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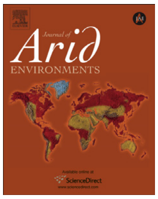

Broad scale mapping of vegetation cover across Australia from rainfall and temperature data

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ABSTRACT

Broad-scale estimation of spatial changes in vegetation cover is of value in many areas of research and land-use management. There is currently no simple method available to estimate vegetation cover at the broad scale (above the level of individual vegetation-type mapping or modelling) that does not rely, at least in part, on remote sensing data. This means that for periods where this data is unavailable (pre 1980 and future forecasting) estimates of vegetation cover are also unavailable. De Martonne's simple Aridity Index (AI) requires only rainfall and temperature data however it is not widely applicable and regularly fails in arid and semi-arid regions. The Climate Aridity Vegetation Index (*CAVI*) has been developed in an attempt to overcome this limitation while retaining simplicity in the data required and in the calculation. The *CAVI* is based on readily available rainfall and temperature data and has been applied and tested across 12 years of monthly data across Australia. The *CAVI* estimates have then been validated by comparing them to the corresponding fractional cover satellite data. Performance is discussed in the context of using vegetation cover estimates in wind erosion research. The results were particularly encouraging in arid to semi-arid regions and can potentially be used as a surrogate for historical broad scale vegetation cover and possibly future projections.

1. Introduction

Broad scale levels of vegetation cover can currently be estimated via satellite remote sensing data or vegetation-type modelling methods which also rely, to a large extent, on remote sensing data. However, for periods where no satellite data is available there are currently no simple, broadly applicable modelling method or index to realistically estimate and map vegetation cover levels in Australia. This includes any historical periods prior to the 1980s (i.e. prior to satellite remote sensing) and any future forecasting. Broad scale levels of vegetation cover are of interest and value to many areas of environmental, ecological and land-use modelling.

Vegetation cover is a key factor influencing the frequency, intensity and spatial distribution of wind erosion events. Currently estimates of vegetation cover such as the Normalised Digital Vegetation Index (NDVI) and the Leaf Area Index (LAI) are derived from satellite remote sensing data and used in integrated wind erosion modelling systems (Shao et al., 2007). Without these estimates of vegetation cover, historical and future wind erosion rates and dust source areas cannot confidently be estimated or identified.

Levels of vegetation cover are directly influenced by both climate and land management practices. Australia has large arid and semi-arid zones (covering approximate 70% of the continent (Wilson and Graetz, 1979)) which experience consistently low average rainfall (Fig. 1). In addition, the Australian climate is strongly influenced by the cyclical state of the El Niño-Southern Oscillation (ENSO) (Love, 2005; Stone, 2014; Williams and Stone, 2009). During the dry El Niño phases of the Southern Oscillation large parts of the Australian continent receive extended periods of below average rainfall and above average temperatures, consequently suffering extended periods of drought.

In arid and semi-arid rangelands native vegetation is particularly well adapted to low average rainfall and cyclical drought conditions. However, land use for primary production, including stocking and crop and pasture production, can significantly impact vegetation cover levels. Climate factors and land management practices can potentially help to mitigate or exacerbate (to varying degrees) the effect of the other on levels of vegetation cover.

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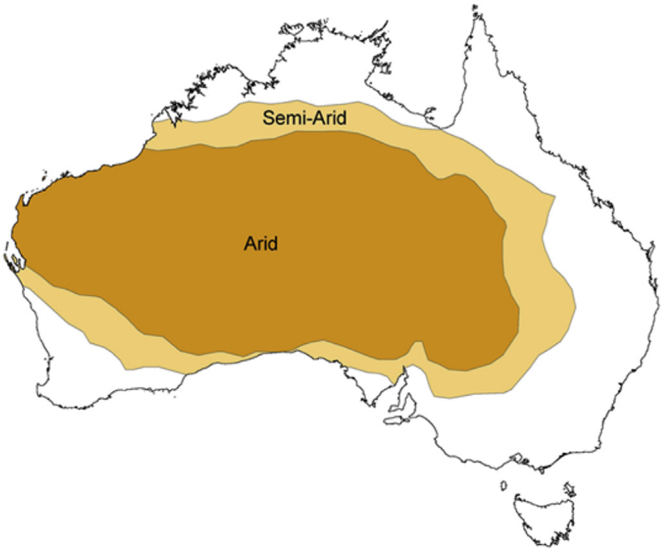

Fig. 1. Arid and semi-arid zones in Australia (Desert Knowledge CRC, 2006).

Additionally, the relationship between vegetation cover and wind erosion itself is non-linear. The probability of wind erosion increases exponentially once total vegetation cover falls below 50% (Leys, 1991, 1999).

Satellite remote sensing data captures the combined effect of both climate and land management practices and records any alive or dead vegetation cover as viewed vertically from above the ground surface. It can be used to estimate fractional vegetation cover, which divides cover into three components: photosynthetically active or green vegetation (f_{PV}), non-photosynthetically active or dead vegetation (f_{NPV}) and bare ground (f_{BS}) components. The relationship between the three components is $f_{PV} + f_{NPV} + f_{BS} = 1$ (Guerschman et al., 2009). Reliable satellite remote sensing data is not available prior to the 1980's, however the Australian Bureau of Meteorology (ABoM) started monitoring meteorological conditions across Australia in 1908 and gridded rainfall and temperature data is readily available across Australia from this time. Rainfall (precipitation) and temperature (evaporation) provide an indication of soil moisture potentially available for plant growth. Therefore, the Climate Aridity Vegetation Index (*CAVI*) developed in this paper attempts to estimate vegetation cover based only on this freely available meteorological data. The research presented here investigates the accuracy and utility of this simple index to predict broad-scale spatial variation in vegetation cover where no satellite remote sensing data is available. Although the performance of the *CAVI* Australia wide and across all seasons was investigated, of particular interest was the performance within the typical wind erosion season through Spring and Summer (September to February) in arid to semi-arid areas were the landscape is most prone to wind erosion and dust transportation events (McTainsh and Leys, 1993; Strong et al., 2011).

In particular, the main aims of this study are to: 1) develop a simple broad scale Climate Aridity Vegetation Index (*CAVI*) for Australia based on rainfall and temperature data only, without modelling individual vegetation types, seasonality and land-use; 2) validate the *CAVI* by quantifying the strength of any relationship between the *CAVI* predictions and vegetation cover estimated from satellite remote sensing data (5 km resolution for all months from Feb 2000 to Dec 2012 at monthly intervals); 3) investigate if reliable spatial and temporal vegetation cover maps can be produced based on the *CAVI*; and 4) comment on current limitations and the potential utility of the *CAVI* to predict past and future vegetation cover levels, acknowledging that land management practices of the 2000 to 2012 period are inherit in the predictions.

2. Data and methods

2.1. Data sources

Gridded daily rainfall and maximum temperature data was sourced from the ABoM from February 2000 to December 2012 and used to develop the *CAVI*. This data had a spatial coverage of 110.00–155.00° E and −10.00 to −45.00° N and a spatial resolution of 5 km.

Fractional cover values derived from remote sensing data were used to validate the *CAVI* estimates. Although lateral (standing) cover would be preferred for wind erosion, there are currently no reliable, long-term records of lateral cover available (Chappell, 2013). Fractional cover data was chosen over the Normalized Difference Vegetation Index (NDVI) (which is also derived from spectrographic data) as it has been more extensively ground-truthed in Australia. Fractional cover is also used in wind erosion research conducted by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Guerschman et al., 2012) and by Dustwatch (Gill et al., 2014).

Monthly remote sensed fractional cover data for both the photosynthetically active (green) fraction (f_{PV}) and the bare soil fraction (f_{BS}) (Guerschman et al., 2009) were used in this study. The potential for wind erosion can be mitigated by total cover (f_{TC}) where $f_{TC} = f_{PV} + f_{NPV} = 1 - f_{BS}$. The f_{PV} is likely to be more dynamically responsive to changes in rainfall and temperature than f_{NPV} and, therefore, has the potential to be more strongly related to the *CAVI*. As the f_{BS} indicates the probable surface exposed to the effects of wind erosion the f_{PV} and f_{BS} estimates represent the two extremes in the remote sensing colour spectrum and were used to help identify the fraction to which the *CAVI* is most closely correlated.

Remote sensed fractional cover data at a 500 m resolution from February 2000 (110.00–155.00° E and −10.00 to −45.00° N) was sourced from the Department of Agriculture, Fisheries and Forestry (DAFF) and the *Commonwealth Scientific and Industrial Research Organisation* (CSIRO) (Gill, 2015). The data was then post processed (re-sampled) and re-gridded to a monthly 5 km grid to match the rainfall and temperature grid of the ABoM data set. This procedure was similar to that used by Shao (2008) to combine different spatial resolution GIS data sets for use in CEMSYS models.

2.2. Climate Aridity Vegetation Index (CAVI) development

The De Martonne (1926) Aridity Index (AI) was used as the basis for development of the *CAVI* in this study. De Martonne defined the AI as a ratio of rainfall (mm) and corrected temperature (°C + 10) for temperatures greater than −9.9 °C for the target month. Where there is no rainfall within a given month, this index fails (returns a zero value). As a majority of Australia is classified as arid to semi-arid (Fig. 1) there are many months recording zero rainfall and the AI generally performs poorly. However, its simplicity, reliance on only rainfall and temperature data provided a template for development of an index appropriate to Australian conditions.

In arid to semi-arid zones vegetation cover is generally influenced by rainfall and temperature over several months leading up to the target month, rather than the rainfall and temperature of the target month itself (Donohue et al., 2009; Klein and Roehrig, 2006). Vegetation in these regions has evolved to persist for long periods without rainfall. Therefore, the *CAVI* for a target month incorporates the preceding 12 months weighted rainfall and temperature to