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IRRIGATION MODERNIZATION IN SPAIN: WHAT INFLUENCES THE EFFECTS ON WATER?

The AudiMod method to capture the complex land-water interactions through robust water accounting and water tenure

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Abstract

The study analyses the key link between water and land, where often the reciprocal linkages between land use change on water availability, and the impact of changes in irrigation technology on land use change are often unknown or underestimated. This land-water relationship, if not well understood and analyzed, could mean decisions in either agricultural policy or water policy can have unintended consequences, including potential negative impacts. Thus, planning ex-ante for these water and land interactions is crucial. The study looks at irrigation modernization from an environmental and socio-economic perspective, presenting the results of a Proof of Concept study undertaken for the FAO/UNU on the concept of water tenure and its application to an irrigation modernization project in the Duero basin in Spain, including a follow up study funded by the Duero River basin agency Spain on the effectiveness of irrigation modernization to comply with the European Union Water Framework Directive.

Key Words: Irrigation, Modernization, Water accounting, Water Tenure

Introduction

The relevance of irrigated agriculture in Spain can be clearly perceived from high-level official data on water use and its associated value, i.e. water use by agriculture in Spain is close to 80% of overall use whereas irrigated land occupy an extension around 20% of agricultural land but produce more than 50% of the gross agricultural value (MAGRAMA, 2012; MAGRAMA, 2015).
Spain currently counts with a broad experience in irrigation modernization. In 1996, the national government approved the first National Plan for Irrigation (with horizon 2005) that was followed up by a second national plan which included a specific plan for supporting irrigation modernization. Regional governments (with are endorsed with competences in agriculture) have also supported irrigation modernization, which often has been co-funded by European Union. As a consequence, in the period 1996-2015, more than 7 billion € have been invested between the EU, Spanish public authorities and farmers themselves in the modernization of approximately 2M hectares (Alarcón, 2017). Further investments are planned under the 2014-2020 EU funding framework.

The more common modernization actions have dealt with the substitution of open irrigation channels by pressurized irrigation networks, as well as the construction of irrigation reservoirs for water regulation and the automatization of irrigation demand systems. In general, the main goal of these projects focused on the delivery of "water savings" to address water scarcity, e.g. expected "water savings" for the investment in period 1996-2013 were estimated at 1.813 hm^3/yr (WWF, 2015). Moreover, the National Irrigation Plans state that irrigation modernization projects were also expected to contribute to better environmental conditions in irrigated areas, improved social conditions for the local population, to help fix population in areas subject to land abandonment, and a higher agricultural productivity (Lopez-Gunn, et al, 2015).

However, the results of this policy push for irrigation modernization, when there is primary data, indicate mixed results in terms of achieving the stated policy objectives through water savings towards addressing water scarcity *and* an increase environmental flow (Dumont et al, 2013). In relation to this, there are no systematic studies analyzing the changes occurred in water use and in general in the factors linked to water, land and energy as a consequence of modernization projects, with lack of data collected beforehand thus only making estimates on effectiveness possible from indirect, derived data). This paper presents the combined results from separate studies aiming to elicit these changes from a combined hydrological, socioeconomic, environmental and agronomic perspective, and in particular looking at the compliance of the projects with their pre-defined goals. In particular, this work builds on a Proof of Concept study undertaken for the FAO/UNU on the concept of water tenure and its application to an irrigation modernization project in the Duero basin in Spain, including a follow up study funded by the Duero River basin agency Spain on the effectiveness of irrigation modernization as one of the main measures in the Basin Hydrological Plan to comply with the European Union Water Framework Directive requirements on good water status. The study analyses the key link between water and land, where often the reciprocal linkages on the one hand, between land use change on water availability, and on the other, the impact of changes in irrigation technology on land use change are often unknown, ignored or underestimated. The paper presents the concept of water tenure as a powerful lens that complements the existing land tenure lens to understand the deep relationship between land and water use. Water tenure as compared to water rights is better able to document the dynamic nature of the land- water interaction, and thus anticipate potential unintended consequences due to e.g. technological changes like irrigation modernization and intensification of water and land use.

Moreover, this paper aims to shed more light into a long-standing debate about the advantages and issues of irrigation modernization in Spain. Currently, this debate is highly polarized between some actors warning about an increase of water consumption as a direct consequence of irrigation modernization (Lecina et al, 2009; WWF, 2015) and agents closer to water users who tend to discredit this potential problem and focus on the benefits linked to these projects (Berbel & Gutierrez-Martín, 2017). In our opinion, there are often wide differences between irrigation modernization projects which can only be fully appreciated and understood through a comprehensive analysis integrating robust water accounting with water tenure aspects. Moreover, the determination of some key variables before the modernization project is executed (analysis ex ante) can provide useful information to water planners on how to guide and impose effective pre-conditions in order to better align the project with the consecution of the hydrologic and environmental objectives, particularly in relation to water rights, tenure and other potential impacts.

Water accounting and the paradox of irrigation technology efficiency

This paradox is brilliantly described by Grafton et al (2018). These authors explain how there is abundant scientific evidence on the fact that although irrigation modernization increases irrigation efficiency at farm scale, this modernization often does not help to reduce water consumption at basin scale. This produces because non-consumed water 'losses' at a farm scale (i.e. water losses in terms of efficiency of the irrigation system) cannot be considered as actual losses at basin scale since runoff or infiltration are often reused or recovered. The paradox happens because although the benefit of improved irrigation efficiency at the local "on-farm" scale may appear high from an agronomic point of view, total water consumption by irrigation tends to increase rather than decrease when properly accounted at basin scale (Perry & Steduto, 2017).

Therefore, a robust water accounting system is the basis for a robust analysis of changes due to irrigation modernization projects. The water use fractional analysis (Batchelor et al, 2017) is a comprehensive framework, which builds on the conservation of mass principle, and is very well fitted to this analysis. The water applied into the irrigation scheme (inflow) is allocated into different fractions, i.e. consumed fraction and non-consumed fraction. The consumed fraction is divided into the beneficial consumed fraction, i.e. evapotranspiration from irrigated crops, and non-beneficial consumed fraction. The non-consumed fraction mainly comprises of deep percolation and runoff, and is divided into recoverable and non-recoverable fractions. An average quantification of these fractions is provided in Figure 1 (based on Grafton et al, 2018).

Figure 1. Average changes in fractional water use as a consequence of improvements in irrigation technology.

In general terms, the increase in irrigation efficiency at farm level tends to produce (see box 1 for an example):

a) Increases the beneficial water consumption due to: i) increased temporal availability of water and automatization of the irrigation systems which allow more frequent irrigation to reduce water stress of crops and increase in productivity, ii) increase in the irrigated area (hectares) after modernization, and ii) increase in areas cultivated with crops with higher water requirements (m3/ha) and new patterns of cropping, e.g. double-cropping (cultivation of two or more crops in the same plot in the same year) (number of crops/ha).
b) Reduction in the recoverable fraction because the new pressurized irrigation systems limit the amount of water that infiltrates into aquifers or returns to surface water bodies.

Figure 2. Example of change is farming plots size in an irrigation district before (image on the left) and after modernization (image on the right). The figure on the right (Sources: analysis undertaken by ICATALIST based on Ortofotography provided by CNIG; cadastral data provided by Dirección General de Catastro – Government of Spain)

Figure 3. Infrared images showing irrigation land use in a farming area of Almudévar irrigation district. (Source: Sentinel 2 images provided by European Space Agency)

The "water tenure" concept

The application of the "water tenure" concept was part of a Proof of concept study conducted by FAO/UNU in 2014 and developing case studies on different aspects related to water management in three countries, i.e. India, South Africa and Spain (López-Gunn et al, 2014). The rationale for the study was to apply the concept of "tenure" to water, looking at the potential application parallelisms with the well-developed and accepted concept of land tenure[1]. For the purposes of the study water tenure was defined as 'the relationship, whether formally or customarily defined between people, as individuals or groups, with respect to water resources' (Hogson, 2016). Thus the way it is understood is as a boundary concept i.e. a theoretical construct required to think across the boundaries of the natural sciences and the social sciences. It straddles the interaction of formal water rights on the one hand and on the other of its actual implementation on the ground.

The approach is bottom-up and user led, as compared to water rights which are top-down and state led. Thus the focus has been on the reality on the ground, and mapping the existing relationships without a priori normative judgements. Instead this bottom up approach gave insights into the complex system of water use, and – through water tenure analysis- i.e. the analysis of relationships between users and water use, whether formal or informal- helped to identify areas where e.g. formal laws are too rigid, formal laws are un- implementable for a number of reasons, there are problems of coherence between laws, etc. Water Tenure thus becomes a good diagnostic tool on the gap between (formal) water rights, normally top down, and bottom up de facto use, and also on the reasons for this gap and ways to align formal water rights with actual water use. It can also be an entry point for policy coherence (land rights, water rights, energy

[1] http://www.fao.org/tenure/resources/collections/land-tenure/en/

security, etc.). Equally, from a top down perspective it can help raise key issues in relation to reality on the ground and future water planning.

As part of this study, a specific case study was conducted on an irrigation modernization scheme in Riaza river (Spain). The aim was to test whether water tenure as a concept can help transition a system focused on (rigid- property) water rights towards a system which also incorporates some flexibility and potential re-allocation, based on the concept of water tenure without losing important aspects related to security of tenure. The results from this case study show how modernizations may differ one from another (e.g. different degree of intensification in agricultural activity as a consequence of modernization) and also provide a clear example of how a modernization can deliver a positive effect to help achieve a good status of related water bodies.

The Riaza case study: methodology and results

In this section, we present the main methodological aspects and results from the analysis of two related modernization irrigation projects ("Cabecera de Riaza" y "Canal de Riaza") in Riaza river, part of the Duero river basin (Spain). The study area is sited in the lower-course of the Riaza, downstream of the Linares Dam. Both irrigation areas directly benefit from the regulation provided by this infrastructure, which ensures water availability along summer when it is naturally scarcer and higher value-added crops can be produced.

The specific steps in this study in relation to the water tenure aspects were:

- Step 1: FRAME (SUBJECTIVE) Describe the formal water rights system under the typology of uses and relationships provided by water tenure
- Step 2: MEASURE (OBJECTIVE) Through the use of the water tenure system, map the real existing relationships and real water use, e.g. by providing a solid water accounting.
- Step 3: DIAGNOSE (ASSESS) Diagnose the reasons for gaps and differences and potential for re-alignment, i.e. water tenure on the basis of solid knowledge on actual use and resources available established through water accounting.

As a result from the framing phase, existing water rights were identified in the broader that encompasses the municipalities with area inside the modernization project domain. A 98% of overall water rights are committed to irrigation. Almost all the rights committed to irrigation are public concessions for the two irrigation schemes depending on surface water diversion from Riaza river. Only a limited volume is granted to the irrigation of other areas using groundwater. This shows the relevance of the modernization projects for this particular geographic area.

The measuring phase was based on the combination of remote sensing data with ancillary agronomic, hydrologic and climatic data for the assessment of the water use fractions before and after the modernization projects (four years before and after were analysed to limit potential biases). The methodology allowed a precise characterization on the annual water demand for irrigation. It also had the additional value of being able to characterize the potential water demand for longer periods from the elaboration of maps of irrigation frequency, which delimits the plots that have been irrigated at least once, within a set period. As a result, the variation in irrigated area (both in spring and summer), in annual water diverted from the river for irrigation, and in water consumed (including beneficial and non-beneficial fractions), were estimated (see figures 4 and 5). Also, potential changes in parameters linked to water quality were investigated although no significant results were found, which was expected because of the limited time span after modernization.

Figure 4. Evolution of summer-irrigated area in irrigation districts diverting water from Riaza river

Figure 5. Changes in fractional water use in irrigation districts diverting water from Riaza river because of the improvement in irrigation technology

In this area, the modernization did not produce an increase in irrigated area. Indeed, the trend before the execution of the projects shows a decreased in the irrigation of high-value crops (irrigated in summer). This is motivated by external factors, affecting in particular to sugar-beet which was the most important crop in terms of irrigated surface and added value production. This is a safe crop for farmers since the final price per ton of product is known with high reliability before the start of the cultivation campaign. However, the drop in the price of sugar-beet caused by a 2006 international trade regulation for sugar forced farmers away from this crop. Some internal factors described below also help to explain this situation.

The estimations obtained for the calculation of water use fractions are coherent with general data provided in figure 1. The estimated water consumption, i.e. beneficial and non-beneficial, increased from 15.6 Mm^3/yr to 19.3 Mm^3/yr. The average volume of water diverted from Riaza river for irrigation is estimated as 20.6 Mm^3/yr (before modernization) and 22.2 Mm^3/yr (after modernization). In any case, these volumes are well below the public water right concession, which provided guaranteed access to more than 39 Mm^3/yr.

The diagnosis phase was supported by interviews and a workshop involving farmers, civil society representatives and water managers. This allowed to align the diagnosis with several intertwined perspectives, i.e. agricultural and socio-economic related topics, as well as hydrological and environmental changes. Some key findings, which help to better understand the trends determined by the water accounting methods are:

- The modernization has significantly improved water availability and water security. Automation of irrigation systems has changed the tenure relationship of farmers with water. Before the modernization, the irrigation was managed by turns including daylight and night turns. A single farmer was not able to irrigate more than 10 hectares of summer crops per year to irrigate to schedule. Water security was a big concern, especially tail end farmers whose lands were at the end of an irrigation channel. Those farmers located closer to the water inlet had a better supply but those further from the water source were concerned over water availability and not being able to cover the crop water requirements due to potential water shortages. After modernization water security in terms of guaranteed supply (and thus less risk) has dramatically improved as well as equity among farmers in access to water.
- Irrigation has often become a complementary economic activity for many water users in the area. The percentage of main farmers, i.e. those who exclusively live from farming activities is currently very limited. As a consequence, many irrigators cultivate crops with limited added-value but reduced risk, e.g. winter cereal.
- Land value has importantly increased after modernization. The farmers have received subsidies for a 76% of the total costs of the execution of the projects. Thus, the increase in land value has already paid off for most of the investment made. This is also an important factor that explains the irrigation pattern observed after modernization. There has not been any spatial grouping of farming plots, which is a process that often is linked to modernization projects. This is also a factor that explains that no significant agricultural intensification has produced.
- Agricultural productivity has increased, and the quantity of water applied to each irrigation turn can be better fitted to crop requirements. Now it is possible to irrigate with a higher frequency and with lesser quantities of water. As an example, in some phenological stages of the crop, -such as during sprouting- it is recommended to use small quantities of water (4mm) under a daily basis

which can be applied with the pressurized irrigation system. However, in irrigation by flooding it is almost impossible to provide crop with a quantity of water lower than 100 mm.

Another relevant findings relate to the nexus between land, water and energy when applying the water tenure lens. In the case of Riaza, the land/water tenure link was perceived in two main ways; first farmers acknowledged that land consolidation had in many ways paved the way for the later process of water rights consolidation undertaken by the irrigation modernization process. Equally, in order to guarantee that the investment was undertaken, private contracts were written between land owners and land renters, with the regional government and the water authority acting as mediators, successfully resolved to ease investment. Yet, the operation and maintenance costs for irrigation have significantly increased, mostly because of the cost of energy. This is perceived a one of the main problems of modernization by farmers. However, now the calculation of the payments is often based on water used by ach farmer which is perceived as a more fair and equitable system that the percentage of irrigable surface per farmer or a shared common quota.

The diagnosis was completed by looking at political-economy and institutional frameworks, e,g, requirements of the EU Water Framework Directive (WFD) for good quantitative and qualitative status of surface and groundwater bodies. The WFD establishes the need to carry out a cost-effectiveness analysis of the measures and, in this line, it is necessary to quantify the effectiveness in terms of achieving the environmental objectives. The evaluation of the good water status achieved thanks to irrigation modernization was undertaken through a series of indicators that allow the evaluation of irrigation modernization in two parts: the ecological status (through the conjunction of the physical-chemical, hydromorphological and biological state of the water body), and the chemical status.

A set of indicators related to irrigation modernization was devised, which were summarised into a limited group of indicators for a more efficient monitoring of the effects of the modernization projects in the good status of water bodies, i.e. linking the modernization indicator with the WFD indicators.
Moreover, a number of measures and strategies were thought out. In particular, it was noted that as a consequence of the modernization, several diversion dams could be put out of use because all required water can now be extracted from two specific points. The Duero River Basin Agency started a program to demolish these dams and improve the river longitudinal connectivity. In addition, fish scales and flow-meters have been required to be installed as a condition to maintain the public concessions for the use of

water. This is expected to improve the ecological status of the river, which is a positive effect not anticipated by the initial modernization project. Non consumptive uses such as sport fishing, or other recreational uses, as well as other indirect cultural and recreational uses are seen by local population as very relevant issues, which are linked to a good conservation status of the Riaza river. In fact, the population in the area increase during the summer with tourism is an important activity for the local economy, thus with a more diversified local economy.

Another co-benefit of the modernization is a potential increase in the production of renewable energy through hydro-power. The achieved reduction in water diverted with the modernization could be partly or fully used in increasing the volume of water stored in the reservoir instead of increasing river flows. This would increase short-term security in water resource availability storage and thus could also increase the profit of the energy production due to the increase in the water jump at the dam. The increase of potential energy would improve the generation of hydro-electric energy. Finally, another positive impact is that non-compliance with Water Law (i.e. water use without water rights) has reduced thanks to the consolidation of all water rights into a single water right, which makes control and monitoring much simpler and devolved to the irrigation communities themselves.

Discussion

Modernization is a measure that potentially helps reduce the demand for irrigation water, but it is key to evaluate to what extent this happens, in order to know how the water resources benefit (or not) from reduced quantitative and probably qualitative pressures, as well as the overall implications for farmers way of life and local economies.

This analysis is important to make objective decisions in the future based on data obtained from previous experiences. Having a robust indicator system is key, to support robust decision making.
The lack of data on the situation prior to modernization is a limitation when determining the degree of effectiveness of the modernization process with respect to the improvement in the state of water resources, impact on farmers and the local economy and the costs involved. Aspects related to modernizations such as the elimination of weirs, the variation in the withdrawal of flows or the reduction of contributions of nitrates substances are key to be able to draw conclusions from the environmental point of view.

In our case study, the so-called water bodies under the EU water framework directive in the case of Riaza did change status as a result of the irrigation modernization and follow up measures by the River Basin Agency. Thus the results are interesting because the study highlights some aspects that are often not discussed or considered when looking at irrigation modernization. First the key important of the spatial aspects, i.e. where in the basin the irrigation modernization takes place, upstream, downstream etc. Also if there are aquifers below that old "inefficient" systems where in fact a very effective, zero investment example of aquifer recharge. It was because old irrigation retention structures could be removed and thus regain geomorphological connectivity, a key indicator for good status for the EU water framework directive. Yet it was not due to "water savings" since the irrigation modernization had no significant impact on this variable, but rather to the new distribution of water abstractions which could be more concentrated in space and the removal of weirs which allowed for the river connectivity to be regained, both sufficient to change the status of the water body from at risk to a good ecological status. However, as it shown in Box 1, this is not the case in other irrigation schemes, where irrigation modernization was not effective in addressing poor water status, and in fact is likely to have made it worse.

Conclusions

The significance of findings for policy, implementation or research agenda are relevant because of the large expectations on the potential for irrigation modernization as a means to become more water efficient, and thus to generate water savings in water scarce areas.

Yet, the concept of water efficiency is in many ways a misnomer, because in the context of the hydrological cycle, efficient gains can become effective losses somewhere else. The experience in Spain of a large public investment of more than 7 billion euros over a 20-year period with indeed some gains and losses and some winners and losers also. Often farmers would turn to more water intensive crops or to double cropping to permanent crops like vineyards and fruit trees. This dramatically changed the nature of the demand in the basin, and often represented an overall increase at both plot and basin level of agricultural water use. Also although often missed in the changed (and often weakened) social relationships between farmers that before had to negotiate turns.

Meanwhile, the real lesson learnt from the Riaza and Ebro case studies confirms the deep interaction between land and water use, and its interconnections which become evident when there is a technological intervention indicate to main takeaways: first, the importance of having good water accounting before, during and after the technological intervention to understand changes in as many parameters as possible that define the overall systemic relationships, and second, the fundamental linkage to governance and ensuring that these water accounting is registered in formalised water rights for before, during and after the intervention.

Thus the most fundamental two elements on irrigation modernization and the chimera of water efficiency lie on a solid water accounting ex ante, where water use is documented before the technology is installed, and an equivalent documenting of existing water rights and/or matching water use that has been accounted for (i.e. a water tenure analysis). If these two key elements are missing, water efficiency can become very efficient at turning upside down existing uses and established rights, which in some cases can lead to increased productivity but often it is at the expense of someone´s else's productivity or the environment itself.

Finally, there are some relevant remarks for discussion which came across when preparing this paper and we consider are valuable to mention:

i) Modernization is a multi-disciplinary and a transdisciplinary topic, which can be analysed from multiple lens. In this context, the use of a common terminology is fundamental to guide a sound discussion. Often terms such as "water use", "water consumption", "irrigation efficiency", "water losses", "agricultural productivity" or "water productivity" have different meaning for different disciplines. Also, sometimes, these concepts are confusingly or incorrectly used. Several of the references provided in this paper, e.g. (Batchelor et al, 2017) or (Perry and Steduto, 2017) make a significant contribution to clarify the use of the key terminology for analysis of irrigation modernization.

ii) The spatial scale is particularly important for a sound analysis of the benefits and consequences linked to modernization projects. As explained through the 'paradox of irrigation efficiency', the irrigation modernization can lead to increases in water consumption. This imply a reduction of the available water resources for other users. Based on this, water planners should look at the integrated impact of modernization projects at sub-basin or broader scale to ensure sustainability of hydrological and environmental systems, in particular in areas affected by water scarcity.

iii) The Riaza case study shows how water managers can effectively impose conditions linked to a modernization project in order to ensure that some requirements not directly within the scope of these projects are fulfilled, e.g. improve compliance of the Water Framework Directive, or to water rights and land consolidation.

iv) General statements are often simplistic and inaccurate, which is also the case for modernization projects. Not all these actions to increase irrigation efficiency have a similar impact and general conclusions and remarks involving modernization projects as a whole may be misleading.

The water tenure analysis in Riaza case study helped to identify some variables with a high explanatory power of the expected effects of modernization projects. Based on this knowledge, additional work is currently being undertaken to develop a system that supports the prediction of potential impacts of irrigation modernization projects (ex ante analysis). (https://climateinnovationwindow.eu/innovations/audimod).

v) The water tenure concept is introduced as a different lens to zoom into specific water governance problems by integrating water tenure use, water rights, and water availability. Water accounting provides the baseline for water tenure since tenure can be described as a share of the overall available estimated resource, which are variable both along a year and among different years. Water accounting is linked to some uncertainty, and is sometimes difficult to understand and not widely accepted by users and stakeholders. However, it is pivotal for an appropriate water planning addressing future sustained, equitable, and efficient water use.

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Figure 1. Average changes in fractional water use as a consequence of improvements in irrigation technology (based on Grafton et al, 2018).

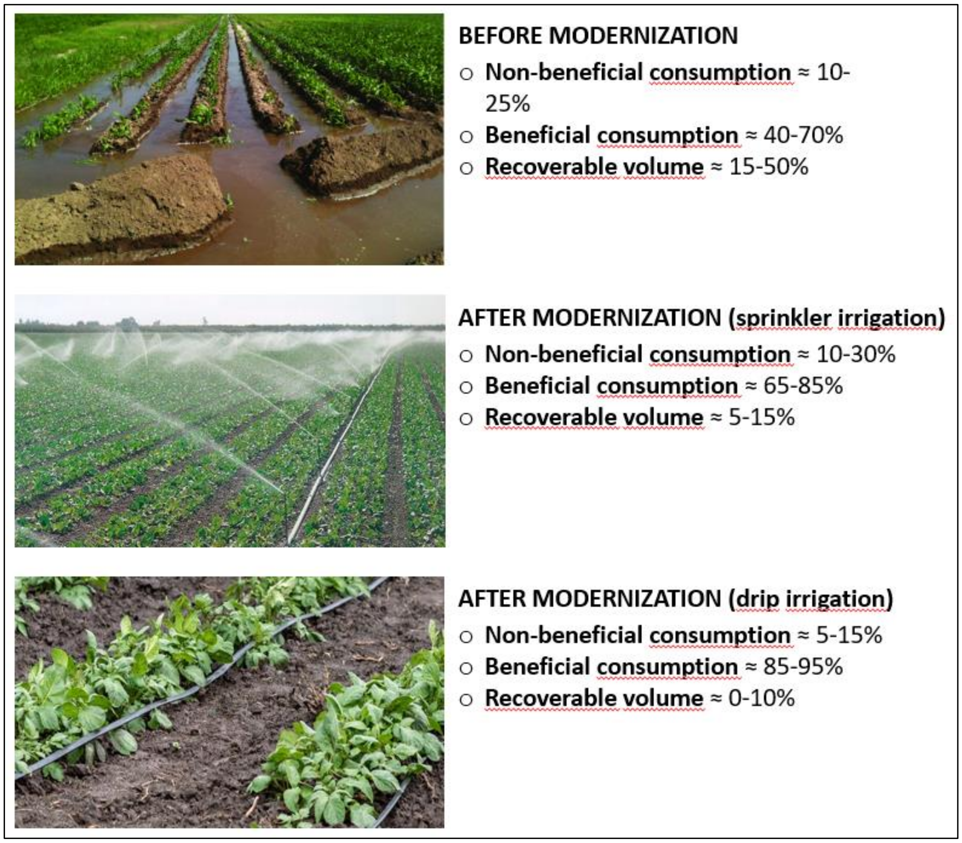
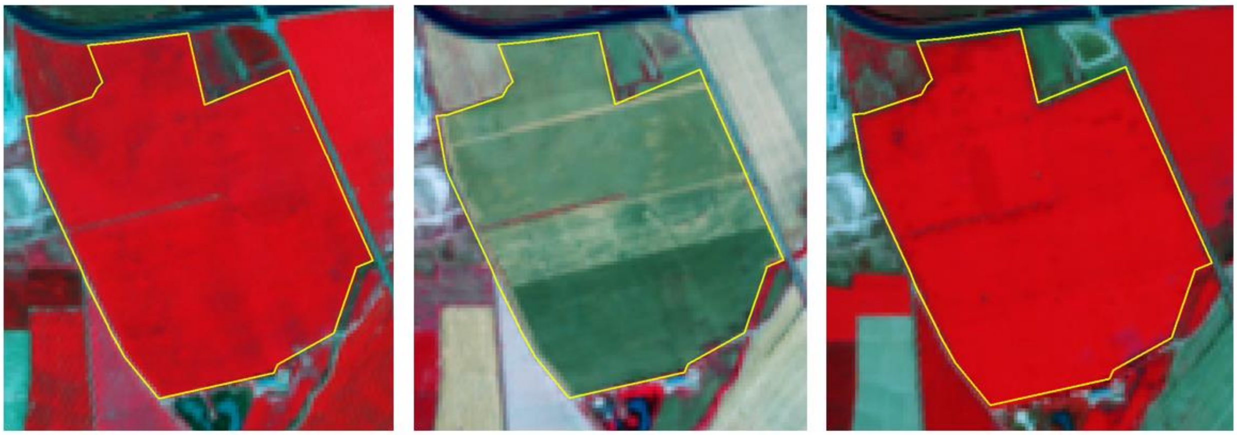


Figure 2. Example of change is farming plots size in an irrigation district bfore (image on the left) and after modernization (image on the right). The figure on the right (Sources: Ortofotography provided by CNIG; cadastral data provided by Dirección General de Catastro – Government of Spain)

Figure 3. Infrared images showing irrigation land use in a farming area of Almudévar irrigation district. (Source: Sentinel 2 images provided by European Space Agency)



May 2018 – irrigated cereal | June 2018 – harvested cereal | Early September 2018 – maize

Figure 4. Evolution of summer-irrigated area in irrigation districts diverting water from Riaza river

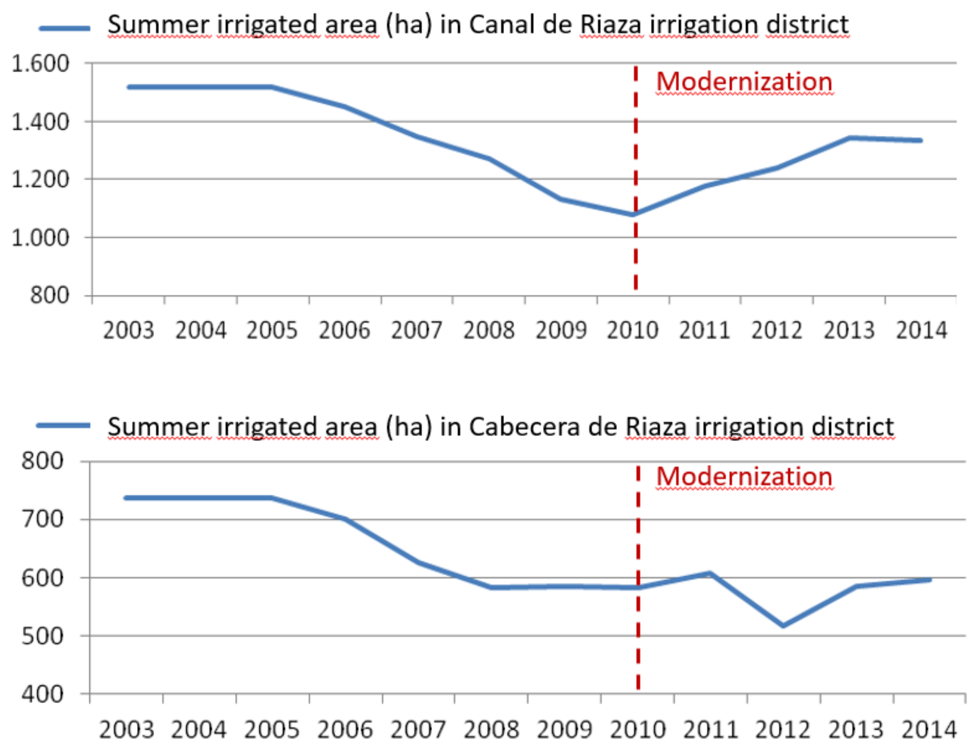


Figure 5. Changes in fractional water use in irrigation districts diverting water from Riaza river as a consequence of the improvement in irrigation technology