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ORIGINAL ARTICLE

Image acquisition for detection of vegetation change based on long-term rainfall in an arid rangeland in Western NSW, Australia

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Abstract Research on vegetation change, rangeland assessment or desertification modelling in drylands using remotely sensed image acquisition normally ignores long-term rainfall as a key criterion in image acquisition. This article will present a novel procedure for image acquisition to investigate vegetation change in a degraded rangeland located in Western New South Wales (Western NSW) Australia. Western NSW experienced an unusually prolonged period of rainfall deficit during the 2000s compared to the 1970, 1980 and 1990s. For this purpose, vegetation changes were assessed using Landsat images supported by field survey. The long-term rainfall variability (42-year) was regarded as a key element in image acquisition. Within the timeframe of the 2000s, 2 years with 25 % lower than the 42-year mean annual rainfall were selected. These images were then compared to an image captured in a year (1988) with rainfall closer to the 42-year mean annual rainfall. Two change detection techniques were used, namely univariate image differencing and GIS approaches. Classification of the produced images was pursued based on the digital numbers (supervised) of ground-checked points within the reference image whilst considering the histogram (unsupervised) of each digital number of the produced image. This research emphasized rainfall as a key variable in image acquisition for vegetation change analysis in rangelands. Image acquisition based on long-term rainfall data allowed for the assessment of changes in perennial plant cover by eliminating the effects of extreme rainfall variation on annual grass dynamics and removing extreme reflections caused by their temporary high photosynthetic activity.

Keywords Landsat · Arid · Rainfall · Multi-temporal · Image acquisition

Introduction

Vegetation quantity and quality are diminished substantially by desertification in rangelands. In general, vegetation cover is the most distinctive observable aspect of dryland ecosystems. Because of this, considerable attention has been directed towards vegetation indicators and these have been given emphasis in recent research related to drylands (e.g. Landsberg and Crowley 2004; Perry and Enright 2006; Pueyo et al. 2006). This reflects the importance of plants as the primary producers in terrestrial ecosystems, as the most vulnerable elements responding to any change occurring in other biophysical factors (e.g. climate), and as measurable alarm systems revealing the degradation of ecosystems.

Regular monitoring in most areas, particularly rangelands, suffers from logistical barriers (Landsberg and Crowley 2004) and remoteness. Remote sensing (RS) is considered to be the only realistic, cost-effective means of acquiring data used for measuring ground cover; supporting habitat mapping; monitoring forests and estimating stand biomass; assessing deforested lands; or monitoring desertification (Aplin 2005; Booth and Tueller 2003; McDermid et al. 2005; Suganuma et al. 2006; Lucas et al. 2002; Xiao et al. 2006).

Image acquisition is the first and important step in remote sensing, yet very little research has covered this issue. Image acquisition processes are often based on

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pre-defined or obligatory criteria and conditions (e.g. availability of imagery for a specific period of time, quality of imagery, required resolution, covering specific events, weather condition). For example, 'the growing season' was the criterion chosen for assessing drought using AVHRR imagery in a semi-arid area in Iran (Rahimzadeh Bajgiran et al. 2008), and to evaluate the correlation between NOAA/AVHRR-derived NDVI and rainfall in arid Jordan (Al-Bakri and Suleiman 2004). Fire risk assessment was done using Landsat-ETM for two specific dates that covered 'before and after fire incidence' (Mbow et al. 2004). In other research for investigating rangeland degradation using Landsat, Geerken and Ilaiwi (2004) found that the time when most fields were harvested were unfavourable acquisition dates for this purpose. In detecting vegetation changes in the Southern Kalahari, Palmer and van Rooyen (1998) considered the end of the wet season as a basis for purchasing Landsat imagery.

Narrowing our subject coverage for image acquisition in drylands, we have found that research on vegetation change, rangeland assessment or desertification modelling in drylands normally ignores long-term rainfall as a key criterion in image acquisition (Amiraslani 2010). Rainfall is clearly the most effective agent in triggering plant growth and development in drylands, but rainfall in these areas is highly variable both temporally and spatially. Any vegetation assessment and monitoring will be futile if this important climatic variation is not considered. In most cases, image selection is either not mentioned (e.g. O'Neill 1996) or is based on factors other than the long-term rainfall: for example, availability and quality of an imagery series (e.g. Xiong et al. 2009) or on atmospheric effects (Lu et al. 2009; Dall'Olmo and Karnieli 2002; Graetz et al. 1988; Geerken and Ilaiwi 2004). Even when rainfall has been a factor in image acquisition, studies often fail to focus on the long-term rainfall pattern (e.g. a maximum of 10 years in Pech et al. 1986).

This article will present a novel approach to image acquisition to investigate vegetation change in a degraded rangeland located in Western New South Wales (Western NSW) Australia. The area's vegetation has been under extreme pressure as a result of grazing following European exploration in the 1840s. Employing Landsat TM imagery, this research will emphasise and highlight the effectiveness of considering longer term (42-year) rainfall patterns in image acquisition as an approach for detecting longer term changes in perennial vegetation cover in drylands.

Materials and methods

Study area

Historically, Western NSW has been managed mainly for grazing (Fanning 1999; Mabbutt 1973b; Pressey and Taffs 2001), after initially being dedicated as leasehold grazing lands (Bedward et al. 2007). High sheep meat prices and good wool prices encouraged pastoralists to increase sheep numbers fourfold, from less than 2 million in 1880 to 13 million in 1892, numbers which were reduced by drought to 4 million in 1907 (Fanning 1999; Mabbutt 1973b; Pressey and Taffs 2001).

Located in this degraded arid to semi-arid Western NSW region, the Fowlers Gap Arid Zone Research Station (Fowlers Gap Station; the Station) (Fig. 1) was selected as a case study for this research on desertification for the following reasons:

1. The area is considered to be typical of arid and semi-arid rangelands in Australia (Oke et al. 2007);
2. The area is important from the domestic point of view as a proxy for the West Darling Region, NSW (Macdonald 2000); and
3. The area has a relatively long history of documentation. This recorded information makes it suitable for monitoring vegetation and climatic changes occurring in such a dryland ecosystem.

The Station lies 110 km north of Broken Hill at the northern extremity of the Barrier Range, at latitude 31° S and longitude 142° E, and is 39,200 hectares in extent (Macdonald 2000). Since 1966, the Station has served as an experimental site which has been directed by the University of New South Wales to facilitate research pertinent to the Western NSW pastoral industry (Macdonald 2000). The original charter for the Station was to carry out research to gain an understanding of the arid lands of Western NSW; and the second part of the charter was that the work, where possible, should benefit people of the region (Macdonald 2000).

Fowlers Gap Station comprises three physiographic divisions which trend north–south with the regional strike: undulating lowland in the west, a central belt of ranges, and alluvial plains in the east (Mabbutt 1973a).

Soils on the Station are in some respects typical of soils of the Australian arid zone in general, but present the following unexpected features (Corbett 1973):

- The best-developed profiles in terms of structure and horizon occur in areas devoid of vegetation;
- Scalded claypan surfaces are areas of salt depletion rather than of accumulation; and
- Hill crests bear well-developed and locally deep soil profiles.

Desert loam soils occur extensively in the Fowlers Gap area on the Western lowlands (Chartres 1982a). Some of these soils are developed partly within a mantle of aeolian deposited silts and clays (Chartres 1982b).

The climate of the Station is arid with hot summers and mild winters. With little cloud cover (<25 %), the Station

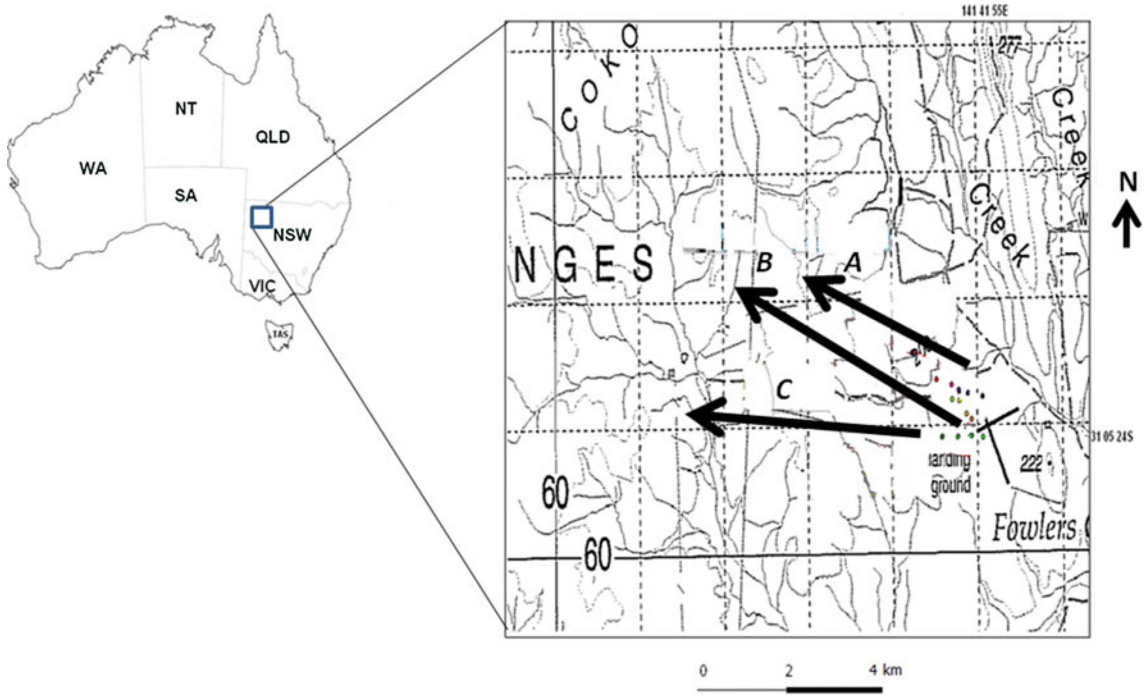


Fig. 1 Location of the studied area, Fowlers Gap Station. Field transect points are shown along with the directions of transect lines *A*, *B* and *C*. Basemap is an extract from map sheet (Geoscience Australia) and Station boundary is enlarged form of map sheet 7235, Scale 1: 100,000 produced by the Land and Property Information, NSW, 2001

receives a mean number of sunshine hours per year of 3270, of the maximum possible total of 4380 h per year. This relatively low cloudiness contributes to very high daily average receipts of solar radiation and ranks second only to paucity of rainfall as a climatic feature of fundamental ecological significance for arid zones (Bell 1973; Macdonald 2000). Typical of the arid world, the Station's rainfall is characterised by meagre and undependable precipitation (Macdonald 2000) with a 42-year mean annual rainfall to 2008 of 235 mm. The months of December and February have the highest mean monthly rainfalls and April and August have the lowest (Bell 1973).

The majority of plant species found in the area are indigenous to arid Australia and include *Atriplex vesicaria*, *Maireana astrotricha*, *Acacia victoriae*, *A. aneura* and *Eucalyptus camaldulensis*.

Data sources and acquisition

Field survey was undertaken in March 2008 (autumn). The aim was to investigate desertification and land degradation processes by gathering data on landscape, vegetation and soils and to record land surface features through gathering ground-based data. This information was to be used as ground-truthing for interpretation of remotely sensed images. In general, two stages were followed during and after returning from the field: gathering ground-based data and information during the field survey, and laboratory analysis of vegetation and soil samples after returning. During field survey, topographic and other relevant surface information was recorded including the slope, altitude, geographical co-ordinates and vegetation coverage. Where possible, prominent features (e.g. evidence of livestock grazing, plant species etc.) were photographed using a digital camera. The approximate number of ground samples required to characterize the properties of a site for remote sensing is 9 for grazed grass and 12 for bare stony soil at the 95 % confidence level (Curran and Williamson 1986). This study covered 15 samples (Fig. 1) in the form of three transects A, B and C, each being more than 200 m in length, and encompassing at least four plots of 30 × 30 m (900 m^2) separated by intervals of approximately 30 m along the transect lines. Each plot was individually assessed by personal observation detailing all relevant field information and data based on the inventory list of location, slope, altitude, cover %, life-forms, aerial biomass and plant species. After returning from the field, the GPS-based points were converted into IDRISI-accepted inputs.

Application of remote sensing

Preliminary selection of imagery

The remote sensing strategy used in this research is 'multi-temporal sensing' in which data about a site are collected on more than one occasion (Lillesand and Kiefer 2000).

Table 1 Datasets used for rainfall analysis at Fowlers Gap Station

Dataset	Timeframe*	Coverage	Source
1	1967–2006	Annual and monthly	Croft (2006)
2	2007–2008	Annual, monthly, daily	BOM (2007–2008)

* The first meteorological station at Fowlers Gap was established in 1968 (Hannah 1984)

The Landsat imagery set was selected on the basis of rainfall records, given that rainfall is the most effective agent in triggering plant growth and development in drylands. In this research, rainfall records have been acquired from two main sources (Croft 2006; BOM 2007–2008) (Table 1).

Three main objectives were considered for image acquisition: first, to cover the period of the 2000s when Western NSW experienced unusually extended (9 years 2001–2009) low rainfall amounts compared to the 1970, 1980 and 1990s; second, to analyse images from each of the two rainfall years during the 2000s, which recorded considerably lower than the 42-year mean annual rainfall to remove the consequent effects of extreme rainfall variation on vegetation dynamics; and third, to include those remote sensing images which were likely, on the basis of rainfall records, to have distinctive signatures affected by rainfall differences.

Image acquisition was carried out in four steps as follows:

Step 1: The total 42-year rainfall record from 1967 to 2008 was taken to represent the long-term rainfall pattern (Fig. 2a). This 42-year period covered the timeframe between the establishment of the first climatological station in the study area and the field work done for this research.

Step 2: Those RS-images captured in March (the first autumn month and month when field-work was conducted) were selected. March images were important in two ways. First, based on the importance of collection time for interpretation and analysis of RS images, there are two types of ground measurements: 'time-critical measurement' in which measurements are made where ground conditions change with time (e.g. vegetation condition) whilst in the other type, 'time-stable measurement', the materials under observation do not change considerably with time (e.g. geologic applications would not change from mission to mission) (Lillesand and Kiefer 2000). Since field work on vegetation condition and ground-truthing was done in March 2008, this month was considered as 'the time-critical and baseline measurement' criterion in image acquisition. Second, due to the spectral reflectance of land objects, image acquisition must normally coincide with periods of no rainfall to monitor the more persistent vegetation cover of perennials and minimise the effect of vegetation flushes upon classification (Washington-Allen et al. 2008; Gardiner et al. 1998). In the study area, annuals and ephemeral grasses are not likely to be active in March.

Image acquisition years were based on annual rainfall in consecutive 12-month periods from March of 1 year to February of the subsequent year. Annual data were then sorted in descending order of total March–February rainfall, with the year which includes February being listed in the groups below (i.e. March 1983 to February 1984 is recorded as 1984). As Landsat-5 and Landsat-7 imagery was available from 1983, rainfall years were calculated from 1984. The 42-year mean annual rainfall of the Station is 235 mm, and years since 1984 were then categorized based on their differences (±15 % assumed) from the long-term average as follows:

Group 1. Considerably higher than average 12-month rainfall: The periods with total rainfall considerably higher than average (>15 %) included 1983–84, 1986–87, 1988–89, 1989–90, 1992–93, 1993–94, 1996–97 and 1999–2000 (varying from +39 to +177 mm);

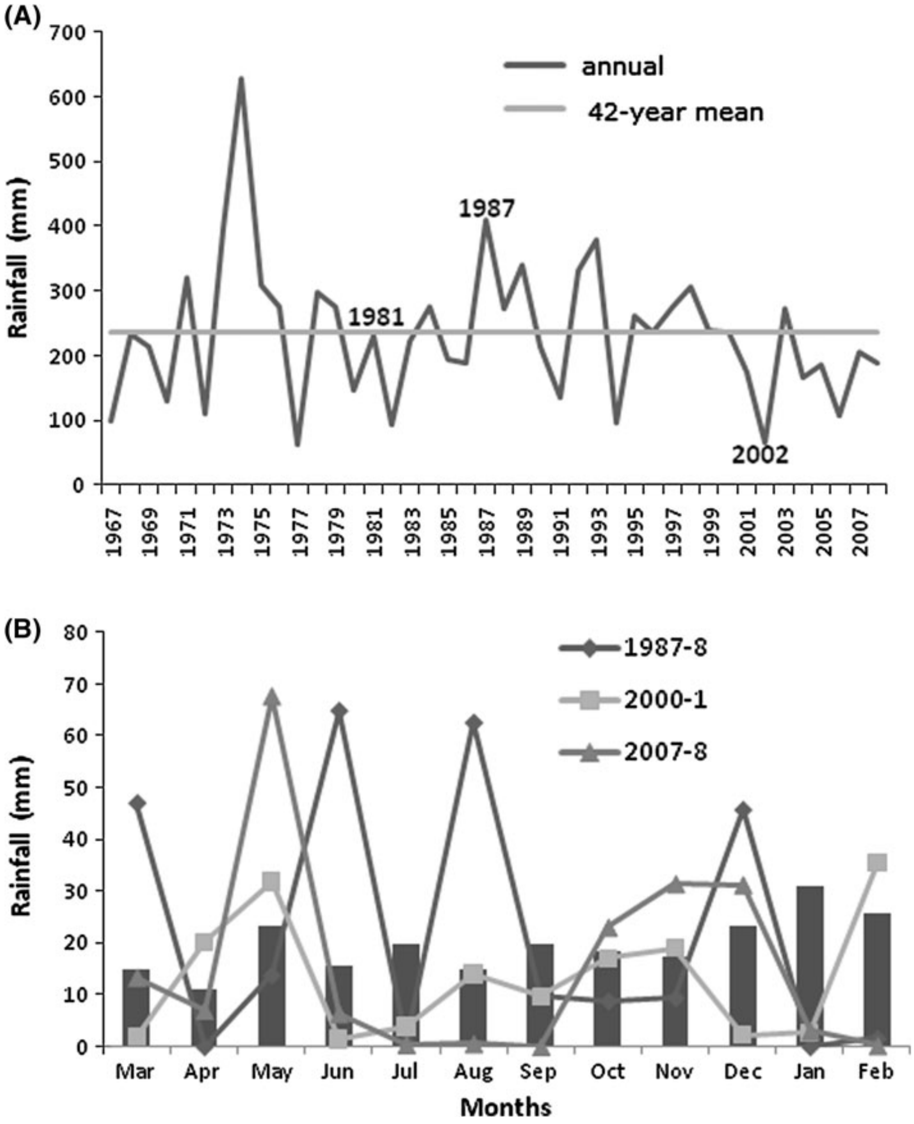
Group 2. Closest to 12-month average rainfall: The periods with rainfall close to average (in between Groups 1 and 2) included 1987–88, 1995–96, 1997–99 and 2003–04 (varying from −23 to +29 mm);

Group 3. Considerably lower than average 12-month rainfall: The periods with total rainfall considerably less than average (<15 %) included 1984–85, 1985–86, 1990–91, 1991–92, 1994–95, 2000–03, 2004–08 (varying from 34 to 135 mm below average).

Step 3: On average, rainfall is greater in the summer than in the winter months in this region. Plant growth and species composition in the area reflects this distribution (Brooke and McGarva 1998). Therefore, all years from 1984 were classified with respect to total rainfall in the summer months (December, January and February). Then, considering the average of total summer rainfall at the Station since 1984 (78 mm), summer rainfall values were sorted in descending order. Only years with at least 50 % of the average summer rainfall of 39 mm were considered. Accordingly, the years of 1984, 1987, 1988, 1989, 1990, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2003 and 2008 were included, confirming the importance of assessing vegetation at a time when no extreme events occurred before the image acquisition.

Step 4: A non-interfering atmosphere is considered a basic component of an ideal remote sensing system as it would not modify the energy from the source in any manner, irrespective of wavelength, time, place and sensing altitude involved (Lillesand and Kiefer 2000). Thus images which were captured in cloud-free conditions were sought.

Fig. 2 Comparison of rainfall at the Station in years for image acquisition: **a** annual rainfall between 1967 and 2008 (*dotted line* shows the 42-year mean annual rainfall; 1981, 1987 and 2002 were the years with close to, higher and lower rainfall than the mean annual 42-year value) **b** 12-month rainfall from March to February for periods of 1987–1988, 2000–2001 and 2007–2008 (*bars* indicate the 42-year mean monthly rainfall) [Fig. 2a, b are based on Croft (2006) and BOM 2007–2008)]



After consulting the image provider on the availability of cloud-free Landsat imagery of those images pertaining to step 3, the year 2001 was chosen. The year 2008, within the range mentioned in step 3 (with summer rainfall of 34.2 mm) was the year in which ground data were collected and ground-truthing done (March 2008). The coincidence of field work with the time of capturing an RS image was crucial to attribute specific signatures of the land to the captured images according to recorded vegetation and soil conditions. Ground data used in remote sensing can be collected before, during or after the collection of remote sensing data; however, those data synchronous with imaging are most desirable (Justice and Townshend 1981).

In total, images pertaining to the years 2001 (lower than the 42-year mean annual rainfall) and 2008 (year of study; lower than the 42-year mean annual rainfall) plus 1988 (higher than the 42-year mean annual rainfall) were chosen (Table 2; Fig. 2b). Although 2001 had a January–February rainfall total of 38 mm, extremely high rainfalls in the months before image acquisition were not recorded; analysis of March images for perennial cover would therefore not be distorted by the persistence of previously active grasses.

Processing imagery

The Landsat images for this research were purchased from a private image provider based in Australia as research was conducted before Landsat imagery became freely available. The images are cloud-free 1/16 sub-scenes (25 × 25 km) covering the Station in each selected year and classified as follows (Table 3).

It is essential that any form of remotely sensed imagery be accurately registered to the proposed map base (Eastman 2001). In this case, all images were geometrically orthorectified to Map Grid Australia (MGA) projection-zone 54 (Mean = 1.74 m; RMS = 1.74 m; SD = 0). All images were also calibrated radiometrically (Application of Algorithm: NASA CPF for each band). This procedure was important because two different Landsat sensors (Landsats 5,7) were used in this research. Supervised classification was done as follows:

Step 1. Defining land cover classes: Based on estimates of vegetation cover (%) gathered during field work (Sect. 2.2), five land cover classes were empirically defined (Table 4). In addition, histograms of an unsupervised classification were analysed to assist in establishing land cover classes. Ground conditions of the three cover classes of 2, 3 and 4 are illustrated in Fig. 3.

Step 2. Locating training sites: The utilized image was a colour composite (3R, 4G, 5B) of Landsat TM-5 captured in March 2008. For the purpose of this research, the defined land cover classes (Table 4) were used as training sites. For each spectral feature or land cover, a specific feature (e.g. ID, colour) was considered based on the reference data gathered in the field and digital numbers (DN) on the image. These features were digitized in the form of polygons according to their spectral features reflected in the image.

Step 3: Establishing spectral signatures: In drylands, the interference of stronger reflectance of non-vegetated signatures on the ground is a major consideration. In this step, using the relevant tool in IDRISI called MAKESIG, the spectral signature file was created. All bands of the Landsat image for 2008 were used to create spectral signatures. It should be noted that the defined land cover classes (Table 4) were considered as ID values.

Step 4. Image classification: In this step, the Maximum Likelihood procedure was applied since it is the most sophisticated, and unquestionably the most widely used classifier in the classification of remotely sensed imagery (Eastman 2001).

In order to assess the accuracy of the classification used in image 2008, two images were crossed using the IDRISI accuracy module ERRMAT which creates an error matrix that tabulates the different land cover classes to which ground truth cells have been assigned. In this case, images include the interpreted land cover image (classified by IDRISI) and the ground-truthed image (includes land cover classes defined for 2008 after field work). Using the Kappa index of agreement and considering the overall Kappa Coefficient as ‘a weighted average of individual kappa values’ (Green 2002, p. 2), the errors for this classification were an overall Kappa Coefficient of 64 % which is considered as representing a substantial strength of agreement (Landis and Koch 1977).

Table 3 Landsat images chosen for analysis

Date	Satellite	Sensor	Map projection	Spectral bands	Path	Row
06/03/1988	Landsat-5	TM	UTM	7	96	82
19/03/2001	Landsat-7	ETM+	UTM	6 + 1[a]	96	82
14/03/2008	Landsat-5	TM	UTM	7	96	82

TM Thematic Mapper, *ETM* Enhanced Thematic Mapper, *UTM* Universal Transverse Mercator

[a] Panchromatic band

Application of change detection techniques

Change detection methods have been widely used in understanding changes in different landscapes and regions. However, RS imagery should be used cautiously since it is influenced by atmospheric absorption and scattering, sensor calibration, image data processing procedures, shadow effects, solar illumination conditions, ground moisture conditions and differences of registration of two images (Nordberg and Evertson 2005; Singh 1989; Lillesand and Kiefer 2000).

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh 1989). It involves the use of multi-temporal data sets to quantitatively analyse the

Table 2 Summary of processes for Image acquisition in this research

Step	Selected years	Criteria
0	1967–2008 (42 years)	Availability of rainfall records
1	1983–2008 (25 years)	Availability of Landsat-5 and Landsat-7 imagery
2	1983–2008 (25 years)	Availability of imagery for March
		Years having annual rainfall above, close to, or below 42-year average
3	1983–84, 1986–90, 1992–98, 1999–2001, 2002–03, 2008 (14 years)*	Years having at least 50 % of the average total summer rainfall (i.e. >39 mm)
4	1988, 2001, 2008 (3 years)	Availability of cloud-free imagery

* The year 2008 was included due to field survey despite its total summer rainfall being less than 39 mm

Table 4 Land cover classes defined for supervised classification of Landsat image 2008

Class	Specifications	Information based on field visit
1	Non-vegetation cover such as bare soil, outcrops, water bodies, infrastructure	Collected UTM coordinates
2	Low vegetation cover (less than 30 %; mostly mixed with bare soil)	Plots A0, A1, A5, C1
3	Medium vegetation cover (30–49 %)	Plots A9, A14, B7, B10, C3, C11
4	Good vegetation cover (50–70 %)	Plots B2, B3, C6
5	Dense shrubs (more than 70 %)	Collected UTM coordinates

Here $N = 13$ which excludes two control points not described in this research

temporal effects of human and natural phenomena to better manage and use resources (Lu et al. 2004). Several applications of change detection have been enumerated such as land use and land cover change analysis, detection of forest fire or mortality, monitoring of shifting cultivation, assessment of deforestation, landscape change, urban change, wetland change and seasonal changes in pasture production (Singh 1989; Lu et al. 2004). Different techniques have been introduced for change detection including univariate image differencing, image regression, image ratioing, principal components analysis, post-classification comparison, direct multidate classification, change vector analysis and background subtraction (Singh 1989).

In this research, change detection will be pursued using two of these techniques: one of the algebra approaches, namely univariate image differencing; and GIS approaches. Image differencing is still the most frequently used change detection method in practice (Lu et al. 2004). On the other hand, integration of GIS in this research provides the way to generate and overlay different vector and raster layers as well as to produce different statistics and analyses.

In univariate image differencing, spatially registered images of time t_1 and t_2 are subtracted, pixel by pixel, to produce a further image which represents the change between the two times (Singh 1989):

$$\mathrm{DX}_{ij}^{k} = X_{ij}^{k}(t_2) - X_{ij}^{k}(t_1) + C \tag{1}$$

where X_{ij}^{k} is the pixel value for band k, I the line number in the image, j the pixel number in the image, t_1 the first date, t_2 the second date and C is a constant to produce positive digital numbers.

Analysing RS imagery

The availability of two or more dates of imagery upon which the same area of land can be observed is a crucial factor in detecting changes (Deng et al. 2008). In this research, for the purpose of generating change detection images, three different periods will be analysed. Each period covers three different timeframes: the first period detects overall changes occurring over the 21 years between 1988 and 2008, the second period covers the 13 years between 1988 and 2001 and the third covers the 7-year period between 2001 and 2008.

The specifications and technical procedures associated with each period are described separately below (Sect. 2.3.5). In all cases, a 'threshold' was applied to detect areas of change based on the number of standard deviations from the mean derived from the histogram of the image (Singh 1989). If an image I(x,y) contains light objects (change) on a dark background (no change), then these objects may be extracted by a simple thresholding (Singh 1989):

$$\mathrm{I}(x,y) = \{\mathbf{1}\text{ when } \mathrm{I}(x,y) > T \text{ and } \mathbf{0} \text{ when } \mathrm{I}(x,y) \le T\} \tag{2}$$

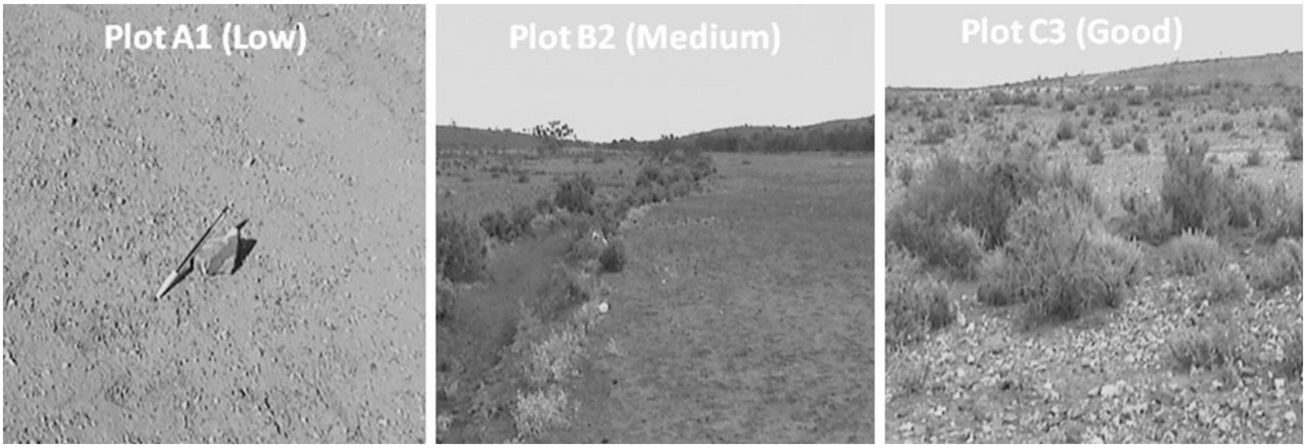


Fig. 3 Ground condition of three GPS-based plots (*white dots*) shown on the Landsat TM Image (RGB) captured in March 2008

where T is the threshold value supplied empirically or statistically by the analyst. In other words, all the pixels which belong to the object (change) are coded 1 and the background (no change) is coded 0 (Singh 1989).

Change detection using non-classified images

For all cases, two dates (t_1 and t_2) were considered (1988 and 2008; 1988 and 2001; 2001 and 2008). The red-band for each year was selected since it is believed that red-band image differencing provides better vegetation change detection in arid and semi-arid environments (Lu et al. 2004). Based on a histogram of the differencing image, a constant value was added to produce positive digital numbers.

A combination of two techniques, namely manual trial-and-error procedure and statistical measures, was applied. Thresholds were considered as mentioned above. Then, according to the histogram results, 100 classes were identified and those classes with values around the mean (±5) were considered as "non-changed areas" (NCA) and the rest as "changed areas" (CA) based on observed results. Then, a Boolean map was produced using the ASSIGN tool in IDRISI in which a value of 1 was allocated for changed areas and 0 for non-changed areas. This will be referred to as map *CA-T* delineating overall changes detected for the total period.

Change detection using classified images

As another change detection method, one can compare independently produced classified images and generate change maps which show a complete matrix of changes (Singh 1989). In this case, the quality and quantity of training sample data are crucial in producing good quality classification results (Lu et al. 2004).

In this research, land cover data relating to the years 1988 and 2001 were not available and therefore those signatures defined for the year 2008 were applied to these earlier 2 years, but histograms of digital numbers were considered for each year to reduce errors.

This evaluation may be regarded as a combination of unsupervised and supervised change detection techniques in which classification for a produced image is pursued based on the digital numbers (supervised) of ground-checked points of the same area of reference image whilst considering the statistics histogram (unsupervised) of each digital number of the produced image. In this method, unsupervised classification logic was considered, i.e. a histogram of the reflectance values shows a number of peaks and troughs in which the peaks represent clusters of more frequent values associated with commonly occurring cover types (Eastman 2001).

In order to assess the direction and degree of changes occurring between the years 1988, 2001 and 2008, all steps required for supervised classification discussed previously for the year 2008 were repeated for the years 1988 and 2001.

Results

The entire area is rangeland, with pockets of 'dense cover' of some species such as mulga (*Acacia aneura*, *A. Victoriae*) and chenopods (*Atriplex vesicaria*, *Maireana sedifolia*). The field visit during 2008 showed very limited plant species mostly as a result of severe droughts which occurred in the early 2000s and the long history of overgrazing (Amiraslani 2010).

Changes in each class

Overall accuracy of the classification of each vegetation class in each selected year was assessed (Sect. 2.3.2, step 4), with the overall accuracy of classification (Kappa Coefficient) being higher than 80 % in all three cases; this represents an acceptable classification. On the other hand, the user's accuracy—or probability that a pixel classified on an image actually represents that category on the ground (Congalton 1991)—is more than 85 % for Classes 2 and 4, more than 58 % for Classes 1 and 5, and 44 % for Class 3.

Although an attempt was made to digitize each class precisely, some errors still occurred which in turn shows that reliance on individual classes should be undertaken with caution. For example, Class 3 may represent weaker results in relation to actual conditions (user's accuracy of 44 %). This may be because classes with apparently similar pixel features may be digitized similarly but pertain to different classes (i.e. similarity between pixels which actually represent different vegetation coverage). Due to a lack of field information for 1988 and 2001, similar pixel ID pertaining to one class of the 2008 image (with available signature) was assigned to a class with similar pixel ID in the images for 2001 and 1988 but these may have had different actual signatures on the ground.

In general, there is little to be done in the artificial delineations in the classification and thus the classification should be modified for better representation (Congalton 1991). In this regard, for assessing changes in each class, classes as representative of 'non-vegetation to low and medium' cover classes were merged. This decision was made considering the results obtained for image 2008 as the benchmark. Using this image, Class 4 (good cover) was categorised separately from Class 3 (medium cover) as

Class 4 showed very scattered and distinctive pixels compared with Class 3.

Comparison of the areas calculated showed the changes in these classes (Table 5). Changes in areas in the three land cover classes (low to medium; good; and dense) since 1988 are also shown in Fig. 4. Each land cover class changed since 1988: the 'non-vegetation to medium vegetation' class reduced between 1988 and 2001 with some increase recorded for 2008. The area of 'dense shrub' fluctuated, increasing in 2001—possibly as a result of higher February rainfall than in 1988 or 2008—and then decreasing in 2008.

An increase in coverage of Classes 4 and 5 (vegetation 'snapshots') in the period 1988–2001 may be interpreted based on the average annual rainfalls between the image years. Average annual rainfall of 258 mm was received for the 14-year period 1974–1987 before the 1988 image, compared to 266 mm for the following 14-year period of 1988–2001. A substantial combined increase of nearly 7 % in Classes 4 and 5 occurred between these latter years. However, following several years of below average rainfall most of this increase was lost by 2008, when imagery showed a substantially greater area being categorised within Classes 1–3.

The 14-year period before the 2008 image had a lower average annual rainfall of 202 mm, reflecting the impact of dry years in the 1990s and protracted drought in the early 2000s. This resulted in relatively minor changes between vegetation cover classes over the 21-year period 1988–2008 of 938 ha or 1.5 % of the mapped area.

Trend of changes

Evaluation of vegetation cover changes in this research include three separate years in an overall 21-year timeframe. In order to reveal probable specific changes of each vegetation cover class occurring between these dates, the overall timeframe was assessed in the three periods 1988–2001, 2001–2008 and 1988–2008, and referred to *CA-1*, *CA-2* and *CA-T*, respectively (Table 6).

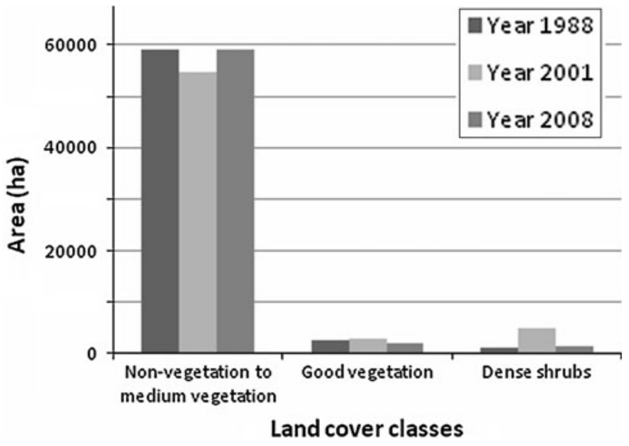


Fig. 4 Areas covered by different land cover classes in the years 1988, 2001 and 2008

An increase in the area of Classes 1–3 represents an increase in low vegetation cover and bare soil, which is reflected in decreasing areas classified in Classes 4 and 5 (medium and good vegetation cover respectively). When Classes 1–3 increase in area and both Classes 4 and 5 decrease, then land degradation would be expected.

The first immediate indication of figures presented in Table 6 is the reduction of vegetation cover for some classes in some time periods. In relation to overall change (CA-T) over the period, classes 1–3 show a positive trend, class 4 shows a negative trend, and Class 5 shows a positive trend. These data indicate that vegetation coverage has decreased, i.e. the area of medium to good coverage has declined and the area of low coverage and bare soil has increased, but the area of dense shrubs has increased.

Discussion

Whilst field observations were used directly to demonstrate landscape degradation and test erosion models at the Station, they were used indirectly for interpretation of remotely sensed imagery. Linkages amongst these information sources were established using reports, laboratory results and standard methodologies. Assessment of vegetation

Table 5 The areas of each land cover class identified in the classified full images

Vegetation class	Specifications	Area (ha)		
		1988	2001	2008
1–3	Non-vegetation to medium vegetation cover (less than 50 %; mostly mixed with bare soil)	5,9028	5,4784	5,9135
4	Good vegetation cover (50-70 %)	2,490	2,801	2,021
5	Dense shrubs (more than 70 %)	982	4,915	1,344
		62,500	**62,500**	**62,500**

* The full image does not cover the whole Station under study

Table 6 The comparison of changed areas of various vegetation cover classes

Vegetation cover class	Index	Period	Years	Overall Change (ha)	Trend
Classes 1-3 (cover less than 50 %)	CA-1	1988–2001	13	4,244	Decrease*
	CA-2	2001–2008	8	4,351	Increase*
	CA-T	1988–2008	21	107	Increase
Class 4 (cover of 50–70 %)	CA-1	1988–2001	13	311	Increase
	CA-2	2001–2008	8	780	Decrease
	CA-T	1988–2008	21	469	Decrease
Class 5 (cover more than 70 %)	CA-1	1988–2001	13	3,933	Increase*
	CA-2	2001–2008	8	3,571	Decrease*
	CA-T	1988–2008	21	362	Increase

The presented area figures have been rounded to ±1. Combined changes (1988–2008) are 938 ha or 1.5 % of mapped area

CA changed areas

* Change involving a minimum area of 3,000 ha or >5 % of mapped area

cover was conducted using field observations and remotely based interpretation.

In this research, multi-temporal Landsat-TM imagery for the years 1988, 2001 and 2008 were compared using remote sensing. Landsat data for the same month (March) in all years was applied in analysing and interpreting imagery, since it is believed that this will reduce problems from sun angle differences and vegetation phenology changes (Singh 1989). However, the absence of being able to provide a detailed change matrix is considered to be a disadvantage of the image differencing technique as a whole (Lu et al. 2004); thus in this research all three imagery datasets were classified first to provide details on changes occurring in each of the 3 years using a post-classification change detection method.

However, four uncertainties may have been introduced in the supervised classification method used:

First, it is likely that defined land cover classes are not completely homogenous and this could not be detected during digitizing each signature.

Second, the proposed non-vegetation class in this research includes broad land cover classes varying from bare soil to rock outcrops. It is possible that this class may still contain some different vegetation cover classes which have not been identified. In a supervised classification, reliability of the collected ground data will strongly affect the validity of extrapolations particularly to those areas not visited in the field (Justice and Townshend 1981).

Third, although an attempt was made to consider remotely sensed driven features for classification of the years 1988 and 2001, application of the signatures for 2008 to other years may have generated different classes compared to the real classes which should be defined for those earlier years. In general, the time-consuming and difficult task of producing highly accurate classifications often leads to unsatisfactory change detection results (Lu et al. 2004).

Fourth, Class 2 was defined as ‘very low to low vegetation cover (up to 30 %), mostly covered by bare soil’. In this case, since low vegetation cover is mixed with bare soil, this class will not give any accurate information on coverage within vegetated patches. However, it is argued that discrimination of bare soil from low vegetation densities is very difficult and vegetation greenness measures are strongly dependent upon and affected by soil brightness (Tueller 1987).

A total of 42 years of rainfall were classified into three groups based on their differences from the long-term average (higher, lower and close to the long-term average). The earliest rainfall records in the research area dated back to the early 1970s, which coincided with the availability of multi-spectral Landsat imagery. Based on differences from long-term rainfall, the earliest date for image acquisition was 1983, and consideration of long-term rainfall helped us to avoid the influence of extreme variations in short-term rainfall on total vegetation cover as reflected in combined grass and perennial growth. Misinterpretation of perennial vegetation response due to its temporary increase or decrease as a result of very high or very low precipitation was thus eliminated, as were potential complications from growth of annual grasses and ephemerals.

We applied Landsat spectral bands 3 and 4 for evaluation as they are correlated with chlorophyll concentration and green vegetation density (Bannari et al. 1995). RS captures photons formed as a result of higher chlorophyll synthesis whether in short-term ephemerals or perennials. In this research, image acquisition based on long-term rainfall and monthly rainfall preceding imagery eliminated the effects of short-term ephemeral grass dynamics captured as a result of extreme reflections made by high photosynthetic activity which may occur following any rain period.

Short-term fluctuations in vegetation cover are considerable but are not necessarily reflected in the direction or magnitude of changes taking place over longer time frames. The longer the time frame, the greater the 'smoothing' of change that occurs, as noted when comparing 1988–2008 with the other two time periods. Classes 1–3 of low vegetation cover and Class 5 (dense cover) make up the majority of changes identified in the mapped area. Change in Class 4 (good cover) comprised only 3.7 % (1988–2001) and 9 % (2001–2008) of total change in those periods. Although Class 4 made up 50 % for change for 1988–2008, absolute changes in all classes over this longer period were small (Table 6).

In arid climates, a decline in rainfall over 1 year to several decades is common (Hare et al. 1977); this research considered various timeframes. Whilst rainfall is the primary trigger for plant growth in rangelands (Ludwig and Tongway 2000), high rainfall fluctuation is a permanent feature of drylands. This issue is obvious for Fowlers Gap Station with its considerable variability in annual precipitation, lack of a clear seasonal pattern of rainfall (Fanning 1999), and monthly evaporation consistently exceeding precipitation (Macdonald et al. 1999). What has been done in this research is in accord with the view that rangeland condition should be assessed on the basis of persistent and rainfall-generated landscape change over periods of at least one or two decades (Pickup et al. 1998). This longer-term view reflects the importance of perennials in contributing to forage availability in rangelands, and the careful selection of RS imagery in this research has permitted assessment of longer-term rangeland condition.

Conclusion

Vegetation changes were established using three remotely sensed images selected on the basis of rainfall patterns, over a 21-year period. Applying remote sensing techniques, this research showed that there has been a considerable change in each land cover class since 1988. Comparison of changes within each class revealed that whilst the area of low vegetation cover has increased, the area of medium, good and high coverage decreased. This is an expected outcome based on rainfall trends.

Using the findings of field observations in 2008 and a review of literature, vegetation cover of the Station in the earlier years had been more diverse than that now present and was dominated by palatable species. This situation has gradually deteriorated due to overgrazing, leading to loss of plant diversity, so that the Station now has a limited number of plant species, mostly unpalatable shrubs.

Assessment of vegetation cover was conducted based on two separate methodologies: field observation and remotely-based interpretation. For the year 2008, field observation coincided with the date of imagery taken by satellite in March. Plant growth does not generally occur in March in this region. Accordingly, considering March as the month for image acquisition, extreme signatures on imagery as a result of high photosynthetic activities of annual grasses were eliminated, assuring the detection of perennial vegetation cover.

The capability of remote sensing as an effective and rapid method of identifying vegetation changes was demonstrated. From the time, labour, cost and technical points of view, remotely sensed evaluation proved to be an appropriate way to assess vegetation status, although it should be accompanied by ground-truthing. In addition to the technical issues associated with multi-temporal and multi-spectral imagery assessment such as atmospheric correction, environmental factors like long-term rainfall patterns should also be taken into account when interpreting vegetation change.

This method may be applied for the detection of various vegetation covers as well as the prediction of any land cover changes in the longer term in drylands, provided that long-term rainfall data (>25 years) are available.

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