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Soil salinity prospects based on the quality of irrigation water used in the Segura Basin

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Abstract. The main objective of this study was to determine the effect of the quality of irrigation water currently used in various agricultural demand units (ADU) on the soil-water salinity, assessing the effects of its use on crop yields and soils agronomic properties. The current state of the water quality used in all ADUs of the Segura Basin (Spain) was identified through sampling points located in surface and groundwater bodies. The geographical relationship established between water quality and crops in each ADU allowed a prospective analysis of the major agronomic risks of salinity, infiltration, toxicity by undesirable ions and the resulting environmental risks of soil degradation. WATSUIT software was used for each existing relationship between water bodies and ADUs. The results of this study provide geo-referenced knowledge of the current status of water quality and of the problems that its use may cause on the crops and the environment. It is also the starting point in establishing actions to increase the quality of irrigation water improving environmental conservation.

Keywords. GIS – WATSUIT – Agricultural Demand Unit – Segura River Basin – Spain.

Prospective de la salinité des sols en fonction de la qualité de l'eau d'irrigation dans le bassin du Segura

Résumé. *L'objectif principal de l'étude était de déterminer l'effet de la qualité de l'eau d'irrigation utilisée actuellement dans les diverses unités de demande agricole (UDA) sur la salinité de l'eau dans le sol, en évaluant ses effets sur les rendements agricoles et les propriétés agronomiques des sols. Pour atteindre cet objectif, nous avons identifié l'état actuel de la qualité de l'eau utilisée dans toutes les UDA du bassin versant du Segura (Espagne) grâce à des points d'échantillonnage dans les eaux de surface et souterraines. Le lien géographique établi entre la qualité de l'eau utilisée et les cultures de chaque UDA a permis de mener une analyse prospective de la situation concernant la qualité de l'eau d'irrigation basée sur une série de risques agronomiques majeurs : la salinité, l'infiltration, la toxicité due à des ions indésirables et les risques environnementaux de dégradation des sols qui en résultent. Pour ce faire, le logiciel WATSUIT a été utilisé pour étudier chacun des rapports existant entre masses d'eau et UDA. Les résultats de cette étude permettent de connaître de façon géo-référencée l'état actuel de la qualité de l'eau d'irrigation et les problèmes que son utilisation peut entraîner sur les cultures et l'environnement. Elle nous permet également d'établir un point de départ pour la mise en place de mesures visant à augmenter la qualité de l'eau d'irrigation et préserver l'environnement.*

Mots-clés. *SIG – WATSUIT – Unité agricole de demande en eau – Bassin du Segura.*

I – Introduction

The Segura River Basin is located in southeast Spain and has an area of 18,870 km² occupied by 1,944,690 inhabitants. It covers territories from 4 regions: Andalusia, Castile-La Mancha, Murcia and Valencia, with a total of six provinces and 132 municipalities. The Murcia region is fully integrated in this basin encompassing most of its surface (59.3%) and population (73.3%) (CHS, 2008).

The climatic characteristics that define the Segura Basin are a semi-arid Mediterranean climate, with mild winters (11ºC on average in December and January) and hot summers (with highs of

45ºC). The average annual temperature is 10-18ºC, rainfall is low, around 365 mm per year, although there is a high variation range (200-1,000 mm). April and October are the wettest months, with frequent torrential rains. The distance from the sea and the features of the terrain means that there are differences in temperature between the coast and inland. The low rainfall contrasts with the high average potential evapotranspiration (827 mm) (CHS, 2008; AEM, 2010).

Agriculture of this basin is among the most profitable in Spain. However, the predominantly intensive agriculture may present a risk of soil salinization due to overuse of fertilizers or irrigation mismanagement. In the Region of Murcia, which accounts for most irrigated crops, irrigated agriculture contributes 75% to the final production of the agriculture product, with vegetables (38%) and fruits (21%) being the major contributors (Arcas *et al*., 2010).

The irrigation water demands in the Segura Basin are recorded, for 74 Agriculture Demand Units (ADU), in the Segura Basin Water Plan (SBWP). The ADU is defined as a separate unit of agricultural management, either by origin of resources, administrative conditions, hydrological similarity or strictly territorial considerations. Based on the information contained in the National Hydrological Plan (NHP), the water irrigation demand for all the ADUs of the basin is 1,662 hm^3/year. The provision of irrigation water per ADU is highly variable and, although on average the net allocation is 3,628 m^3/ha, the variation range is between 938 and 7,483 m^3/ha (MMA, 2001).

The origin of the water used for irrigation in each ADU is very variable, with six different sources. Water comes mostly from surface resources (495 hm^3/year) followed by underground resources (412 hm^3year) and water from the Tagus-Segura Aqueduct (385 hm^3/year). To a lesser extent, ADUs are supplied by water from *azarbes* (trenches or drains for irrigation waters), wastewater treatment plants and other sources, complementing an allocation of 1 432 hm^3/year. Considering the total agriculture demand for water (1.662 hm^3/year), the deficit in the whole basin is around 229 hm^3/year, which together with the overexploitation of groundwater resources (174 hm^3/year) would amount up to 403 hm^3/year (MMA, 2001).

This paper identifies the current status of the water quality in all ADUs in the Segura basin, aiming a prospective analysis of the major agronomic risks induced by the use of poor water quality in the irrigation: salinity, infiltration and ions toxicity. The results of this study will provide geo-referenced knowledge of the current status of water quality and of problems that its use may cause on the crops and the environment. It will also represent the starting point in establishing actions to increase the quality of irrigation water and improve environmental conservation.

II – Material and methods

Demands for irrigation water have been linked with the quality of different water sources through a model based on a geographic information system (GIS) which has allowed relating the quality sampling points with ADUs. Through this process all the variables generated in the study have been represented in maps.

The analysis unit used is the ADU. Both the agronomic characteristics of the ADUs and the source of irrigation water used in them have been obtained from the Segura Basin Water Plan, and the data on quality of irrigation water in 2007 have been provided by the Hydrographical Confederation of the Segura River.

Subsequently, for each sources of water and unit of demand, we used the software WATSUIT (USDA) which predicts soil salinity, sodicity and toxic solute concentration resulting from the use of irrigation water with specific characteristics. The lower quality water has been selected when different water sources are used in one ADU, therefore the simulation results derive from the most unfavourable scenario.

The main outputs of WATSUIT are: electrical conductivity (EC), sodium absorption ratio (SAR) and chlorides content in the root zone (Cl). These parameters allow estimating the risk of salinity, infiltration and toxicity of irrigation water on the crops.

Subsequently, for each ADU, we analysed several risks related to the water quality use: loss of crop yield, following the criteria of Maas and Hoffman (1977) adapted by Ayers and Westcot (1985); compaction and loss of top-soil infiltration, using the criterion of Rhoades (1977) adapted by Ayers and Westcot (1985); and chloride toxicity, determined from the threshold defined by Ayers and Westcot (1985).

III – Results and discussion

There are 74 ADUs in the Segura River Basin which can be divided into 9 macro-ADUs (Fig. 1). The mean values of EC, Cl and SAR for each macro-ADU are shown in Table 1 and Table 2 for surface water bodies and groundwater bodies respectively. Furthermore, after feeding the parameters of irrigation water into WATSUIT, we obtained the values of EC, Cl and SAR in the soil as average values for the entire root area (Tables 1 and 2).

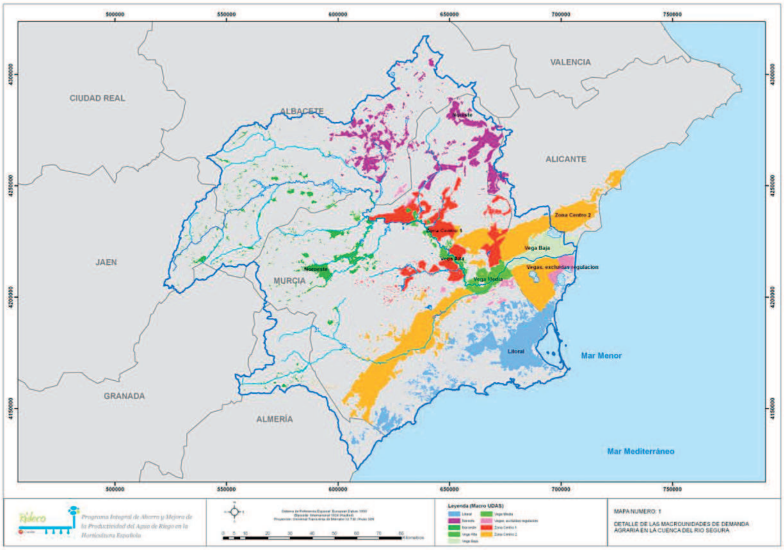

Fig. 1. Location of the nine macro-ADUs in the Segura Basin.

Table 1. Surface water characteristics and soil prospective induced by its use for each macro-ADU

Macro-ADU	Surface water			Soil prospective		
	EC dS/m	Cl meq/l	SAR mmol/l	EC dS/m	Cl meq/l	SAR mmol/l
Litoral	5.70	41.64	8.05	9.59	72.86	16.40
Noreste	2.56	9.48	2.19	3.77	20.83	5.10
Noroeste	1.58	5.16	1.49	2.40	12.36	3.21
Vega Alta	1.51	5.63	2.03	2.39	12.08	4.22
Vega Baja	3.99	19.76	5.65	6.38	39.34	11.86
Vega Media	5.33	10.00	10.61	9.91	76.54	21.22
Vegas, excl. regulat.	3.29	15.57	4.95	5.21	26.83	10.10
Zona Centro 1	3.88	21.62	4.61	5.86	40.95	9.82
Zona Centro 2	5.52	44.45	13.54	10.66	83.11	26.34
Average	3.70	19.26	5.90	6.24	42.77	12.03

Table 2. **Groundwater characteristics and soil prospective induced by its use for each macro-ADU**

Macro-ADU	Surface water			Soil prospective		
	EC dS/m	Cl meq/l	SAR mmol/l	EC dS/m	Cl meq/l	SAR mmol/l
Litoral	3.97	33.58	6.44	8.12	63.64	13.37
Noreste	1.43	5.11	1.83	2.11	9.99	3.64
Noroeste	0.60	1.73	0.73	0.90	3.67	1.58
Vega Alta	0.73	6.34	2.66	1.83	12.33	4.84
Vega Baja	2.28	15.99	3.65	4.79	29.40	7.62
Vega Media						
Vegas, excl. regulat.	6.44	41.26	7.08	9.65	79.36	15.50
Zona Centro 1	2.08	14.44	6.11	3.98	25.43	12.68
Zona Centro 2	3.55	21.07	5.84	5.56	42.66	9.71
Average	2.64	17.44	4.29	4.62	33.31	8.62

Considering the EC of irrigation water for each macro-ADU, it is possible to appreciate that groundwater quality is higher than surface water for the entire basin. The Coastal Zone *(Zona Litoral)* presents a very high level of EC, 5.7 and 3.97 dS/m for surface water and groundwater respectively. The average quality of surface waters in the 2nd Central Zone *(Zona Centro 2)* is also very high (5.52). In groundwater, the highest EC values are in the fertile valleys *(Vegas)* excluded from hydraulic regulation (6.44). By contrast, the highest-quality sources of irrigation water, both from surface and underground, are found in the north of the basin, with values below 2.56 dS/m for surface water and 1.43 dS/m for groundwater.

Analysing the values obtained for the different ADUs, and considering the quality of irrigation water according to SAR and EC, severe use restrictions according to the infiltration criteria established by Rhoades (1977) and Oster and Schroer (1979) have not been found. However, a slight reduction in infiltration is found in the Northeast *(Noreste)* and Northwest *(Noroeste)* ADUs for both sources of water, while in the 1st Central Zone the risk only exists in some ADUs being supplied with groundwater (Fig. 2).

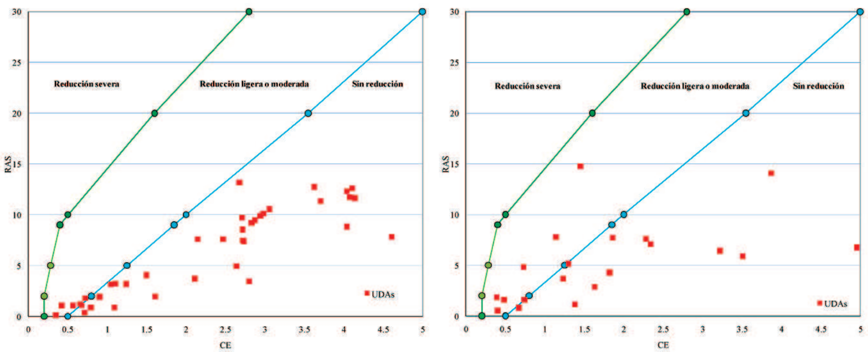

Fig. 2. Relative reduction of infiltration caused by salinity and sodium adsorption ratio in ADUs of the Segura Basin, for surface water (left) and groundwater (right).

Under the criteria described above, we also analysed the potential risk of surface crusting from the use of irrigation water. As occurred with the degree of infiltration, crusting risk is greater in ADUs of the northern region, due to the use of very hard water with low salinity (Fig. 3).

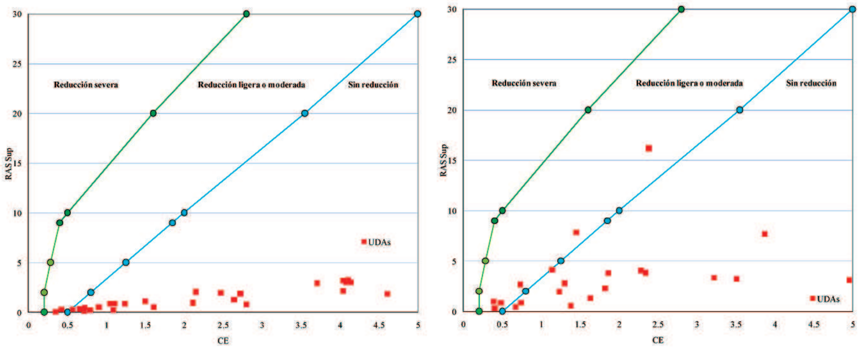

Fig. 3. Risk of surface crusting caused by salinity and sodium adsorption ratio in ADUs of the Segura Basin, for surface water (left) and groundwater (right).

Regarding irrigation water toxicity due to high chloride concentration, it is clear that most of the water used for irrigation in Murcia exceeds the threshold set by Ayers and Westcot (1985), which consider values greater than 10 meq/l as a significant problem. These levels are exceeded in all macro-ADUs except northern ones (Northwest, Northeast and *Vega Alta*). In general, the chloride concentration is higher in surface waters (Fig. 4).

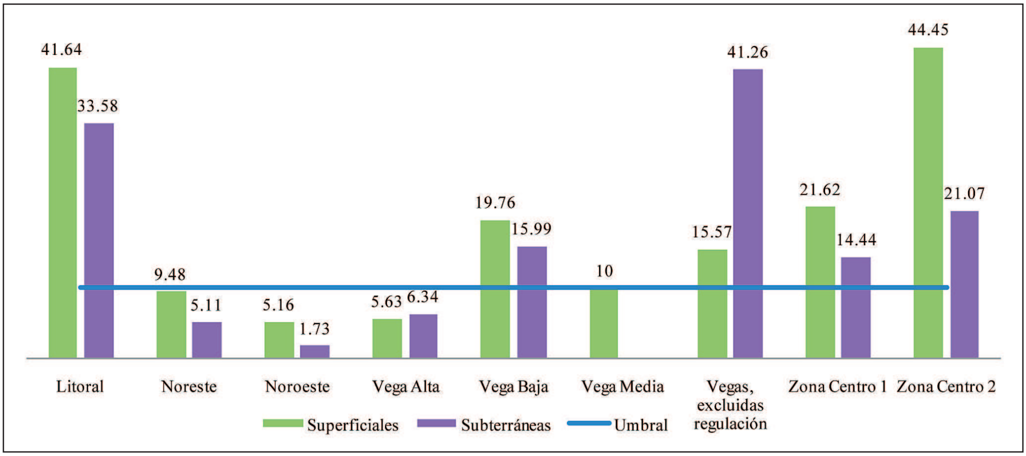

Fig. 4. Concentration of chlorides in irrigation water.

The most important predictive parameter related to the quality of irrigation water has been the estimated crops yield loss. The potential risk of yield loss per ADU was estimated by the ratio between surface water and groundwater used. This overall yield parameter is shown on Fig. 5, where significant risks of reduced yield production are observed for the Coastal Zone and Middle and Lower *Vegas* of the Segura Basin.

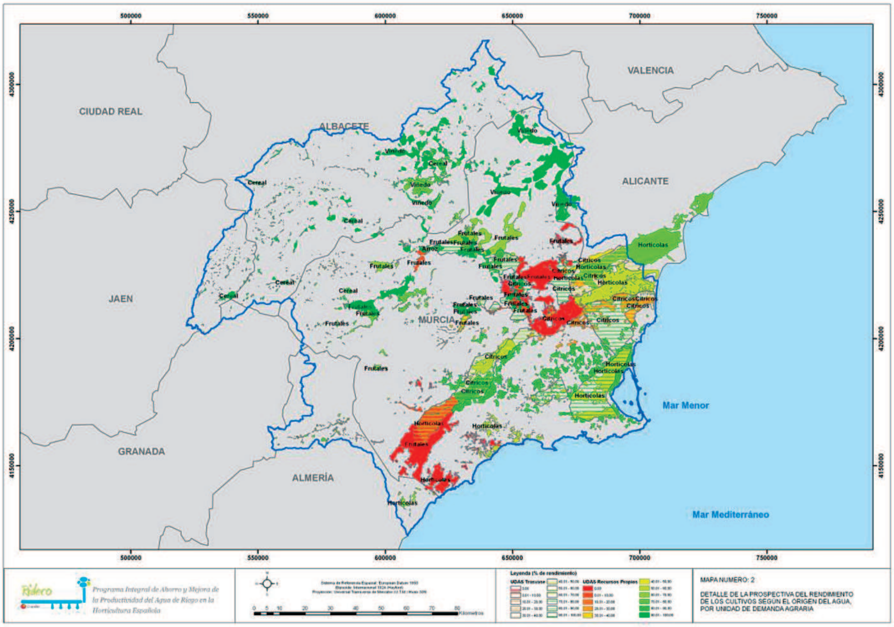

Fig. 5. Estimated percentage of yield reduction for each ADU of the Segura Basin, depending on the quality of water used and the main crop.

IV – Conclusions

The quality of irrigation water in the basin is, in general, moderately acceptable given the arid conditions in south-eastern Spain. In general, the quality of surface water is lower than groundwater. While in the upper watershed resources are of better quality, water salinity increases as we descend through the valleys of the different rivers, both for surface water and groundwater, with the quality of water in coastal zones being the lowest.

Surface waters in the high valley of the Segura, as well as those from the Tajo-Segura Aqueduct, have an acceptable quality which decreases as the distance between the source of water and the point where it is applied increases. The good-quality waters channelled through the post-aqueduct infrastructure represent an essential contribution for irrigation in the Guadalentín Valley, the *Campo de Cartagena* and the Segura Lower Valley.

As for groundwater, permanent withdrawals and overexploitation of many aquifers in the basin have resulted in a widespread loss of quality that gets stronger in the lower areas of valleys and in the Coastal Zone. The continued use of these water resources for irrigation will probably put crops and the environment at risk from salinization, soil compaction and undesirable ions toxicity. This situation will result in a loss of crop yield and therefore will impact the welfare of farmers.

In the coastal area, significant yield reductions are expected. In the *Campo de Cartagena* (yield=72%) and especially in the west coast (yield=40%) these reduction could be alleviated with the use of alternative water resources (reclaimed water, desalinized water, Tajo-Segura transfer, etc.). In these areas, it is necessary a reduction in withdrawals to allow recovery of aquifers, highly saline. There are no problems of loss of soil structure, but chloride toxicity risks are found.

Irrigated crops in the Northeast and Northwest areas, both with surface and groundwater resources, will not suffer from reduced yields in the future, although the low conductivity of irrigation water may generate a slight problem of infiltration. Toxicity problems are not foreseen.

The waters flowing through the Segura River require special attention as river flow decreases. In the upper part *(Vega Alta),* serious loss of crop yields is not expected neither infiltration nor surface crusting. In the middle part *(Vega Media),* problems begin to be most prominent, as yields could fall to 35% of the agronomic potential due to toxicity risk, and in the lower part *(Vega Baja)* yields could fall to 15% as the risk of toxicity from chlorides increase. The levels of water salinity will prevent infiltration and surface crusting problems.

In the Central Zone, irrigated areas mainly use water from the Aqueduct and although in the Mula River Basin some water bodies are of reduced quality, overall performance in the region exceeds 70%, being in most ADUs close to 100%. Again, the contributions of the Aqueduct are able to compensate for the low quality of the rare surface waters of the inland basins and the medium quality of groundwater. The risks of soil compaction are practically inexistent and those related to chlorides toxicity will depend on the use of groundwater and intermittent streams. Given the current situation of irrigation in the Segura Basin and the potential risk of degradation of irrigation water and agricultural soils, it will be necessary to take action on water bodies, both surface and groundwater, in order to support the continuation of efficient and profitable farming system in the basin. These actions should be aimed at increasing the quality of irrigation water, especially in the middle and lower parts of the watersheds and in coastal areas. The waters of the Tajo-Segura Aqueduct have proved to be a source of vitality for irrigation, without which crop yields in the basin would be seriously compromised, and the problems of soil salinity and toxicity should be further aggravated. Thus, the new Segura Basin Water Management Plan must consider not only the quality aspects of water bodies, but also the impact of these waters on the crops and the risk of soil salinization.

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