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Digital soil assessment for regional agricultural land evaluation ☆

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ABSTRACT

The development of irrigated cropping is an important component of the strategy to intensify land use in sparsely populated northern Australia. An integrated resource assessment study has been conducted, with the aim of evaluating the potential for irrigated cropping in the Flinders and Gilbert river catchments – an area of 155,500 km^2 in north Queensland. The coupling of digitally derived soil and land attributes with a conventional land suitability framework facilitated the rapid evaluation of regional-scale agricultural potential in this remote area. Approximately 50% of the total area was found to be suitable for a range of irrigated crops, but the vast majority of this area has significant soil limitations and other constraints to production. Growing crops successfully in the dry tropics of northern Australia remains a challenge. Quantified uncertainty associated with the digital soil mapping outputs was used to estimate the reliability of the land suitability assessments.

1. Introduction

Northern Australia is broadly defined as the area north of the tropic of Capricorn (BITRE, 2009), and therefore occupies most of the Northern Territory, more than half of Queensland, and significant parts of Western Australia. This vast region has an area of approximately 3 million km^2 (i.e. 39% of Australia) but the population density is low (~5% of Australia) (BITRE, 2009). Land use is dominated by beef cattle grazing and natural resource conservation. While contributing significantly to the Australian economy, particularly in the resources and energy sectors, development and diversification of this region has long been a priority for Australian governments. The drivers of this development goal include a desire to boost investment and national trade accounts, the proximity of northern Australia to the large and growing economies of Asia and a requirement to improve national security and regional stability. The expansion of agriculture – especially cropping, which currently accounts for only 0.13% of the area of northern Australia (BITRE, 2009) – is seen as one possibility that is both achievable and desirable (DPMC, 2014).

Agricultural expansion in the tropics is also seen as a means of addressing potential water shortages and other climate-based threats to Australia's southern farming zone. The perceived capacity of northern Australia to supply food products to the expanding Asian market has led to the oft quoted phrase, 'food bowl of Asia' (DPMC, 2014; Australian Broadcasting Corporation, 2014) based on the premise that northern Australia is a vast under-utilised area with large supplies of freshwater and large areas of land suitable for cropping. The Ord River irrigation area in Western Australia is the major existing area of irrigated agriculture in the dry tropics of Australia, and is currently being expanded. The total value of irrigated crop production from the Ord River was estimated to be approximately A$101 million in 2008–09 (Kimberley Development Commission, 2014).

To effectively plan for land use intensification, governments and planning agencies require information about the capacity of the land to support various land uses. Resource management agencies, commonly working with limited baseline data are challenged to develop innovative ways to meet the growing demand for land resource information, and appropriately evaluate the land in terms of its potential for alternative kinds of land use. In the global context, there is a need for practical and efficient land evaluation techniques to identify the remaining areas of arable land across the globe, as well as those soils suitable for sustainable intensification of agriculture.

In Australia, agricultural land evaluation has been strongly influenced by the land evaluation guidelines prepared by the Food and Agriculture Organization (FAO, 1976, 1985). Most State agencies have adopted crop-specific land suitability systems with a five-class

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ranking based on FAO (1976). Combining crop requirements (or land use limitations) with soil, landscape, climate and other information at appropriate scales in a geographic information system (GIS) facilitates the implementation of site-specific crop suitability evaluations.

Agricultural land evaluation in Australia has generally been conducted as a component of integrated land resource surveys that involve the systematic collection, by field-based teams, of primary data related to the soil and land resource, and subsequent land resource mapping. Most traditional soil maps show soil types with sharp cartographic boundaries – *polygons* in GIS terminology – between taxonomic units, and are interpreted using map legends and supporting information (McKenzie et al., 2008).

Digital soil mapping (DSM) described fully by others such as McBratney et al. (2003) and McKenzie et al. (2008) is an alternative approach. Fundamentally, DSM is a set of models derived from statistical relationships between soil data and various environmental covariates, which are landscape, soil and climate factors prepared as continuous data themes – *rasters* in GIS terminology. It differs from traditional soil mapping in that the outputs are usually single soil attributes (e.g. pH, soil depth) predicted for individual cells (pixels) in the raster image. Key advantages of DSM are that (i) its statistical models are quantitatively based, flexible and repeatable, (ii) it can be applied rapidly across large areas, and (iii) estimates of uncertainty can be routinely produced as a guide to the reliability of the DSM outputs. DSM has become the preferred method for many soil mapping applications (e.g. Mansuy et al., 2014; Gooley et al., 2014) and is the technique being adopted to deliver a soil map of the world (Arrouays et al., 2014).

DSM has progressed beyond being simply a technique for predicting soil attributes, and is now used as a tool for assessing soil functions, processes and capability – i.e. digital soil assessment (DSA), (Carré et al., 2007). DSA translates DSM outputs into risk-based, spatial decision-making aids (McBratney et al., 2012). DSM outputs have been used to create functional land suitability maps in Mozambique (van Zijl et al., 2014), and operationally in a DSA to model land suitability for proposed irrigation expansion Tasmania, Australia (Kidd et al., 2014b).

The Australian and Queensland governments collaborated to develop the North Queensland Irrigated Agriculture Strategy. A key part of the strategy was a two-year integrated resource assessment study – the 'Flinders and Gilbert Agricultural Resource Assessment' (FGARA) (CSIRO, 2014). The aim of the project was to evaluate opportunities for irrigated cropping in the Flinders River (109,000 km^2) and Gilbert River (46,200 km^2) catchments. This paper considers the land suitability component of the FGARA project. Other components of the project included the identification of water capture and storage opportunities, testing the commercial viability of irrigation enterprises, groundwater investigations, river modelling, flood mapping and socioeconomic analysis. All reports and data associated with the FGARA project are freely available for internet download (CSIRO, 2014).

Due to the short time frame available (less than two years from project commencement to reporting) and the paucity of existing soil data across such a large area, it was not feasible to use a traditional land resource assessment. Therefore, a DSA approach was adopted; with the DSA components being: (i) a statistically-based design to identify new soil sampling sites to supplement the existing survey site database; (ii) the digital derivation of soil and land attributes (chosen specifically to meet land suitability requirements) across the catchments; and (iii) using the digital outputs to apply an FAO-style land suitability assessment.

The DSM components of this land evaluation have been reported in Thomas et al. (2015). As such, Thomas et al. (2015) acts as a precursor and companion to the present paper. The purpose of this paper is to (i) summarise the steps in an example of operational DSA that can be applied rapidly to accomplish a regional land evaluation and (ii) report and discuss the outcomes of the land suitability component of the FGARA project.

2. Methods

2.1. Study area

The Flinders and Gilbert catchments have a combined area of 155,500 km^2, but the population is sparse – totalling about 7200. All towns service the surrounding cattle-grazing properties ('stations'), while Cloncurry is also a significant mining town (Fig. 1). Most cattle stations are large, with sizes of >4000 km^2 not uncommon.

The Flinders and Gilbert catchments are fairly typical of the dry tropics of Australia, which are dominated by grassy open woodland (savanna) landscapes, with variable tree density. Treeless grasslands occur on heavier soils and where drainage is impeded. Both catchments drain northwest to the Gulf of Carpentaria and share a common watershed in the Great Dividing Range where they have a maximum elevation of approximately 1050 m. The Flinders is dominated by extensive lowlands in the centre and north, with highlands to the east and west. The Gilbert has a higher proportion of hilly country, but is flat in its lower reaches.

Climatically, the FGARA area ranges from semi-arid in the southwest to subhumid in the north and northeast. Rainfall strongly coincides with intense summer monsoons; some centres have over 90% of their rain in the months November to March. Average annual rainfall ranges from less than 350 mm in the southwest to approximately 1000 mm in small areas of the north, but the overriding feature of the rainfall is its year to year variability. Severe heatwaves are common, especially in the dry southwest; Julia Creek has an average of 154 days per year with maximum temperatures of >35 °C (BOM, 2014).

The soils of the Flinders catchment are dominated by cracking-clay soils in the lowlands, formed in alluvial sediments and also from in situ weathering of Cretaceous mudstones. These are Vertosols using the Australian Soil Classification (ASC) (Isbell, 2002) or Vertisols using the World Reference Base (WRB) (IUSS Working Group WRB, 2014). Vertosols are commonly used in Australia for dryland and irrigated cropping, as well as for the grazing of native and improved pastures. In the Gilbert catchment, Vertosols are restricted to small areas of local alluvium and the less extensive northern floodplain. Strongly weathered earthy soils (ASC: Kandosols; WRB: Ferralsols) occur on older residual surfaces in both catchments. Structured non-cracking clays (ASC: Ferrosols; WRB: Nitisols) along with some Vertosols have formed on areas of basalt, especially in upland areas of the Gilbert catchment. Quartzose sandstones, metamorphic rocks and granitic rocks have produced soils with an abrupt textural difference (ASC: Chromosols, Kurosols; WRB: Abruptic Luvisols/Lixisols/Acrisols) along with shallow sands and stony soils (ASC: Tenosols, Rudosols; WRB: Leptosols, Cambisols, Regosols) in steeper hilly country. Small areas of texture-contrast soils that have sodic or natric subsoils (ASC: Sodosols; WRB: Abruptic Luvisols, Planosols, Solonetz) are scattered throughout. Both catchments have areas of seasonally wet soils (ASC: Hydrosols, Aquic Vertosols; WRB: Gleysols, Stagnosols) on the lower floodplains.

2.2. Soil data and soil survey

Data from 1374 pre-existing soil survey sites scattered across the FGARA area and a broader zone surrounding it were compiled and harmonised. These data came from Queensland's Soil and Landscape Information (SALI) database (Biggs et al., 2000) and the National Soil Database (CSIRO, 2013). Because of the sparse distribution of existing sites, some additional site sampling was conducted.