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Salinity hazard and risk mapping of point source salinisation using proximally sensed electromagnetic instruments

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ABSTRACT

In many irrigated areas in the Murray–Darling Basin, New South Wales, Australia, point-source salinisation has occurred in isolated cases. In the lower Macquarie valley, near Trangie and Warren, the cause appears to be the mobilisation of salts from perched water tables and as a function of excessive deep drainage from water storages and conveyance channels. In order to understand these hazard factors and understand the risk of further salinisation, the spatial distribution of the various factors need to be mapped. Two methods have previously been employed and include the use of GIS hazard layer (e.g. geology, topography) analysis or airborne electromagnetic (EM) mapping. The former uses qualitative data which is often unreliable, whilst the latter has large start-up costs. In this study, various sources of proximally sensed data (i.e., EM38, EM34) are first used to develop stepwise-multiple linear regression (MLR) models to map the spatial distribution of vadose-zone (0–7 m) clay and salt stores. Using a salt-water balance model (SaLF), deep drainage (mm/year) is estimated. The model has an exponential form and uses ancillary data as predictors. The predicted clay, salt store and deep drainage hazard maps are further employed to develop a map of overall salinity risk using Boolean logic and indicator kriging. Results suggest that the areas exhibiting the largest conditional probability of salinity risk correspond to permeable soil types associated with the Trangie Cowal, Contemporary Macquarie and Backplain of Old Alluvium Pedoderm. It was also noted that the predicted salinity risk was consistent with where salinisation had occurred in both Trangie and Warren districts. The methodology indicated where a more strategic approach needs to be implemented when considering options to improve irrigation efficiencies and water delivery southeast of Warren and Trangie. It also showed where more detailed investigations could be undertaken to better understand the stratigraphic nature of the landscape and the mobilisation of the salts therein.

1. Introduction

Irrigation is an indispensable technology used to augment agricultural production in the semi-arid and arid regions of the world. However, poor irrigation management can lead to excessive deep drainage, which is the downward movement of water across the bottom of the root zone (Seyfried et al., 2005). Unfortunately this has led to the creation of perched water-tables (Peck, 1977; Muirhead et al., 1996). In many irrigated areas in the Murray–Darling Basin, point-source salinisation has subsequently occurred (Triantafilis and Buchanan, 2010), whilst in others there is little or no evidence of point-source salinisation. This is because waterlogging and salinisation occur as a function of interactions between various biophysical factors such as agronomy (e.g., location of water storages), geology, hydrology, climate and topography. In order to understand the causes or risk of secondary salinisation in a given area, which is the increase of salt-to-water ratio due to anthropogenic factors (Lamb, 2011), it is first necessary to map the spatial distribution of salt stores (Mullen et al., 2007). Because the salinisation process is usually closely related to surface soil and hydrological processes (Xu and Shao, 2002), biophysical information is also required to map the spatial distribution of secondary sanilisation, which includes a source of stored salt and a means to mobilise the salt.

In Australia two methods have been employed to develop salinity hazard and/or risk mapping. The first is the collation of hazard factor data layers, such as; maps of geology, soil type, rainfall and elevation, into geographic information systems. Using composite indices and trend based approaches (Bradd et al., 1997) the data

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have been employed at catchment (Dowling et al., 1997) to nationwide (NLWRA, 2001) scales to determine salinity hazard and/or risk. However this approach is semi-quantitative and it is unable to account for the many uncertainties associated with hazard and risk modelling at the local scale. An alternative approach has been the use of airborne transient-electromagnetic (TEM) induction geophysical methods to map salinity risk (e.g. Lee and Ignetik, 1994) and saline groundwater (e.g. Fitterman and Stewart, 1986; Viezzoli et al., 2012). The start-up cost of this type of work dictates large areas need to be covered. However, where EC_a is low (<100 mS/m) the measurement of shallow layers (i.e. soil profile) can be masked by large EC_a at depth (Cresswell et al., 2007).

The use of proximal sensing electromagnetic (EM) induction instruments offers an alternative. The most popular has been the use of a commercial EM induction instrument, namely the EM38 (Geonics Ltd., Mississauga, Ontario, Canada). This is because it provides measurement of the apparent electrical conductivity (ECa – dS/m) of the rootzone (0–1.5 m). However, while many examples of how an EM38 has been used at the field scale and to measure and map salinity in countries such as Indonesia (McLeod et al., 2010), Uzbekistan (Akramkhanov et al., 2011), Turkey (Cetin et al., 2012) and China (Guo et al., 2013), there are few examples where it has been applied over a district scale. Where this has occurred, the deeper measuring EM34 (Geonics Ltd., Mississauga, Ontario, Canada) has been preferred. One of the first was Williams and Baker (1982) who used an EM34 on a 5 km grid to map salinity across a large area. More recently, Buchanan and Triantafilis (2009) mapped the extent of a shallow saline ground water table (6–12 m) using EM38 and EM34 along with γ-ray spectrometry and morphometric data, whilst Woodforth et al. (2012) applied a hierarchical spatial regression modelling technique to calibrate estimates of deep drainage to EM34 measurements.

The objective of this study is to develop digital maps of hazard layers which in combination give rise to isolated instances of point source salinisation in the Trangie and Warren irrigated cotton growing areas. In the first instance we use various sources of ancillary data (e.g. EM38, EM34, trend surface components) to develop multiple linear regression (MLR) models to map the spatial distribution of vadose-zone (0–7 m) salt store and clay content. With regard to the latter we are interested in identifying where in the landscape a subsurface layer might exist and which is capable of causing perched water tables. In addition, we model the relationship between estimated deep drainage using a salt and leaching fraction (SaLF) model (Carlin and Brebber, 1993), because this appears to be a major hazard factor causing mobilisation of salt to the rootzone. To account for the uncertainty and to develop a map of salinity risk, we assess the maps discerning hazard factor values. Using these and Boolean logic, we use indicator kriging to generate a map of overall salinity risk across Trangie and Warren.

2. Materials and methods

2.1. Study area

The Macquarie River is a tributary of the Darling, which drains the northern part of the Murray–Darling Basin (Fig. 1). The study areas are located in the lower Macquarie valley southeast of the townships of Warren (Fig. 2a) and Trangie (Fig. 2b). It includes both irrigated and dryland farming. The latter is mostly wheat (*Triticum aestivum*) production and native pastures. Irrigation is mostly for cotton (*Gossypium hirsutum* L.) production. The irrigated infrastructure (including major water storages) is also shown in Fig. 2a and b.

McKenzie (1992) identified several Pedoderms in the Macquarie valley (Fig. 2(c and d)). According to McKenzie (1992), a pedoderm is a mappable unit of soil which is at either the land's surface, or partially or wholly buried. It has physical characteristics and stratigraphic relationships that permit consistent recognition and mapping. The clay content of characteristic soil profiles are shown in Table 1. The largest Pedoerm is the Trangie Cowal, which dominates the northern half of Trangie and runs parallel to the Macquarie River in Warren. It consists of three components: (i) Alluvial Plain (ii) Depressions and (iii) Source Bordering Dunes. The Alluvial Plain consists of Wilga Calcic (28%) and Non-Calcic soil (27%), which have small clay contents. The soil in the Depressions (mostly Byron) predominantly are silty cracking clays (35%), with the Source Bordering Dunes consisting of uniformly textured profiles (4%).

The second largest Pedoderm is the Old Alluvium. It is mainly found in the southwest of Trangie. It consists of two components, Meander Plain and Back Plain and resembles the Riverine prior streams (Butler, 1950; Pels, 1964). According to McKenzie (1992), The Mitchell soil of the Meander Plain Pedoderm component is a texture contrast (49%) soil. The texture of the Backplain Pedoderm component is more diverse with a uniform cracking clay nature. It includes the Mullah Black (52%) and Grey (47%), Buddah (48%) and Snake (50%) soil classes (McKenzie, 1992).

The third largest Pedoderm is the Contemporary Macquarie. It is situated along the Macquarie River and forms the western margin of Trangie. Smaller pedoderms, include the Gin Gin Hills (uniform to gradational texture profiles), consisting of Crests and Slopes

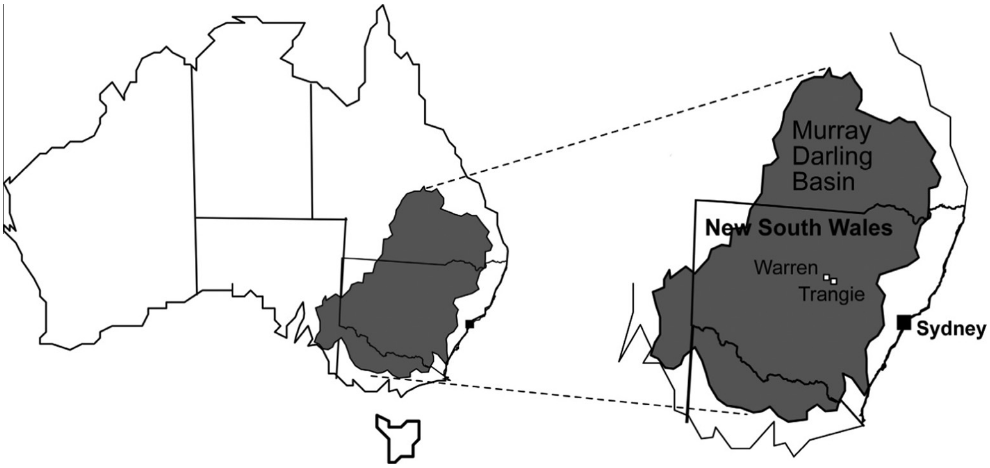

Fig. 1. Location of the study areas in Australia.