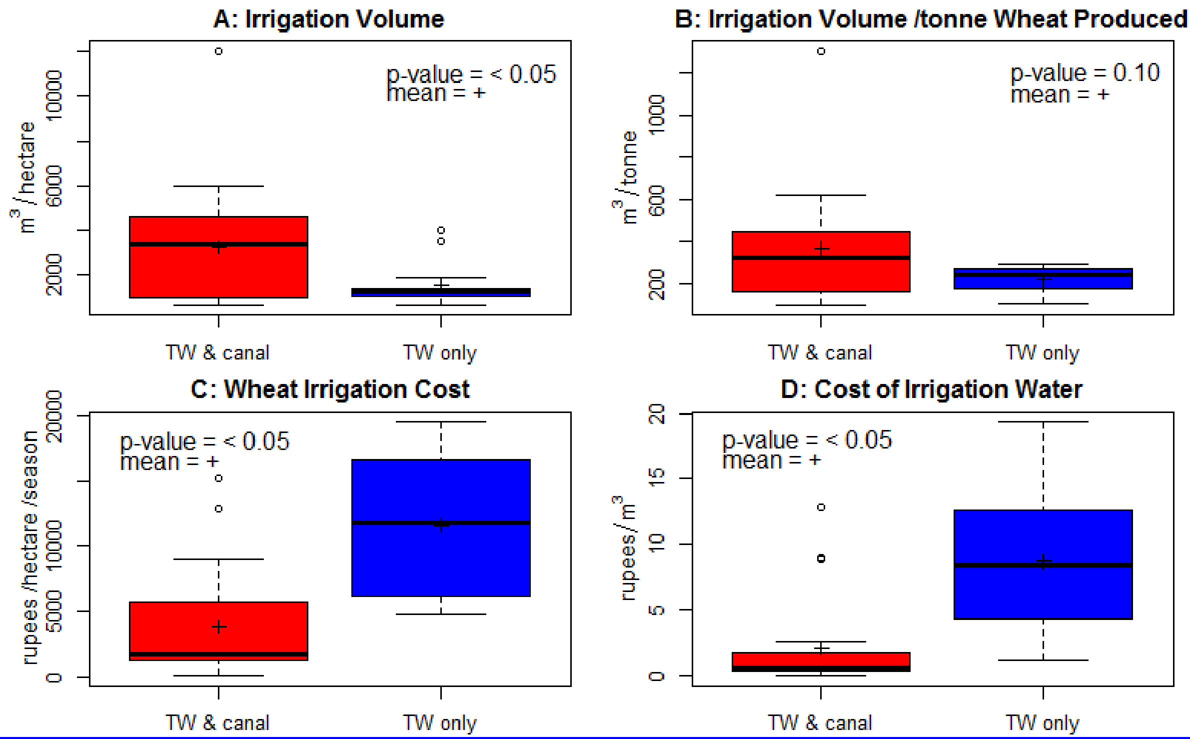

Figure 6: Differences in irrigation practices between tubewell/canal users and canal only users in the district of Jalaun, India. The boxplots represent variability between farmers in each district. The boxes represent the 25 to 75 percentiles; the whiskers represent 1.5 times the interquartile range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

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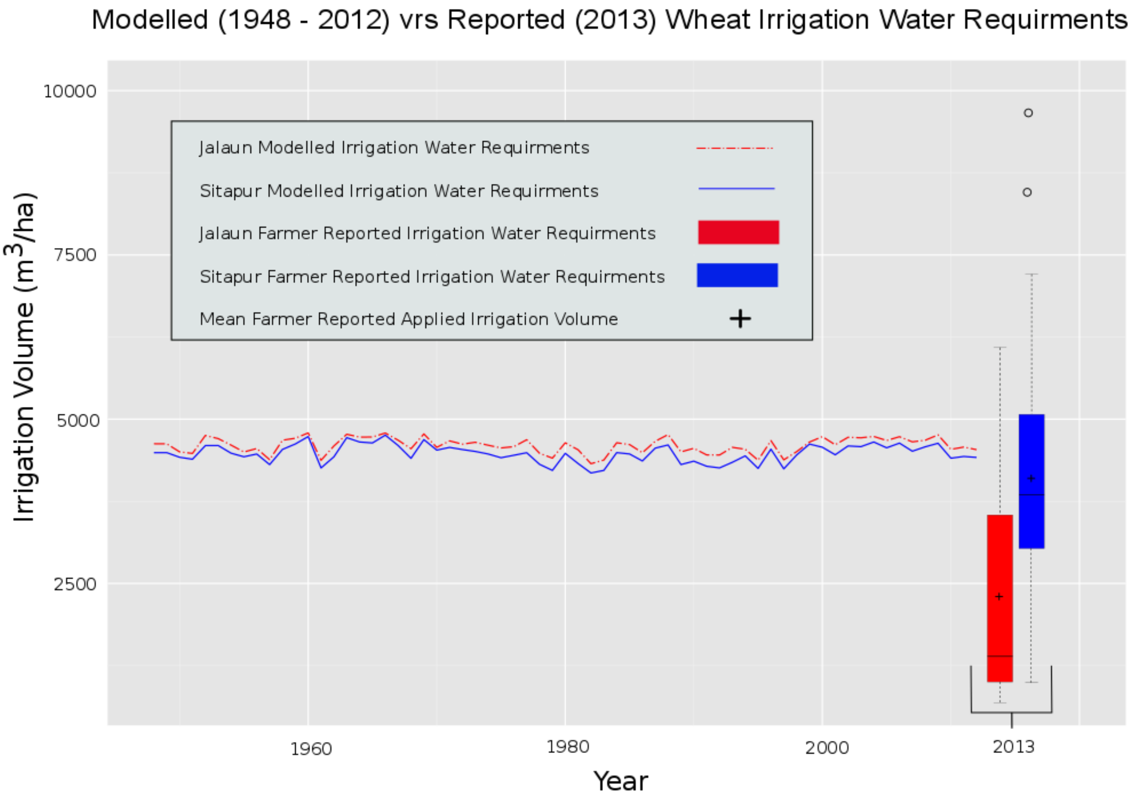

Figure 7: Differences between wheat irrigation volumes reported by farmers (boxplots) and modelled irrigation water requirements (time series)

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?

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