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Landscape evolution and agricultural land salinization in coastal area: A conceptual model

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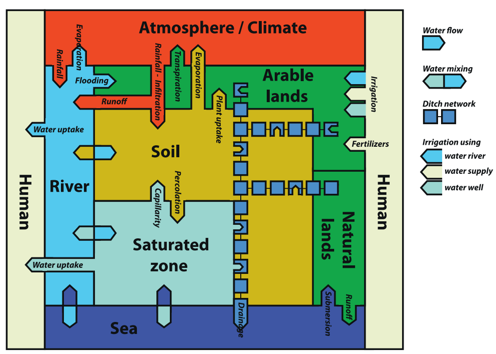
HIGHLIGHTS

- We investigated soil and water salinity in an agricultural coastal landscape.
- We drove a time analysis of climate, river and land system since 1962.
- We proposed a conceptual model of water fluxes for salt affected lands.
- Landscape evolutions were responsible for system equilibrium disruption.
- Natural and human induced changes favored salt accumulation in soil root zone.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil salinization is a major threat to agricultural lands. Among salt-affected lands, coastal areas could be considered as highly complex systems, where salinization degradation due to anthropogenic pressure and climate-induced changes could significantly alter system functioning. For such complex systems, conceptual models can be used as evaluation tools in a preliminary step to identify the main evolutionary processes responsible for soil and water salinization. This study aimed to propose a conceptual model for water fluxes in a coastal area affected by salinity, which can help to identify the relationships between agricultural landscape evolution and actual salinity. First, we conducted field investigations from 2012 to 2016, mainly based on both soil ($EC_{1/5}$) and water (EC_w) electrical conductivity survey. This allowed us to characterize spatial structures for $EC_{1/5}$ and EC_w and to identify the river as a preponderant factor in land salinization. Subsequently, we proposed and used a conceptual model for water fluxes and conducted a time analysis (1962–2012) for three of its main constitutive elements, namely climate, river, and land systems. When integrated within the conceptual model framework, it appeared that the evolution of all constitutive elements since 1962 was responsible for the disruption of system equilibrium, favoring overall salt accumulation in the soil root zone.

1. Introduction

Land resources are being irreversibly lost and degraded due to pressure generated by human populations and activities and by changes in climate and land use (EEA, 2000). For agricultural lands, anthropogenic changes are induced by farmers at both field unit and farm scale or by

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policymakers from farming to administrative divisions (Verburg et al., 2002; Rounsevell et al., 2005; Claessens et al., 2009). Climate-related changes are induced by climate factors as predicted by projections of future climate change (IPCC Core Writing Team, 2014).

Within this context of land degradation, soil salinization is a major threat. According to FAO in 2000, around 830 Mha of land worldwide contains salt-affected soil (SAS) (Martinez-Beltran and Manzur, 2005). SAS can be found on all continents apart from Antarctica and occurs in >100 countries worldwide (Szabolcs, 1985; Rengasamy, 2006), with the most prominent areas being arid and semiarid climatic zones. In Europe, soil salinity affects about 3.8 Mha of land (Tóth et al., 2008; Rhoades et al., 1999; JRC, 2012) and is particularly problematic in the coastal areas of southern Europe (Daliakopoulos et al., 2016). Salinization is an increase in the concentration of water-soluble salts in water and soils. Soluble salts could be of environmental origin (geological, climatic, topographic, and hydrological) or result from inefficient or inappropriate human activities (Shrestha, 2006; Szabolcs, 1992; Daliakopoulos et al., 2016). Whatever the origin, salinity threatens the sustainability of agriculture by affecting crop production through decreased yields and plant death (Feinerman et al., 1982; Maas and Hoffman, 1977; Li et al., 2012), according to processes summarized by Rengasamy (2010).

In order to preserve land resources and crop production potential, a possible solution to salinization is the promotion of sustainable land management practices that sustainably reduce salinity. To this end, modeling is an appropriate method for simulating the evolution of soil salinity according to different land management scenarios. Daliakopoulos et al. (2016) and Coletti et al. (2017) have listed models for studying the evolution of salinity in agricultural environments. However, the use of these models presumes the ability of users to produce quantitative data and to have hypotheses on system functioning and complexity. A preliminary step prior to this numerical work could be to use a conceptual model as an evaluation tool, allowing the reduction of complexity (Margoluis et al., 2009).

Estuaries are defined as areas where salt water from the ocean mixes with fresh water from land drainage (Potter et al., 2010; Whitfield and Elliot, 2011). For centuries, estuarine wetland ecosystems have been valuable to humans. Now, estuaries have become hotspots not only for agricultural land use but also for human settlements, tourism, and industries. Due to this anthropogenic pressure, estuaries are susceptible to land degradation and ecosystem disturbances. Indeed, estuaries represent highly complex situations, e.g., situations where social, political, economic, cultural, and environmental factors interact (Brechin et al., 2002; Hannah et al., 2002). In France, the Orb River estuary is an appropriate example of agricultural land where conceptual models could be helpful in identifying the main factors of land salinization.

Consequently, the objectives of this study were (i) to determine actual soil and water salinity in the Orb estuary, (ii) to determine the landscape evolution, and (iii) to build a conceptual model of water fluxes in a coastal area affected by salinization in order to identify the relationship between landscape evolution and actual salinity.

2. Materials and methods

2.1. Study area

The study area is located in the Orb River delta connected to the Mediterranean Sea (Fig. 1). Research was conducted in the Sérignan municipality (43°28′N; 3°31′E) where the main human activities are viticulture and tourism. Over the last decade, there has been a yield reduction in wine production and winegrowers generally assumed that soil salinization is the trigger. Interviews between the local authority and the local winegrowers' association (Cave Coopérative Les Vignerons de Sérignan) in 2016 estimated that around 43% of Sérignan vineyard soil surfaces has been affected by salinization over the last decade.

From a geomorphic perspective, Sérignan is located in a sedimentary basin of alluvial origin (Orb River) connected to the Mediterranean

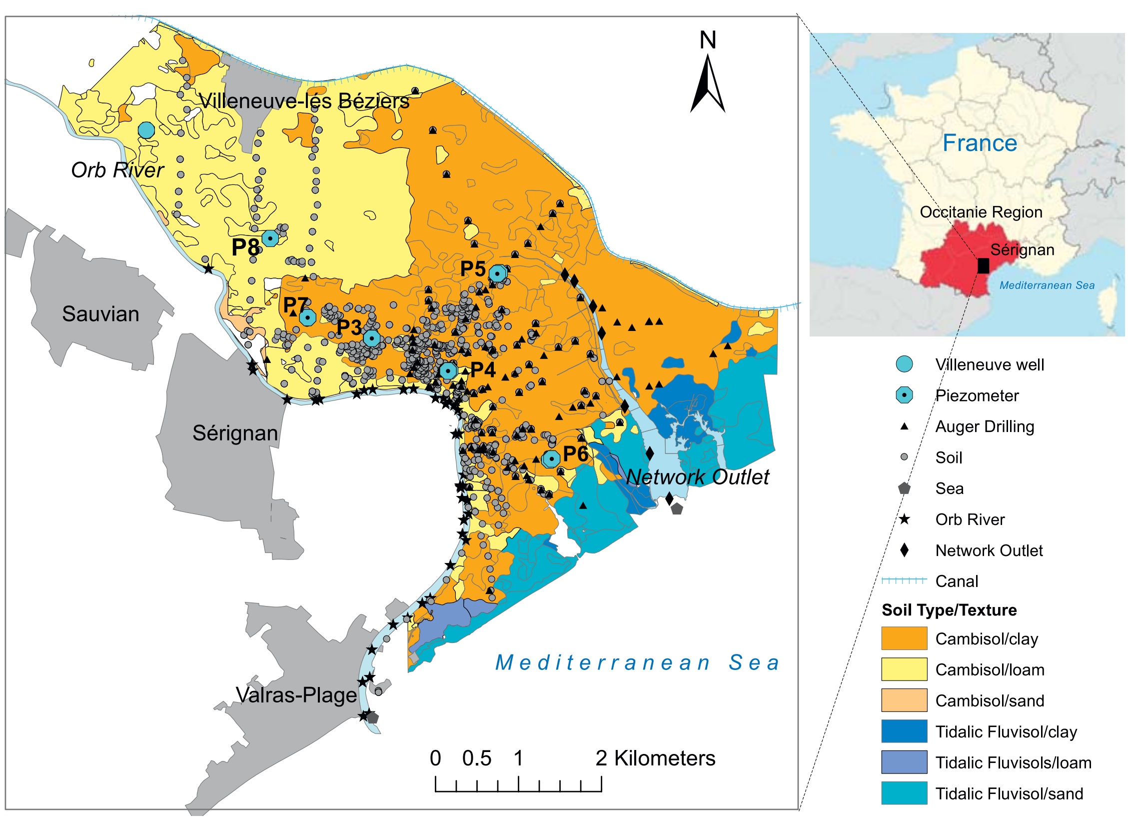

Fig. 1. Map of soil type and texture in the study area (Sérignan, France) and sampling locations for soil and water (piezometer, auger drilling, Orb River, network outlet, and sea) sampled from year 2012 to 2016.