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Identifying soil landscape units at the district scale by numerically clustering remote and proximal sensed data

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ABSTRACT

Identifying soil landscape units at a district scale is important as it allows for sustainable land-use management. However, given the large number of soil properties that need to be understood and mapped, cost-effective methods are required. In this study, we used a digital soil mapping (DSM) approach where remote and proximal sensed ancillary data collected across a farming district near Bourke, were numerical clustered (fuzzy *k*-means: FKM) to identify soil landscape units. The remote data was obtained from an air-borne gamma-ray (γ-ray) spectrometer survey (i.e. potassium-K, uranium-U, thorium-Th and total counts-TC). Proximal sensed data was collected using an EM38 in the horizontal (EM38h) and vertical (EM38v) mode of operation. The FKM analysis (using Mahalanobis metric) of the kriged ancillary (i.e. common 100 m grid) data revealed a fuzziness exponent (ϕ) of 1.4 was suitable for further analysis and that $k = 4$ classes was smallest for the fuzziness performance index (FPI) and normalised classification entropy (NCE). Using laboratory measured physical (i.e. clay) and chemical (i.e. CEC, EC_e and pH) properties we found $k = 4$ was minimised in terms of mean squared prediction error (i.e. $\sigma^2_{p,C}$) when considering topsoil (0–0.3 m) clay (159.76), CEC (21.943), EC_e (13.56) and pH (0.2296) and subsoil (0.9–1.2 m) clay (80.81), CEC (31.251) and EC_e (16.66). These $\sigma^2_{p,C}$ were smaller than those calculated using the mapped soil landscape units identified using a traditional approach. Nevertheless, class 4A represents the Aeolian soil landscape (i.e. Nb4), while 4D, represents deep grey (CC19) self-mulching clays, and 4B and 4C yellow-grey (II1) self-mulching clays adjacent to the river and clay alluvial plain, respectively. The differences in clay and CEC reveal why 4B, 4C and 4D have been extensively developed for irrigated cotton production and also why the slightly less reactive 4B might be a source of deep drainage; evidenced by smaller topsoil (2.13 dS/m) and subsoil (3.76 dS/m) EC_e. The research has implications for providing meaningful DSM of soil landscape units for farmers at districts scales where traditional methods were restrictive in terms of time and cost.

1. Introduction

Identifying soil landscape units at a district scale is important as it allows for the sustainable land-use management. This is because inappropriate use of land threatens rich and fertile farm land. This has been the case across large tracts of the state of New South Wales, Australia. For example, the removal of crops for agricultural export has removed nutrients and led to soil acidification (SoE, 2012). In addition, the over irrigation of fields which have small tracts of lighter textured soil types (i.e. prior stream channels) than the surrounding alluvial clay plains (Woodforth et al., 2012) has led to excessive deep drainage (Triantafilis et al., 2004) and in some cases the creation of shallow saline water tables (Buchanan and Triantafilis, 2009) and soil salinization (Zare et al., 2015). What is therefore required is a way to either map these soil properties individually or identify soil types which differ in terms of various soil properties in a given area. Soil properties which are important in terms of land use management include clay, cation exchange capacity (CEC), electrical conductivity of a saturated soil paste extract (EC_e – dS/m) and pH. This is because these properties indicate the ability of soil to: shrink and swell (clay and CEC); affect plant growth or nutrient availability, respectively.

Given a large number of soil properties contribute to land-use management considerations, each one needs to be mapped using a cost-effective method. Increasingly, the approach of digital soil mapping is being used because cheaper to acquire ancillary data is coupled to soil property data using statistical and mathematical approaches. For example, clay has been mapped using electromagnetic (EM) induction instruments that measure the apparent soil

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electrical conductivity (EC_a – dS/m). This includes places like Australia (Triantafilis et al., 2001), Germany (Weller et al., 2007) and Belgium (Saey et al., 2009). Equivalent research has also been carried out to map soil properties which also influence the EC_a including; salinity (Huang et al., 2015a), cation exchange capacity (Triantafilis et al., 2009a), and soil moisture content (Huang et al., 2016). Upscaling of this approach to district scale (i.e. >5000 ha) is a little more complicated although recent research has demonstrated various individual soil properties have been mapped, including individual soil particle size fractions (PSF) to map soil texture (Buchanan et al., 2012) and to map available water content (Gooley et al., 2014). In both cases remote-sensed gamma-ray spectrometry and proximal EM38 data were used in conjunction with mathematical models and soil property data.

However, in some instances individual soil properties of importance in land-use management, such as soil pH, are often not correlated with this type of ancillary data. In this regard, it still may be possible to map these soil properties using ancillary data, but by considering such data as surrogates for air-photo interpretation; whereby the ancillary data is numerically clustered to identify soil landscape units. At the field level EC_a from an EM38 instrument has been used in concert with ancillary data derived from a digital elevation model (Fraisse et al., 2001), crop yield (Anderson-Cook et al., 2002), EM31 with digital numbers of color (i.e. red, green, and blue), from an aerial photograph (Triantafilis et al., 2009b), red reflectance (Bramley et al., 2011), and Quickbird imagery (Guo et al., 2013). More recently, EC_a data has been clustered along with gamma-ray (γ-ray) spectrometry data to map management zones in Germany (Altdorff and Dietrich, 2012), Belgium (Van Meirvenne et al., 2013) and the UK (Huang et al., 2014a).

In this study our aim is to use remote (airborne γ-ray spectrometry) and proximal sensed EM38 data acquired across the geologically and geomorphological diverse Aeolian and alluvial clay plain of the Bourke Irrigation district, to identify soil landscape units (Northcote, 1966). Specifically, we will discern the merit of using fuzzy *k*-means (FKM) analysis to identify soil landscape units using both γ-ray (i.e. K, Th, U radioelements and TC) and EC_a (i.e. EM38 in horizontal [EM38h] and vertical [EM38v] modes of operation) data. We use the mean squared prediction error of various topsoil (0–0.3 m) and subsoil (0.9–1.2 m) physical (clay) and chemical (CEC, ECe and pH) soil property to identify the most appropriate number of classes. We compare these results with the traditional soil landscape unit map.

2. Materials and methods

2.1. Study area

The township of Bourke is located approximately 760 km north west of Sydney, in New South Wales (Fig. 1). The study area covers approximately 270 km^2 to the west and south. The soil landscape units (Northcote, 1966) include: uniform textured-deep yellow grey (II1) and -grey self-mulching cracking clays (CC19) and yellow grey self-mulching cracking clays (II1) (Fig. 2A). Both are found on low lying alluvial floodplains of clayey silt, sand and gravel (Qrs) of the Darling River (Fig. 2C). Conversely, red earths characterised by neutral reaction trend (My1), occur on gently sloping tableland remnants in association with duplex profiles with red clay subsoil (Nb4). These soil landscapes are formed upon Aeolian dunes and low stony ridges. Given they are lighter in texture (loam) these soil types are generally not suitable for agriculture although they have recently been developed for drip-irrigated horticultural cropping.

Climatically Bourke is located in a semi-arid zone, with a low annual rainfall (~355 mm) and high potential evaporation (2000 mm). The temperature varies from a mean maximum of 36.3 °C in summer to a minimum of 17.9 °C in winter. Owing to the suitability of the climate, the soil quality and the availability of good quality water from the Darling River, the area was developed in 1968 initially in the CC19 soil mapping unit and for irrigated cotton production. Today the region supports 14,000 Ha of

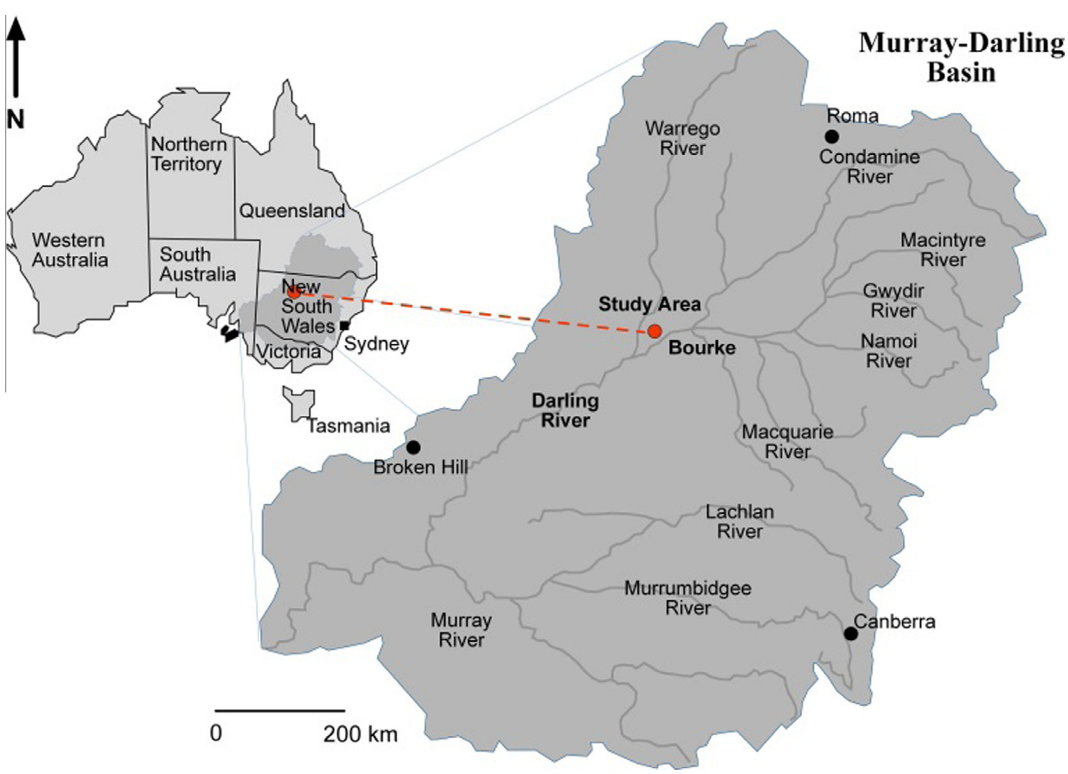

Fig. 1. Location of study area in northern New South Wales and Murray-Darling Basin, Australia.