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Development of cost-effective strategies for environmental monitoring of irrigated areas in Mediterranean regions: Traditional and new approaches in a changing world

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ABSTRACT

A series of reliable and cost-effective microbioassay-based techniques for routine water quality monitoring were developed and tested on a recently developed irrigation area in western Spain. Results from these assays were compared to a screening-level risk characterisation based on pesticide concentrations in water samples from the study area. The levels of 147 pesticides were measured in irrigation channels, fluvial water and selected animal (Red swamp crayfish, *Procambarus clarkii*) and plant (Willow, *Salix* spp. and Holm Oak, *Quercus ilex*) tissue. The presence of 59 human and veterinary pharmaceuticals in the watershed was also explored. Mitochondrial activity (tetrazolium salts reduction), lipid peroxidation (thiobarbituric acid method), chlorophyll content (autofluorescence) and total amount of DNA (Hoechst fluorimetry) were evaluated in fern (Soft shield fern, *Polystichum setiferum*) spores and gametophytes as markers of effects on plant development. Lipid peroxidation was assessed as a measure for acute animal toxicity in zebrafish embryos (*Danio rerio*). Pollution by pesticides (atrazine, diuron, molinate and oxadiazon) and pharmaceuticals (caffeine, cotinine, ivermectine, nicotine and paraxanthine) was detected in water courses receiving irrigation drainage. Pesticide traces were detected in red swamp crayfish (oxadiazon), and Holm oak leaves (oxadiazon, terbutilazine) but not in willow leaves. Preliminary risk assessment described potential moderate or high risk in the lower waters of both studied rivers. The battery of bioassays was able to detect toxicity in the waters of the lower Gargáligas as well as toxic effects on the waters from the irrigation channel. Such methods could both cut costs and improve the prognostic capability of current monitoring programmes.

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1. Introduction

According to current global change models, Mediterranean areas will continue to experience reductions in precipitation during the next few decades. These predicted changes are expected to pose a challenge to traditional rain-fed agriculture, increasingly supporting the expansion of irrigation-based production (Döll, 2002; Lehner et al., 2006).

The expansion of irrigation-based agriculture in Mediterranean areas has obvious effects on water demand and availability, but it can also have a significant impact on water quality. The intensive use of agrochemicals in irrigation based-agriculture, together with the dynamic nature of these systems is known to facilitate pollutant mobilisation to natural and artificial water bodies through run-off, drainage or even spray drift (Mañosa et al., 2001).

Reduced water quality along with increased water demand places the already vulnerable Mediterranean aquatic environments in a challenging situation through the increased need for the use of marginal-quality irrigation waters (e.g. wastewater, agricultural drainage water, etc.). The use of these sources of water for irrigation could not only have significant environmental effects, but also challenge agricultural production itself (Chandler and Savage, 1980; Fernández Cirelli et al., 2009).

In recent years, the widespread presence of pharmaceutically active compounds (PhACs) in some of these marginal-quality waters has been shown (Bottoni et al., 2010). At the same time, these compounds seem to appear at detectable levels in biosolids

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or compost, even after treatment for agricultural use (Radjenović et al., 2009a,b; Borgman and Chefetz, 2013). The amendment of agricultural soils with these products is a controversial practice, and has long attracted researchers' attention due to the presence of micropollutants (e.g. PhACs and other compounds with high biological activities) with high biological activities whose effects on crops and agricultural environment may be detrimental reviewed by (Jjemba, 2002). Despite this knowledge, the occurrence of these compounds in agricultural environments has been poorly investigated.

Approximately fourteen per cent of the total agricultural area in Spain is farmed using irrigation techniques. This small area provides, however, more than sixty per cent of the total agricultural production value in the country and accounts for the consumption of 68% of Spanish water resources (Barbero, 2005). In order to protect this strategic part of its economy, the Spanish Government developed the Spanish National Irrigation Plan (PNR) in 2002. The main goals of the PNR were to improve and update traditional irrigation systems, some of which dated back to Roman and Muslim times, along with the introduction of these techniques in new suitable areas. Actively acknowledging the potential for increased diffuse pollution, one of the focus points of the PNR is to reduce and control the inputs of agrochemicals into natural ecosystems. Water quality monitoring is, therefore, a key point in the application of the plan, through the implementation of an Environmental Monitoring Programme (PVA, after its initials in Spanish).

According to currently applied monitoring programmes, water quality and ecosystem health are to be studied by traditional water chemistry analysis and/or standard ecological assessments. Traditional chemistry gives no information on the ecological effects of the pollutants. On the other hand, complete ecological assessments provide a precise diagnosis but are not suitable for routine monitoring due to the need of highly qualified human resources, time consumption, and low predictive capabilities (the ecological damage may be irreversible by the time it is detected). With these limitations in mind, the development of effective environmental monitoring methodologies faces the challenge of incorporating new techniques able to merge cost-effectiveness, reliability, prognostic power and ecological relevance.

Monitoring toxic organic micropollutants (e.g. pesticides or PhACs) in different environmental compartments is, undeniably, of high importance due to their potential adverse effects on crop yield (Chandler and Savage, 1980) and non-target organisms (Roloff et al., 1992; Monserrat et al., 2003) including humans (Páldy et al., 1987). In systems where complex pollution exists (both in terms of source and composition), the assessment of the environmental risk posed by a single given pollutant by means of its measured concentration and known toxicological effect (Tier I Environmental Risk Assessment) is hardly accurate. This is the case even when dealing with well-known compounds for which extensive toxicity data is available. In order to be able to account for the influence of phenomena like hormesis, mixture toxicity, or the effect of combined stressors, toxicity testing of real environmental samples becomes essential. Current standard tests for environmental monitoring, such as those recommended by the U.S. EPA on their Whole Effluent Toxicity (WET) methods (U.S. EPA, 2002a,b,c), present a series of drawbacks such as, large sample volume, high costs, and low ecological and biological relevance of standard test organisms (Catalá et al., 2009).

Understanding these limitations, the objectives of this study are to: (1) develop new methodologies and tools for cost-effective, reliable, and prognostic environmental monitoring; (2) compare the new techniques to traditional risk characterisation methods based on collected pollution data.

2. Materials and methods

2.1. Study area

The Centro de Extremadura irrigable area (Fig. 1) is a 23,666.62 ha agricultural site in the Badajoz province (western Spain) considered of general national interest for management purposes under the Spanish National Irrigation Plan (PNR). Its original landscape comprised on rain-fed agriculture and oak wood pasture together with seasonal wetlands formed by the wandering channels of the riparian network after spring rains. During the last decade, this traditional landscape has been transformed into new irrigated maize fields and rice paddies following the PNR (Barbero, 2005).

Water distribution in the area is mainly provided by a network of concrete channels flowing from the Garcia-Sola (554 hm^3) and Orellana (808 hm^3) reservoirs. In addition to this network, two natural rivers (Table 1) flow through the study area from the upper non-irrigated land to the lower traditionally irrigated zone (tomato,

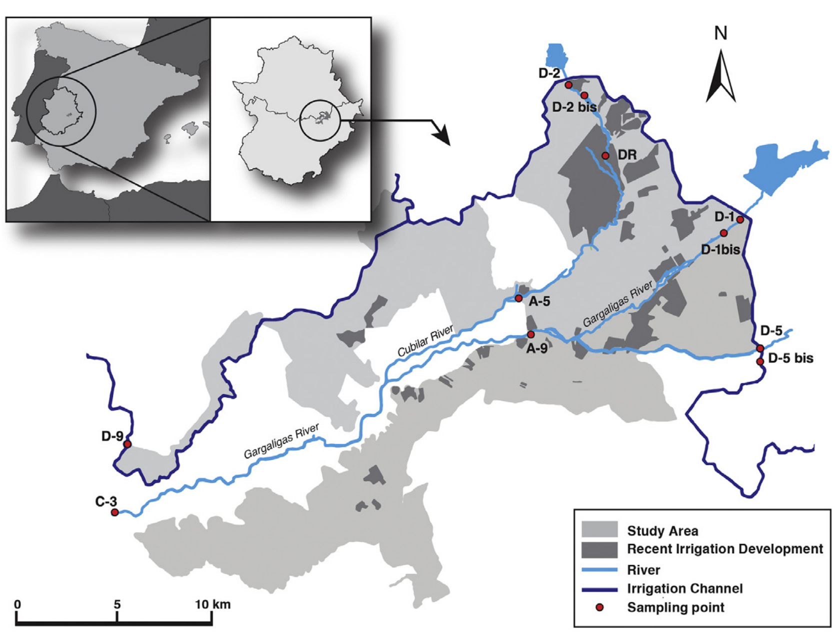

Fig. 1. Map of the area of study.

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