

FACTORS OF UNCERTAINTY IN THE INTEGRATED MANAGEMENT OF WATER RESOURCES: THE CASE OF WATER REUSE

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ABSTRACT

The non-conventional water resources (water reuse (WR) and desalination) are a strategic option to compensate the structural water deficit of the southeast of Spain. In addition to increasing water availability and reducing the pressure on conventional resources, these resources show strategic functions at environmental, social and economic level. However, WR does not experience sufficient acceptance by some water users. Uncertainties regarding the quality of reclaimed water, food safety, price or regulations are factors of rejection or ambiguity. The results of a survey carried out on 114 users belonging to irrigation communities of several river basins in Spain are presented. In general, results show a moderate level of implementation of WR. However, the growth potential of WR is significantly high. This depends on water quality and price, which are the two most important valuation factors of WR. Regulations, food safety or water quality for crops generate uncertainty and concern among the irrigation communities. The effects on the environment or the control of availability are aspects positively valued. Conventional resources (transfers and groundwater) are better valued than non-conventional ones (WR and desalination). This constitutes a factor of vulnerability to consolidate the transformation of the Spanish hydrological model. The information presented can be useful to guide the design of future hydrological policies and reduce the socio-institutional vulnerability related to the integrated management of water resources.

Keywords: Irrigation Communities, Social Perception, Southeast of Spain. Uncertainty, Water Reuse.

1 INTRODUCTION

Water reuse (WR) is a strategic option to increase the supply of water resources in the deficit regions of Spain. The region of Murcia or the province of Alicante is exposed to a structural water deficit, caused by very little rainfall (<350 mm/year) and high evapotranspiration (high temperatures and insolation). In this sense, the effects of climate change are a threat to the southeast of Spain, where it is expected a reduction in rainfall of up to 30% and a considerable thermal increase in the medium-long term (CEDEX [1]). These climatic variations can favor a worsening of the drought episodes and force an unsustainable pressure on the water resources (Pascual *et al.* [2]; Valdes-Abellan *et al.* [3]). In this framework, non-conventional resources are important to optimize an integrated management and guarantee the continuity of the socio-economic development model of deficit regions (Olcina & Mantero [4]; Morales *et al.* [5]). In Spain, the articulation of WR in water management began its expansion in 2004, with the repeal of the Ebro transfer project contemplated in the National Hydrological Plan of 2001. The modification of this plan caused a significant change in Spanish hydraulic policy, since it introduced management criteria more related to the WR and desalination than to the policy of transfers. At that time, the policy of transfers was exposed to socio-political tensions and important uncertainties regarding its environmental viability. The EU Water Framework Directive (Directive 2000/60/EC) also favored the transition of the Spanish hydrological model, directing management towards criteria such as environmental quality, sustainable use of water or technological development.

Along with desalination, WR is the main alternative of this new paradigm of water resources management. This option increases the offer, reduces the pressure on conventional resources and shows socio-environmental advantages. At the environmental level, WR attenuates the overexploitation of aquifers and improves the ecological flow of rivers. It is a circular economy practice, which imitates the natural hydrological cycle of water in its phase of use and exploitation. This allows to stabilize the control of water availability, increasing the self-sufficiency of the territories (Garcia & Pargament [6]). The cost of reclaimed water, in general, is affordable for users (Melgarejo [7]), especially when its consumption is subsidized by the public administration (Melgarejo & López-Ortiz [8]). However, the growing demands on quality could impose the use of more advanced technologies that favor an increase in prices (Molina [9]).

Despite its advantages, WR has not yet obtained sufficient social acceptance, and currently faces some challenges that may compromise the generalization and consolidation of its practice. According to FAO [10], risk to public health is the main challenge facing WR. There is growing concern about chemical contaminants – known as ‘emerging pollutants’ (drugs, pesticides, hygiene products ...) – detected in reclaimed water, which come from the domestic and agricultural uses that the resource experiences throughout its lifecycle (Rosal *et al.* [11]). The effects of these pollutants on human health are not known exactly (Tejada *et al.* [12]), although effects of endocrine disruption have been proven (Patiño *et al.* [13]). Currently there are technologies capable of eliminating these substances (Deblonde *et al.* [14]), although their implementation could increase production costs and reduce the economic affordability of WR. Knowledge about the presence of emerging pollutants in reclaimed water can cause important changes in the regulations about treatment of reclaimed water, mainly because of the possibility that these substances are included in the quality parameters (Galvín [15]). Its control and regulation, despite offering public health guarantees, could require the reconversion of the current treatment systems. Another problem is the high conductivity that sometimes presents reclaimed water, especially in coastal areas (Yangali-Quintanilla *et al.* [16]). The excess of salinity causes some adverse effects in the crops, so that it is an important factor of concern among the irrigation communities (ICs). Finally, public opinion about the WR still does not reach optimal levels of satisfaction. March *et al.* [17], after studying the perception of citizenship in different municipalities of the province of Alicante (southeast of Spain), found an important concern about the energy and economic cost of the WR, as well as its impact on public health. WR faces significant challenges, which in essence could require the increase in the quality of reclaimed water and the maintenance of its economic affordability.

Knowledge about the social perception of WR is very limited (Melián-Navarro & Fernández-Zamudio [18]). Although some researches in Spain have approached this subject (Domènech & Saurí [19]; March *et al.* [17]; Costa [20]), the information about the different dimensions of WR is insufficient. WR is a new topic, in progressive growth, which requires exploratory initiatives that provide strategic information to guide future actions of integrated water management. The objective of this study is to describe the perception and implementation of WR by ICs in Spain. This group is the main socio-economic stakeholder directly linked to WR, so that knowledge about their concerns is strategic. To achieve this goal, a survey has been carried out to 114 users belonging to ICs. Multiple technical, social and economic aspects were asked. This research provides some notions about the way in which water users are adapting to the changes that the Spanish hydrological model is undergoing through the boom of non-conventional resources, the regressive dynamic of policy of transfers and the potential impacts of climate change. This study can offers key information about

the socio-institutional vulnerability experienced by the system and its users in the face of new management realities and future hazards.

2 MATERIAL AND METHODS

2.1 Case study

The study population of this research is ICs of Spain. ICs are farmers' corporations created with the objective of managing the distribution of irrigation water among its members under agreed principles.

Due to the exploratory orientation of this study, the geographical dimension of the selected case studies (river basin) has not been subjected to statistical stratification criteria. However, those ICs that establish a direct relationship with WR have been more focused. These ICs belong to the river basins of southeastern Spain: Júcar and Segura. The case studies of these basins have a greater quantitative importance in the investigation. Figure 1 shows the percentage of study cases in the survey for each of the participating river basins. 59.6% of the cases belong to the two basins of the southeast. This high percentage is consistent with the WR level of this region. In Murcia and the Valencian Community 63% of the WR of Spain is carried out. The volume of WR in the rest of river basins is significantly lower, mainly because they have a lower water stress and/or a lower volume of irrigated area.

In relation to the socio-demographic characteristics of the sample, 64.9% were over 50 years old. 90.4% were men. 45.6% had university studies, 24.6% had secondary education, 16.7% had primary education and 13.2% had no studies. Finally, 37.7% of the respondents

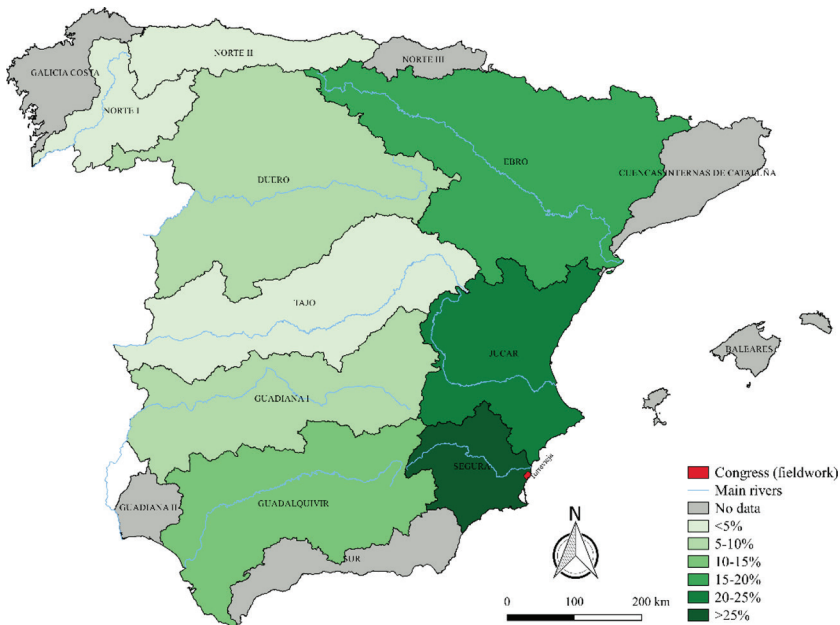


Figure 1: Percentage of sample by river basins.

Source: own elaboration.

were irrigators (farmers), 31.6% managers of the ICs, 15% were administrative and 10.5% developed technical-scientific tasks in these corporations.

2.2 Methodology

The technique of data collection was the survey. This technique consisted in the formulation of structured questions through individual face-to-face interviews. In order to ensure the recruitment of a significant number of case studies belonging to the basins of Júcar and Segura, the fieldwork was carried out during 15 and 16 May 2018 at Torrevieja International Auditorium (Alicante), place where the XIV National Congress of Irrigation Communities was being held. The congress gathered 350 experts from agricultural sector, most of them belonging to ICs. During the fieldwork, 114 people were interviewed. This sample size was sufficient to satisfy the demands of a non-parametric exploratory study.

The nature of this research is descriptive-exploratory, since it proposes an approach to the most important general issues of WR in the field of irrigation. Several dimensions of this phenomenon are studied, so it has been difficult to deepen the study of sub-themes or specific issues. On the contrary, implementing a generalist approach has been advantageous due to the scarce information that exists in the specialized literature about WR perception.

3 RESULTS

In this section, the results of the research are presented, specifically the descriptive data of 19 analytical variables related to different aspects of WR. Three sub-sections or types of variables can be distinguished, which offer information about: implementation, perception and preferences.

3.1 WR implementation

According to the data (Table 1a), the percentage of users that implement WR is 50.9%. Within this category, 44.2% stated that reclaimed water represents less than 30% of the total water resources managed to carry out the irrigation of crops (Table 1b). 38.5% indicated that reclaimed water accounts for between 30 and 50% of their water consumption. WR levels greater than 50% are residual among the interviewed cases.

On the other hand, the level of productive incidents related to WR implementation is low (Table 2a). 55% of the cases said they suffer incidences with low frequency, while 28.3% indicated that they have never suffered any problems. The medium and high frequency of problems related to irrigation with reclaimed water represent residual categories.

Table 1: WR implementation levels.

Water reuse (a)		Percentage of water reused (b)	
Yes	50.9%	<30%	44.2%
No	46.5%	30–50%	38.5%
DK/DA (do not know/do not answer)	2.6%	50–70%	3.8%
–	–	>70%	5.8%
–	–	DK/DA	3.5%

Table 2: Incidents during implementation and scope of affectation.

Incident frequency (a)		Scope of affectation (b)	
Never	28.3%	Crop toxicity	4.5%
Low frequency	55.0%	Crop productivity	9.1%
Medium frequency	6.7%	Soil contamination	11.4%
High frequency	1.7%	Contamination of other types of water	13.6%
DK/DA	8.3%	Pumping and storage	38.6%
–	–	DK/DA	22.7%

When problems occur (Table 2b), these usually affect WR infrastructures (pumping and storage of reclaimed water). Irrigators (farmers) are likely to point to infrastructure problems as a way to show concerns about the energy cost of transporting reclaimed water. On the other hand, a considerable percentage of respondents declared not knowing the incidents they suffer. The contamination of other types of water (water transferred or rainwater), despite not being a majority, occurs in 13.6% of cases. The rest of the categories do not present significant response percentages.

3.2 WR assessment

On the one hand, the economic cost of WR seems to be a matter of great ambiguity. 40.4% of respondents said they do not know the price of reclaimed water (Table 3a). Most people who proposed a quantity chose the categories below 0.40 €/m³. A very low percentage of people indicated prices higher than 0.40 €/m³. However, the highlight of this variable is the significant ignorance of the price of reclaimed water.

In relation to the price assessment (Table 3b), the highest percentage of responses is in the category 'DK/DA', which is consistent with the high level of ignorance that appears in the data of the previous variable. However, a quarter of the respondents considered that the price of reclaimed water is 'regular'. The lowest percentages are at the extremes ('very good' and 'very bad'). When converting the ordinal levels of the question into numerical scale positions (1 as very bad; 2 as bad; 3 as regular; 4 as good; and 5 as very good), the average score of the price assessment is 2.96 out of 5.

Table 3: Perception and assessment of WR price.

Price perception (a)		Price (b)	
<0.10 € m ³	13.2%	Very bad	4.4%
0.10–0.20 € m³	11.4%	Bad	18.4%
0.20–0.30 € m³	13.2%	Regular	26.3%
0.30–0.40 € m³	14.0%	Good	15.8%
0.40–0.50 € m³	4.4%	Very good	4.4%
>0.50 € m ³	3.5%	DK/DA	28.9%
DK/DA	40.4%	–	–

Table 4: Assessment of environmental effects and quality for crops of WR.

Environmental effects (a)		Quality for crops (b)	
Very bad	5.3%	Very bad	6.1%
Bad	10.5%	Bad	19.3%
Regular	30.7%	Regular	26.3%
Good	25.4%	Good	19.3%
Very good	17.5%	Very good	16.7%
DK/DA	8.8%	DK/DA	11.4%

In relation to the effects on the environment (Table 4a), the most repeated category is 'regular'. However, the percentage of responses is significantly higher in the positive categories than in the negative ones. Therefore, the average of this variable is 3.44 out of 5. Opinion about this topic is generally positive, and this may be due to ability of WR to control wastewater discharges or to carry out practices such as artificial recharge of aquifers.

On the other hand, the general assessment of the quality of reclaimed water for crops is again 'regular' (Table 4b), with 26.3% of survey replies placed in this category. However, the number of responses located in the negative range is greater than in the previous variable. Therefore, the average score of this variable is 3.24 out of 5.

The food safety of reclaimed water for irrigation is a subject valued negatively by the respondents (Table 5a). 31.6% think that WR presents a 'regular' food security. It also highlights the category 'bad', which accounts for 24.6% of the responses. The average of this variable is 2.99 out of 5, the second lowest of this block of variables. The quality and food safety of the crops seems to be a matter of central concern among the irrigators, which could be related to the knowledge about the presence of emerging pollutants in reclaimed water.

Regarding the control of resource availability (Table 5b), the assessment is relatively positive. The most repeated category is 'good', with 27.2% of survey replies. The category 'very good' concentrates 19.3% of the opinions of the respondents, which also happens with the category 'regular'. The average score of this variable is 3.44 out of 5. In general, the availability of the resource is valued positively. By depending on the supply flows (urban and agricultural), its control arouses less uncertainty than conventional resources (rainwater, aquifers, water transferred...).

Table 5: Assessment of food safety and control of availability of WR.

Food safety (a)		Control of availability (b)	
Very bad	7.0%	Very bad	7.9%
Bad	24.6%	Bad	12.3%
Regular	31.6%	Regular	19.3%
Good	14.9%	Good	27.2%
Very good	11.4%	Very good	19.3%
DK/DA	9.6%	DK/DA	9.6%

Table 6: Assessment of regulations and infrastructures of WR.

Regulations (a)		Infrastructures (b)	
Very bad	2.6%	Very bad	14.0%
Bad	21.9%	Bad	18.4%
Regular	31.6%	Regular	28.1%
Good	21.1%	Good	16.7%
Very good	3.5%	Very good	6.1%
DK/DA	17.5%	DK/DA	15.8%

In relation to regulations (Table 6a), its assessment is ‘regular’, since its average score is 3.01 out of 5. This category concentrates 31.6% of the survey replies. The category ‘bad’ also stands out, since it contains 21.9% of the total opinions of the people surveyed. However, the high percentage of responses that agglutinates the category ‘DK/DA’ is surprising. As with pricing, regulations are an important issue of ambiguity, perhaps related to the possibility of developing new regulatory frameworks in the immediate future.

However, the most valued issue in this block is the infrastructures used to implement WR (Table 6b). Despite the most repeated category is ‘regular’, the weight of the categories ‘bad’ and ‘very bad’ stands out, since both make up 32.4% of the opinions. This explains why the average score of this variable is 2.79 out of 5, the lowest in this block of variables. The problems related to the costs of implementation (infrastructures) the reclaimed water (identified in section 3.1), could explain this negative assessment.

3.3 WR preferences

To identify the preferences about the different water supply options, data on the valuation of each of them are presented. Regarding non-conventional options, desalination is valued negatively, and is the worst rated of the four supply sources analyzed (Table 7a). Although the most repeated category is ‘regular’ with 27.2%, the ‘very bad’ option stands out considerably, since it concentrates a quarter of the answers. The average score obtained is 2.78 out of 5. The overall rating is negative, and this may be related to problems such as the cost of desalinated water or the damage caused to crops by their concentrations of chlorine, sodium or boron.

Table 7: Assessment of non-conventional resources.

Desalination (a)		Water reuse (b)	
Very bad	25.4%	Very bad	4.4%
Bad	10.5%	Bad	14.0%
Regular	27.2%	Regular	21.9%
Good	24.6%	Good	33.3%
Very good	7.9%	Very good	26.3%
DK/DA	4.4%	DK/DA	–

Table 8: Assessment of conventional resources.

Groundwater (a)		Transfers (b)	
Very bad	–	Very bad	5.3%
Bad	17.5%	Bad	8.8%
Regular	37.7%	Regular	14.0%
Good	28.9%	Good	27.2%
Very good	14.0%	Very good	41.2%
DK/DA	1.8%	DK/DA	3.5%

As for WR (Table 7b), the most repeated category is ‘good’, with 33.3% of the answers. The percentage of responses of the category ‘very good’ is also important, since one in four case studies chose this option. WR is the second best analyzed option, with an average score of 3.63 out of 5. It is a positive overall rating, which positions WR as the non-conventional option best valued by irrigators. However, reclaimed water is also exposed to some drawbacks, such as high levels of conductivity or high concentrations of phytotoxic ions. The average score of the non-conventional options (desalination and WR) is 3.21 out of 5.

As for conventional options, groundwater has an average score of 3.40 out of 5 (Table 8a). The most repeated category is ‘regular’, although the option ‘good’ also stands out. The assessment is relatively positive, although with some nuances, which appear around the high percentage of opinions concentrated in the category ‘bad’. Despite being a conventional option, groundwater also presents some drawbacks. Problems such as pollution or partial control of the availability of the resource prevent irrigators from experiencing greater satisfaction with this resource.

The favorite option for the irrigators consulted is the water transferred (Table 8b). His score is the highest of the four options consulted, with an average of 3.94 out of 5. The most repeated category is ‘very good’, with 41.2% of the answers. The second most repeated category is ‘good’, which concentrates 27.2% of the opinions expressed. The lower price of the transferred water and its higher degree of quality are factors that can explain this overall positive assessment. The average score of conventional options (groundwater and transferred water) is 3.67 out of 5, almost half a point more than the average of non-conventional options (desalination and WR). Approximately, this data may reflect the preference of the conventional hydrological model by irrigators, especially those belonging to the deficit river basins of southeastern Spain.

On the other hand, it is interesting to analyze how price and quality influence the assessment and implementation of WR in irrigation. There is a very significant difference between those who declared reusing at the moment and those who expressed their intention to reuse if the prices were more competitive and the quality reached an optimum level. With these conditions, 80.7% of users would implement WR (Table 9a), which represents a potential increase of 34.2% users.

Under these assumptions (better price and quality), the percentage of water reclaimed over the total of water resources consumed would also increase considerably (Table 9b). The option ‘>70%’ becomes the most repeated category. However, the option ‘<30%’ remains the second most numerous category.

Table 9: Level of implementation of WR with optimum quality and competitive price (*).

Water reuse* (a)		Percentage of water reused* (b)	
Yes	80.7%	<30%	21.1%
No	19.3%	30–50%	16.7%
DK/DA	–	50–70%	17.5%
–	–	>70%	25.4%
–	–	DK/DA	19.3%

Table 10: Willingness to pay more for a reclaimed water with optimum quality level.

Willingness to pay more (a)	
No	29.8%
Yes, with a minimum price increase	35.1%
Yes, with a moderate price increase	24.6%
Yes, even if the price increase is high	1.8%
DK/DA	8.8%

Finally, to continue to test the influence of costs, the willingness to pay a higher price for water with an optimum quality was analyzed (Table 10). 35.1% of respondents said they were willing to pay a higher price as long as the increase was minimal. This option constitutes the most repeated category. Secondly, 29.8% of the users declared that they were not willing to pay more for reclaimed water with higher quality. One in four people showed their willingness to assume a moderate price increase. Only 1.8% of the respondents were in favor of facing a high price increase. This shows the enormous importance of the price of water in the assessment of different water sources by irrigators.

4 CONCLUSIONS

The results allow the interpretation of four types of uncertainty related to the perception and implementation of WR, as well as the way in which the ICs –water users in general– are adapting to the changes experienced by the Spanish hydrological model. In the first place, an economic uncertainty can be appreciated. The price and costs of WR are a primary vector in the valuation of this water supply. In parallel are the quality levels, which also influence the opinion that water users have about WR. However, it is highly probable that the increase in quality of the reclaimed water has to be accompanied by an increase in treatment costs, which consequently could reduce the affordability of the prices.

On the other hand, a technological uncertainty can be distinguished. The quality determines the value granted to water supply options. The perception of respondents about the food safety of reclaimed water confirms this idea. The emerging pollutants constitute a fundamental factor of uncertainty, since their regulation could require the conversion of current treatment systems and the hardening of quality parameters. These changes, which could force the adaptation of some users and management mechanisms, could hinder the technological transition of the water management model.

Third, a socio-political uncertainty can be perceived. Users feel less adherence to the new water management model (non-conventional resources), as they continue to show preference for elements of the conventional hydraulic paradigm. The widespread support for transfers – especially in the deficit river basins of the southeast– confirms this idea. This constitutes a significant factor of uncertainty, since the new management frameworks are increasingly oriented towards the development of non-conventional water supply practices. In turn, climate change could alter the hydrological regime of the basins of northern Spain and increase the socio-political conflict in the decision-making of transfer projects currently implemented.

Finally, a cultural uncertainty can be estimated. This is related to the influence of the habits acquired by water users on their willingness to accept the changes experienced by the sector in the short, medium and long term. The partial validity of the conventional hydraulic model –progressively oriented towards exceptionality– and the support received by users are factors that could hinder the internalization of the changes faced by the management system. The hydrological culture, if it does not experience an adaptation, could be overcome by the impacts of climate change, since this hazard could have a dimension not yet contemplated in the field of water resources.

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