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Functional digital soil mapping: A case study from Namarroi, Mozambique☆

G.M. van Zijl [a,1], D. Bouwer [a,1], J.J. van Tol [b], P.A.L. le Roux [a,2]

[a] Department of Soil Crop and Climate, University of the Free State, Bloemfontein, South Africa
[b] Department of Soil Science, University of Fort Hare, Alice, South Africa

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ABSTRACT

The value of soil is often neglected in developing countries, partially due to a lack of spatial soil data. Conventional methods of soil survey are too cumbersome and expensive to fulfil the need for soil maps in these countries. This study presents an expert knowledge based digital soil mapping (DSM) approach to provide in-time spatial soil information in developing countries. The objective of this study was to evaluate the potential of DSM soil survey methods to rapidly produce land suitability maps of a large area with acceptable accuracy. An expert knowledge approach was used, with soil surveyors creating conceptual soil distribution patterns, and populating the patterns with covariate values to create soil–landscape rules. A soil class map was created by running an inference with those rules. The map achieved an absolute validation accuracy of 80%, and 59% at a 95% confidence level. Land suitability maps were created based on the soil class map. Furthermore the data indicated that 14 or more soil observations are needed per homogeneous area to achieve acceptable results and that multiple scale covariates were useful to map different parts of the landscape.

1. Introduction

More than 95% of the world's food comes from land-based agriculture (FAOSTAT, 2003). Despite this, the value of soil surveys is often neglected. In South Africa, the lack of soil maps is given as one of the reasons for failure among upcoming farmers (Gaetsewe, 2001), although the return on investment for a soil survey is estimated to be 1:20 in the first year for dryland crop production (le Roux et al., 1999). One reason for the lack of soil maps is that conventional methods of soil survey are cumbersome and expensive (Hensley et al., 2007). In South Africa the conventional soil survey method is to make soil observations on a 100–200 m grid (le Roux et al., 1999), dependant on soil variation, and grouping similar observations together. It works well on small fields, but cannot produce maps for large areas which often need to be mapped in developing countries. With stereoscopy soil mapping is supported by using overlapping stereopairs of black and white photographs to delineate terrain units for application as mapping unit representative of soils, after making observations in those areas (Zhu et al., 2001). However, this requires aerial photographs, which is often not available, and it remains a time consuming manual process, which limits the application of expert knowledge for large areas. Expert knowledge based digital soil mapping (DSM) methods provide an answer to deliver in-time spatial soil information in developing countries. It also has the advantages that the expert knowledge of the soil surveyor is captured and constantly applied, the process is semi-automated, thus saving time and reducing errors, and it allows for higher levels of soil detail to be represented than what is routinely found in conventional surveys (Qi et al., 2006).

In Southern Africa soil survey for quantification of soil as a natural resource has stopped and surveys are now driven by industrial needs, implying that the map has to serve a specific aim, comply with a budget and fit a time frame. As in Van Zijl et al. (2012) surveys often cover large areas (10,000 ha and more) with limited accessibility and little legacy data. Available ancillary data varies dependent on the resources of the client. Requirements for land uses vary and they need to be matched with land qualities to produce an easily understandable map legend, for the map to be usable by the client (Bui, 2004). To apply site specific management, detailed, application orientated and functional soil maps are needed (Zhu et al., 2013).

The objective of this study was to evaluate the potential of DSM soil survey methods to rapidly produce land suitability maps of a large area with acceptable accuracy. The area to be mapped is near Namarroi, Zambezia Province, Mozambique, where a forestry company aims to establish forestry plantations. The soil map is a primary input to

☆ This paper is the original work of the authors. It shows how a soil map for 10,000 ha can be created in a reasonable time, using Expert knowledge DSM methods in an area with no existing soil data. The soil map is then used to derive production potential, soil erodibility risk and soil compaction risk, which will be used to determine management procedures for forestry production in the area.

E-mail addresses: vanzijlgm@ufs.ac.za (G.M. van Zijl), bouwerd@ufs.ac.za (D. Bouwer), jvantol@ufh.ac.za (J.J. van Tol), lerouxpa@ufs.ac.za (P.A.L. le Roux).
[1] Tel.: +27 51 401 9245.
[2] Tel.: +27 51 401 9628.

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determine where the trees will be planted, and which soil preparation works are necessary. Specific research questions include:

1. What is the minimum observation density needed to achieve acceptable map accuracy?
2. Which covariates are the most important in predicting soil classes?

The hypothesis is that a soil map for a large area, suitable for forestry, can be produced using DSM methodology with acceptable accuracy and fitness for use.

2. Site description

The site (Fig. 1) is located in the Namarroi district, Zambezia Province, Mozambique, with 15.7°S; 36.6°E as its centre point. The site is divided into two areas, Nammarua (6820 ha) to the South, and Cassarano to the North (4 150 ha). The vegetation forms part of the Miombo Woodland Forest (Snyman, 2012). The area is burnt annually by the locals to catch moles and mice for food. Subsistence crop production takes place, with cassava and maize being the most popular crops.

The area is very hot and humid. Fig. 2 shows the rainfall and mean temperatures for the period 1951–1968, the only period for which climate data exist. The climate is marked by a distinct wet and dry season. Very little rain falls between May and October, which places a specific emphasis on the water holding capacity of soils to bridge the dry season.

Granite and gneiss are the main lithologies, both of which weather to very coarse, bleached, sandy soils. There are some basic igneous rock intrusions, which produce red structured clayey soils. Because of scale restrictions the existing geological map (Direcção Nacional de Geologia (DNG), undated), at a small scale of 1:1,000,000, does not show all of these intrusions. Large steep granite inselbergs are common, while the rest of the terrain is relatively flat, often dipping steeply near the streams.

3. Material and methods

Two Lidar interpolated DEMs (10 m and 30 m) were used as ancillary data. Multiple resolutions were used, as multiscale terrain analysis is known to improve prediction accuracy (Behrens et al., 2010). Terrain

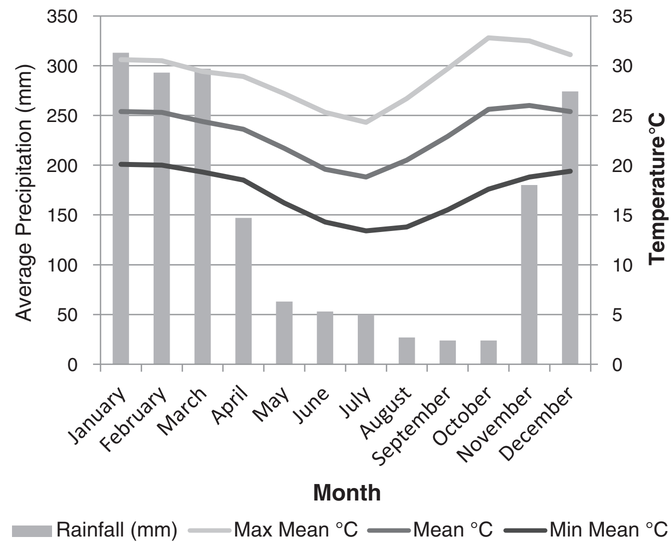

Fig. 2. Rainfall and temperature for Namarroi, Zambezia, Mozambique for the period 1951–1968 (obtained from ATFC, 2013).

variables were derived in SAGA (SAGA User Group Association, 2011) with the "Basic Terrain Analysis" module. Conditioned Latin Hypercube Sampling (cLHS; Minasny and McBratney, 2006) was used to determine pre-determined field observation points. The cLHS method allows for observations at positions representing the entire attribute space. For the Nammarua site, cLHS was conducted on the 30 m resolution grids using Slope, Profile curvature, Planform curvature, Wetness index and Altitude above channel network (AACN) as ancillary data. These terrain variables were used, as it was thought that they have the largest effect on the soil distribution. For the Cassarano site a different approach was taken by conducting principal component analysis on all the 30 m resolution derived topographic layers and using the resulting three layers to perform the cLHS. The different approaches were used out of curiosity to see whether it made a big difference in the soil

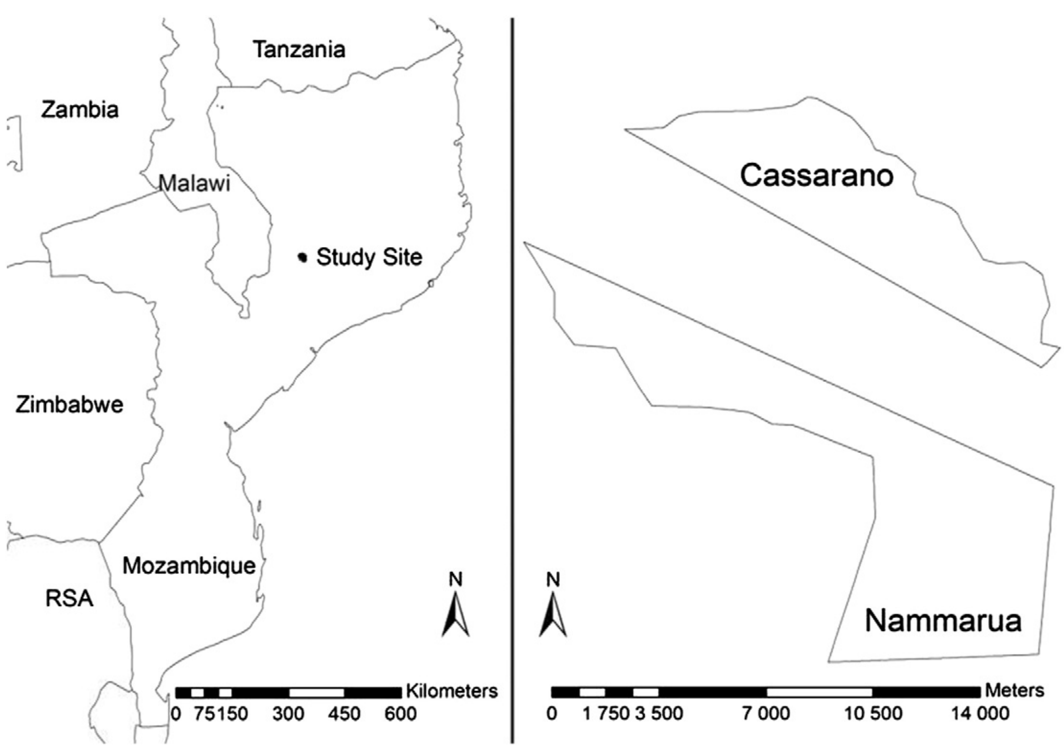

Fig. 1. The study area. Nammarua is to the South and Cassarano to the North.