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Mapping the transition from pre-European settlement to contemporary soil conditions in the Lower Hunter Valley, Australia

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ABSTRACT

The concept of soil security has been proposed with the dimensions of capability, condition, capital, connectivity, and codification of soil. However, it remains a challenge to accurately and efficiently assess the soil's capability and condition as a function of soil change. The idea of genoform and phenoform was proposed 20 years ago and recently revitalized. Herein, we were inspired by these concepts to develop a general approach and concepts of genosoils and phenosoils for distinguishing the soil changes within soil mapping units as affected by human activities. Across a 220 km^2 district with a diversity in landforms, parent materials, and land use types, we generated maps of Pre-European (soil classes that existed prior to agricultural development) soil classes using a digital soil mapping approach. Based on the land use change, Pre-European genosoils and present genosoils and phenosoils were identified and mapped within each of the Pre-European soil classes. The measured topsoil (0–10 cm) and subsoil (40–50 cm) properties have shown differences between the present genosoils and phenosoils. By objectively calculating the distances between the present genosoils and phenosoils in a principal component space using a recently published comprehensive soil classification system, several present phenosoils displayed significant differences among several soil properties (distance > 8% of overall distance) and were redefined as new genosoils. The approach has successfully mapped genosoils and phenosoils within Pre-European soil classes at the district scale and identified shifts between present genosoils and phenosoils. It showed potential in detecting areas of soil changes due to human activities. Future work is required to separate seasonal fluctuations from long-term variations in NDVI and improve land use classification using remote sensing data. The method developed here can be applied in areas without remnant vegetation to separate the soil condition from capability by gauging phenosoils against genosoils.

1. Introduction

Soil serves as the intersection of the lithosphere, hydrosphere, atmosphere and biosphere as a global resource to produce food, fibre, and fresh water, contribute to energy and climate sustainability, and to maintain the biodiversity and the overall protection of the ecosystem (De Groot et al., 2002; Lavelle and Spain, 2001). To secure the soil resource, it is necessary to monitor the spatial variations and temporal changes of soil properties (Arrouays et al., 2012; Jandl et al., 2014; Chauveau et al., 2014).

To frame this, the concept of soil security has been proposed with the dimensions of capability, condition, capital, connectivity, and codification of soil which encompass the social, economic and biophysical sciences and recognize policy and legal frameworks (McBratney et al., 2014; Kidd et al., 2018). However, it remains a challenge to accurately and efficiently assess the soil's capability and condition as a function of soil change. This is because soils are formed as a result of climate, organisms, relief, parent material, and humans and are susceptible to natural but more importantly anthropogenic disturbance over time (Amundson and Jenny, 1991; Pulleman et al., 2000).

The idea of genoform and phenoform was proposed 20 years ago (Droogers and Bouma, 1997) and recently revitalized by Rossiter and Bouma (2018). Genoforms are defined as soil classes as identified by the soil classification system used as the basis for detailed soil mapping in a given area while soil phenoforms are defined as persistent variants of a genoform with sufficient physical or chemical differences to substantially affect soil functions. These concepts are potentially useful in identifying the soil spatial variations and monitoring the soil changes through time (Rossiter and Bouma, 2018). However, Rossiter and Bouma (2018) only focused on the current soil survey map (i.e. soil series) to identify the genoforms and phenoforms at one stage. As the soil may change with time, the soil phenoform identified in the past can become a new genoform at the present time. More specifically, depending on the extent of change, people may wish to distinguish

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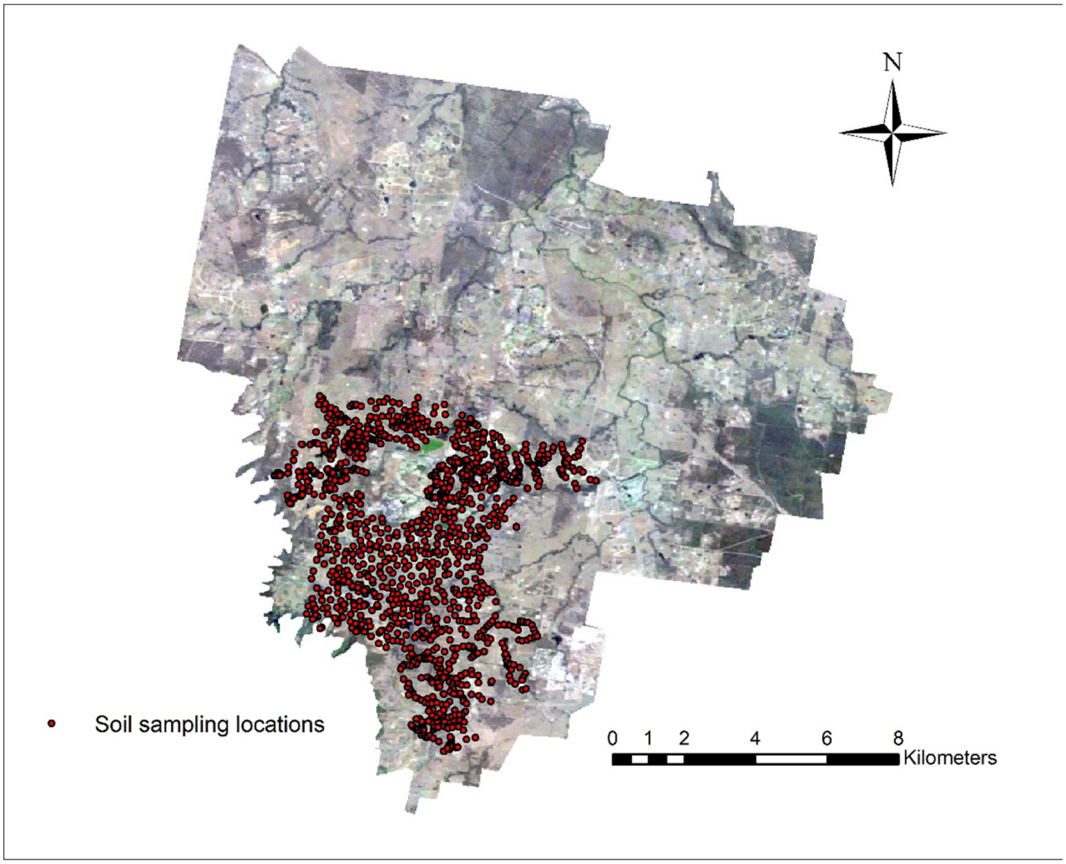

Fig. 1. Landsat 5 Image of the Hunter Wine Country Private Irrigation District (HWCPID), NSW, Australia. Note: the red dots indicated the locations of the soil samples collected during 2001 and 2011. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

differences among phenoforms. In addition, there is a need to apply these concepts to soil mapping units across large areas, particularly when maps of soil series are not available. Based on the concepts of genoforms and phenoforms, we proposed genosoils and phenosoils to monitor soil changes within different soil mapping units as affected by human activities. The aims of this study were to 1) develop a method to identify genosoils using a digital soil mapping approach, 2) using remote sensing data to delineate phenosoils and monitor human-induced soil changes from an initial genosoil to different phenosoils and from a previous genosoil to a new genosoil, 3) propose a quantitative method to define the various genosoils and phenosoils based on soil properties, and 4) ultimately provide guidance for soil monitoring and land conservation for soil security.

2. Materials and methods

2.1. Study area

The study area is located in the Hunter Wine Country Private Irrigation District (HWCPID), NSW, Australia (32.83°S, 151.35°E). It covers an area of approximately 220 km^2 (Fig. 1). The climate of the HWCPID is temperate, with warm humid summers, and relatively cool and humid winters. The average annual rainfall is ~750 mm and is mostly uniformly distributed throughout the year (Bureau of Meteorology, 2017). Topographically, this area consists mostly of undulating hills that ascend to low mountains to the south-west. The underlying geology of the HWCPID includes predominantly Early Permian siltstones, marl, and some minor sandstone (Hawley et al., 1995). Other extensive parent material includes Late Permian siltstones, and Middle Permian conglomerates, sandstones, and siltstones. The soils are variable and predominantly weathered kaolinitic–smectitic, ranging from light to medium texture grade. In terms of land use, an expansive viticultural industry is situated in the area and is possibly the most widespread in rural industries, followed by dryland agricultural grazing systems and forest. It is this diversity in landforms, parent material, and land use that make this a suitable area to address the research aims.

2.2. Soil data

Soil data used in this study are based on a collection of 1354 soil profiles that have been collected and described in the years including and between 2001 and 2011 (Fig. 1). Primarily located in the southern area of the HWCPID, each soil profile was described to the sub-order level of the Australian Soil Classification (ASC) (Isbell, 2002). Unlike the USDA Soil Taxonomy (Smith and Ahmad, 1986), the ASC does not rely extensively on quantitative diagnostic characteristics and horizons to classify the soils. Instead, the ASC system uses a key to allocate a soil profile to a certain order in turn. By evaluating the criteria of different orders sequentially, a soil profile will be classified into a soil order. In addition, ASC also uses soil colors (e.g. Red, Brown, Yellow, Grey, Black) to differentiate the suborders of certain soil orders (e.g. Kurosols, Sodosols, Chromosols, Ferrosols, Dermosols, Kandosols).

A number of soil properties were recorded for each soil profile horizon including soil texture, color and pH and electrical conductivity (1:5 soil: water) for the 0–10 cm and 40–50 cm depth intervals. Soil organic carbon concentration was also estimated for these depth intervals using an a priori calibrated vis-NIR soil spectral model developed from soil spectra of the data set described in Geeves et al. (1995). In general, the description of data used in the study has been given previously in Malone et al. (2014) and Odgers et al. (2011). The use of these data in this study was for the dual purpose of first mapping soil types (soil class data) and for verification of genosoils and phenosoils