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Assessment of Impact of Drought on Desert Vegetation through Remote Sensing

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Abstract: Arid vegetation shows monsoonal growth. When rains fail in the event of drought, regenerated annuals and perennials turn dry. Since NDVI senses greenness of vegetation, such dry and pale vegetation in the desert needed to be assessed by some other way. We have therefore used another index, PD-54, based on cover of dried vegetation and compared its results with those from NDVI in real time in five grazinglands in Shergarh tehsil of Jodhpur district in Rajasthan. Satellite data of IRS 1C/1D/P6 with LISS 3 sensor for different seasons were acquired for three contrasting wet-dry season events. After calibrating these radiometrically and registering geometrically, index of vegetation cover PD54 as well as NDVI were calculated. PD54 is a perpendicular vegetation index based on the green and red spectral band width. Ground radiometric observations were also used to calculate the PD54 and NDVI and were related to vegetation cover measured on ground in permanent plots. This confirmed superiority of PD54 for estimating cover in arid dry grasslands. Sequential trends in cover of ground vegetation in a protected and nearby unprotected, open grazinglands from a good rainfall year to drought year were related with satellite data. A grass cover of 14.9% by wheel point method in the protected area (compared to zero per cent grass cover in unprotected site) in October drought event could not be detected by NDVI while PD 54 successfully captured it. Total vegetation cover of 17.4% as measured on ground (i.e., total of forbs, grass and woody perennials) in unprotected site after drought in October was assessed more by NDVI though it was much less than that at protected site (39.8%). Reverse was true for PD54. Thus drought impacted vegetation in arid grazinglands could be more accurately assessed through satellite data using PD54. Such estimate on real time scale helps to prepare plans for drought preparedness, pastoralism and transhumance.

Key words: Grazingland, arid zone, spectral reflectance, vegetation index, degradation, NDVI.

Grazing based livestock economy is well known to be the mainstay of desert dwellers in the Indian arid zone. Over the past 50 years, area under grazinglands has shrunk to half while livestock population has increased many fold (Faroda *et al*., 1997). Availability of grazable material is further accentuated by highly variable rainfall often culminating in droughts. Effective management of drought calls for ensuring availability of adequate grazing resources so as to save precious livestock. Already, the grazing lands are being over used and getting more and more degraded. In fact, nearly 66-70% of these grazing lands are severely degraded, as revealed from ground surveys. Using NDVI for vegetation assessment has been the most common approach in the Indian desert, first of which was in Central Luni basin. Shankarnaryan and Singh (1982) also reported range biomass in three different soil types of Jodhpur using correlation coefficient with NDVI. Kumar and Saxena (1989) showed amenability of Indian Remote Sensing Satellite (IRS) – IA data to identification and mapping of Sewan grasslands in the western Rajasthan, and showed that NDVI does not often give true results. Potdar *et al*. (1993) used NDVI of NOAA-11, AVHRR data from nine districts of Rajasthan to study effects of monsoon rainfall on the change in the vigour of vegetation. The NDVI value of homogeneous sand background was used to define the threshold for non-vegetated area. Vegetation vigour and senescence were further correlated with the soil moisture level. Hence it was possible to infer vegetation vigour as indicated by the "greenness" deduced from

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NDVI. But vegetation in extreme desert area regenerates and resumes growth with onset of summer rains to appear green. This becomes dry, especially grasses becoming pale, within two months of receding of monsoon. These dry grasses are in fact, important feed sustaining the livestock till next summer rains. Hence, estimating dry vegetation cover using an index that measures greenness is most likely to give erroneous results. Likewise, assessing vegetation by using NDVI has given conflicting results in different arid zones (Townshend and Justice, 1986; Holben, 1886; Dregne *et al*., 1988; Drengne and Tucker, 1988; Malo and Nichlson, 1990; Bastin *et al*., 1993 and 1996; Wallace, 1994; Kumar, 2000). An index of cover was therefore needed.

In contrast PD54 index (Pickup *et al*., 1993, 1994) has been successfully used in central Australian desert for assessing vegetation degradation after isolating anthropogenic impacts from environmental induced degradation. We therefore report here assessing dried vegetation resulting from drought of 2002 in Indian arid zone, using PD54 and NDVI on real time satellite and ground data.

Material and Methods

Study area

Community grazinglands of Shergarh block in Jodhpur district, Rajasthan, India. Site located 80 km west of Jodhpur were selected for this study. Sandy plains, hummocks and dunes occupy most of the area. Average annual rainfall is 255 mm received mostly from July to September during the southwest monsoon season. In summer (April to June), the temperature often touches 48°C with intense heat and scorching winds. The wind velocity is high (20 km hr^{-1}) and dust storms are common. The mean relative humidity for most part of the year is low (57%) except in rainy season when it may be 80%. The winter from November to March has mean daily minimum temperature of 19.9°C which can drop as low as 1-4°C and incidence of cold waves often affecting the area.

Vegetation in this area comprises of *Prosopis cineraria, Tecomella undulata* as dominant trees; *Leptadaenia pyrotechnica, Acacia jacquemontii* as major shrubs, *Ziziphus nummularia, Aerva pseudotomentosa, Crotalaria burhia,* as under shrubs and *Lasiurus sindicus* and *Panicum turgidum* grasses. The large majority of ground vegetation is predominantly annual and monsoonal. Cropping is entirely rainfed. 'Bajra' (*Pennisetum typhoides*), 'Guar' (*Cyamopsis tetragonoloba*), 'Mung bean' and 'Moth bean' are the dominant crops in Kharif. Harvesting of leaves of *P. cineraria* and *Z. nummularia* for livestock feeding is very common here.

Ground Radiometry

Ground radiometry was carried out to first record spectral signatures of different plant canopies, dried twigs, litter, and bare soil The spectral reflectances were recorded from the months of September 2001 to May, 2002 using Ocean Optics spectrometer during 11 am to 1 pm, each object being referenced with respect to white reflective plate of 'Spectralon'. Spectral indices developed from ground radiometry provide a fairly good idea of applicability of a particular index on satellite data and the relative merit of each index for the desired purpose. These reflectances were then resampled in the bandwidth of IRS-IC-LISS sensor and plotted in respect of each target in their NDVI plot (Fig. 1). For the same targets their reflectance in red band and green band were also plotted to fit soil line in the PD54 plot (Fig. 3). We selected PD54 as an alternative to NDVI because PD54 has been developed in central Australian arid grazinglands which are much the same as the Indian arid grazinglands

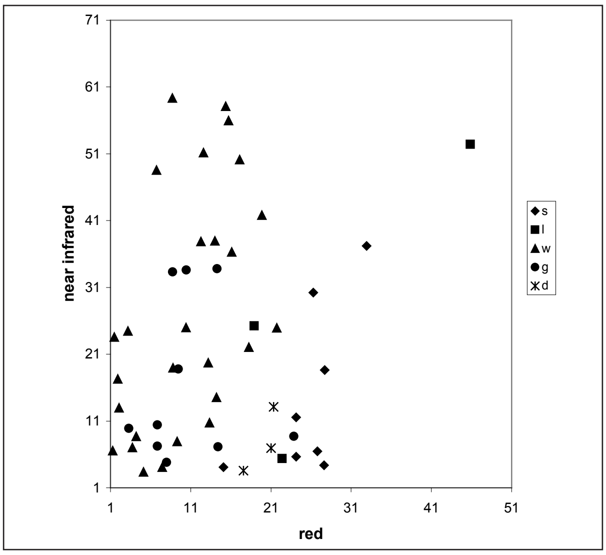

Fig. 1. NDVI plot of reflectance of different surface features at Shergarh area (s=soil, l=litter, w=trees & shrubs, g=green herbage, d=dry herbage).

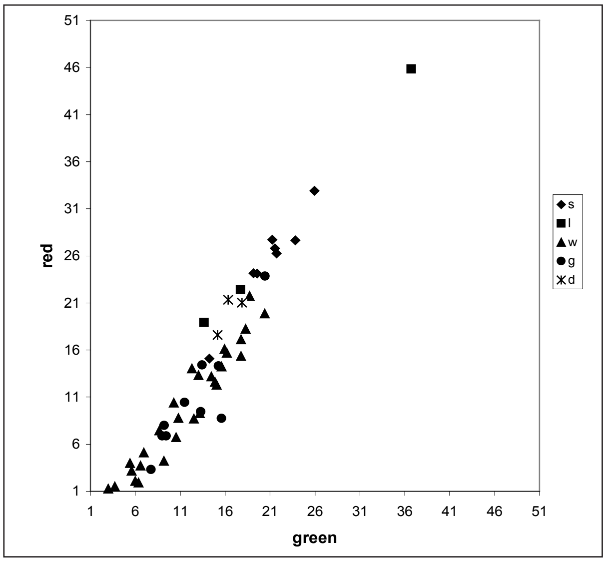

Fig. 2. Relative reflectance of selected surface features in the band1-band2 data space of IRS 1C imagery. (s=soil, l=litter, w=trees & shrubs, g=green herbage, d=dry herbage).

as well as their degradation scenarios. Ground radiometry was carried out to see whether a perpendicular vegetation index such as PD54 was appropriate for monitoring vegetation cover of the region. This index calculates vegetation cover based on pixel digital numbers in the visible green (Landsat MSS band 4) and red (MSS band 5) data space. Bare soils of varying color and other features with low cover tend to have higher reflectance and plot towards the brighter end of the data space in both bands. Features with high vegetation cover are darker in both bands and plot closer to the origin. Index values are calculated by fitting a "soil line" to the top of the data space and then calculating the perpendicular distance to each pixel relative to the perpendicular distance of the most densely vegetated pixels. These pixels are perpendicularly most distant from the soil line (Graetz, 1982).

Ground vegetation sampling

A permanent plot of 100 x 100 m area at each site was marked. Within each of these plots,wheel point apparatus was used to estimate plant cover of forbs, grasses and woody plants, along with litter and bare soil. The canopy cover of tall shrubs and trees was assessed by Bitterlich gauge in 25 x 25 m grid in 200 x 200 m area (Friedel and Shaw 1987b). This data was used to arrive at the percent cover of different categories of plants, i.e. tree, shrubs, grasses, litter as well as bare soil.

Analysis of satellite data

Using satellite data of IRS 1C Path/Row (92/53) of October 16, 2001 and September 17, 2002 (Source: NDC, NRSA, Hyderabad, India) Normalized Difference Vegetation Index (NDVI) was calculated as follows:

NDVI = (IR-RED) / (IR + RED)

We then calculated PD54 for the same data (Pickup *et al*., 1993). PD54 was calculated in ER Mapper using IRS 1C imagery as follows. Pixel values in the green-red (band 1 - band 2)

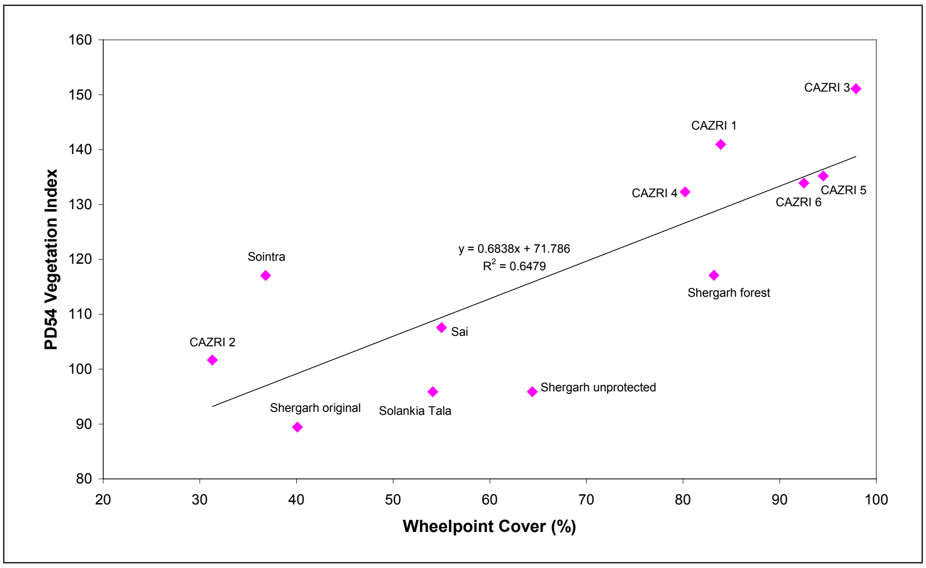

Fig. 3. Initial plot of PD54 values at selected sites of different vegetation cover.

Table 1. Per cent vegetation cover at ground validation sites using wheel point method during 2002

	Shergarh-1			Sai			Sointra			Solankiya Tala		
	Jan.	May	Oct.	Jan.	May	Oct.	Jan.	May	Oct.	Jan.	May	Oct.
Bare	58.6	59.3	59.9	54.0	69.7	45.0	41.0	52.7	63.2	49.9	59.5	45.9
Forb	14.4	11.8	17.0	23.0	12.8	39.9	2.4	0.0	0.0	26.5	9.9	20.1
Grass	0.7	0.6	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Litter	25.0	23.8	21.6	20.6	16.9	15.1	7.6	8.7	9.7	20.3	28.3	33.9
Woody	1.3	4.5	1.5	2.0	0.2	0.0	49.0	38.6	27.1	3.3	2.3	0.0

data space were put in a scatter plot to fit "soil line" and point representing maximum vegetation cover. After computing the gain, offset and distance parameters, these were used in an ER Mapper algorithm to produce the PD54 image. Therafter, NDVI and PD54 were related to vegetation cover by linear regressions between the Index value and the ground vegetation cover. The NDVI and PD54 outputs of satellite scenes of October 2001 and September 2002 showing protected and unprotected grazingland at Shergarh were compared with each other keeping in view their ground vegetation cover.

Results

Spectral indices

Spectral reflectance in the NDVI plot (Fig. 1) shows a highly scattered reflectance values i.e., the photosynthetically active (or "green") features/targets are well dispersed and tend to plot away from soil and dry vegetation. These do not form a band towards the bottom of the data space. In the PD54 plot, an upper soil line and a lower vegetation line (not shown) (Fig. 2) clearly indicated the potential of PD54 being a candidate vegetation index.

Index performance against ground data

Selected sample sites in four villages of Shergarh block were marked using GPS data on IRS-1C October 2001 and September, 2002 imagery. The PD54 values of these 11 selected sites from satellite data plotted against their vegetation cover (Fig. 3) yielded significant correlation (R^2=0.6478). Robustness of the PD54 was tested by adding data of 9 more plots within CAZRI campus, thus making a set of 20 ground observation sites of which vegetation cover was plotted against their NDVI and PD54 which proved that PD54 was a better vegetation index (Fig. 4) than NDVI (Fig. 5).

Satellite data analysis

Comparing PD54 image of October 2001 with September 2002 clearly revealed a decline in the vegetation cover in these areas. These observations were confirmed also through ground sampling of vegetation in January, May and October month of 2002 (Table 1). In January 2002 the vegetation cover (total of forbs +grasses + woody perennials) was maximum at Sointra (51.4%) followed by that at Solankiya Tala (29.8%), Sai (25.4%) and Shergarh-I (16.4%). This cover declined sharply in May 2002 at Sointra (38.6%) and Solankiyatala (12.2%) and Sai (13.4%) and by and large same at Shergarh-I (16.9%). The maximum decline in cover from January to October was at Solankiyatala (37.98% decline) followed by that at Sointra (48.6% decline), and while it increased at Sai (57.08%) and Shergarh-I (12.80%), the increase being mainly in unpalatable forbs such as *Aerva pseudotomentosa*. In order to get a clear picture of the trends we compared total vegetation cover of protected reseeded plot with an adjoining unprotected sites. In the protected paddock at Shergarh, the vegetation cover was 43.6% in June 2002 which declined to 39.8% in October whereas unprotected site had a total of 18.6% vegetation cover that declined to17.4% in October 2002. Most importantly, grass cover was 14.9% after drought in protected plot mainly of *Cenchrus ciliaris* which was absent

Table 2. Per cent vegetation cover at two adjoining ground validation sites using wheel point method during 2002

	Shergarh-protected			Shergarh unprotected		
	Jan.	May	Oct.	Jan.	May	Oct.
Bare	-	25.8	16.6	-	46.8	35.6
Forb	-	13.8	24.8	-	13.3	17.3
Grass	-	26.6	14.9	-	1.7	0
Litter	-	30.6	43.6	-	34.6	37.1
Woody	-	3.2	0.1	-	3.6	0.1

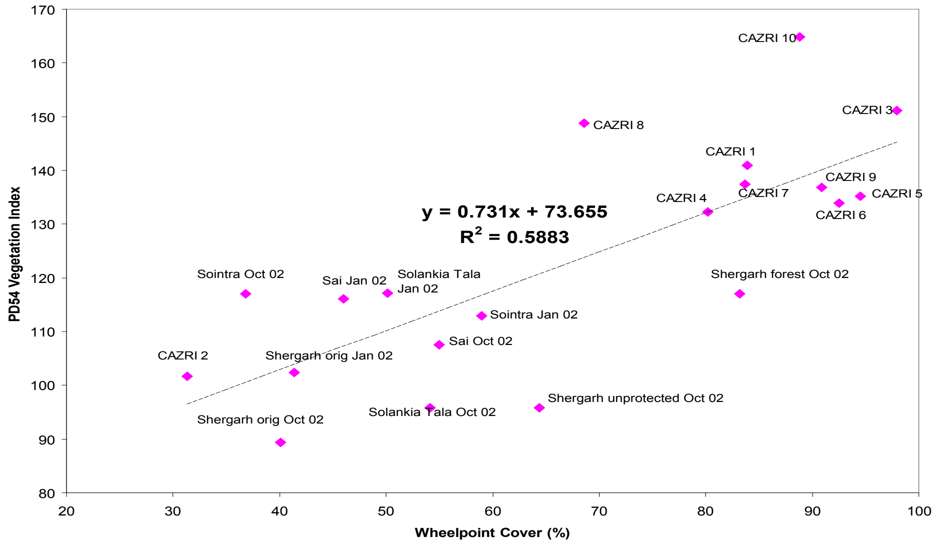

Fig. 4. Final plot of PD54 values at selected sites of different vegetation cover.

in unprotected site having zero percent grass cover (Table 2).

This decline in vegetation cover continued drastically by Sept. 2002 due to failure of summer rains at all sites, except at Shergarh protected and reseeded paddock where grazing was not allowed and grasses and forbs became dry and pale (Table 2). These grasslands when detected on satellite data of Sept. 2002 (IRS-LISS-III) reveled that NDVI could not detect grass vegetation in that scene in protected area having dried grass. But PD54 succinctly brought out this vegetation (Fig. 6). Thus PD54 successfully showed presence of dry vegetation in protected paddock in September 2002 imagery.

Discussion

Evidently, attempts to accurately estimate range vegetation using NDVI specially after failure of rain when standing vegetation is pale and dry has not met with success in the present exercise. In a detailed study of these rangelands by employing over 35 permutation and combinations, limitation of conventional vegetation indices was reported in the Indian arid zone (Kumar, 2000). Image differencing of NDVI scene of IRS LISS II of September 1988 and January 1989 has also been attempted (Sahai,1993) to locate four major classes of the Sewan grass at Jaisalmer which lacked field verification. Since vegetation cover is reported to be very low often less than 1 percent in all the notified nine districts of desert (Sahai, 1993) its accurate assessment using NDVI is questionable in the light of findings of Townshend and Justice (1986). Hence suitable vegetation index for detection of low cover arid vegetation is ought to be independent of “greenness” of vegetation so that it can estimate cover at different time intervals especially after low rainfall or drought. PD54 tested in this study fulfils this requirement. PD54 output showed good grass cover after a good rainfall in protected area in October 2001 which NDVI could not detect. After failure of rains in September, 2002, the protected paddock at Shergarh still had better grass cover while adjoining open grazing land was severely degraded with poor cover. This difference in ground vegetation could not be detected by NDVI in September 2002 scene which showed negligible vegetation in both protected paddock as well as unprotected area. In contrast, PD54 output showed good vegetation in protected paddock and poor vegetation in unprotected area which matched the actual ground vegetation. This comparison of outputs of PD54 with NDVI proved the efficacy of PD54 index in detecting vegetation cover that exists but is dried and pale due to drought which NDVI failed to detect.

These findings get credence from Malo and Nicholson (1990) who found poor correlation between NDVI and rainfall in the African Sahel

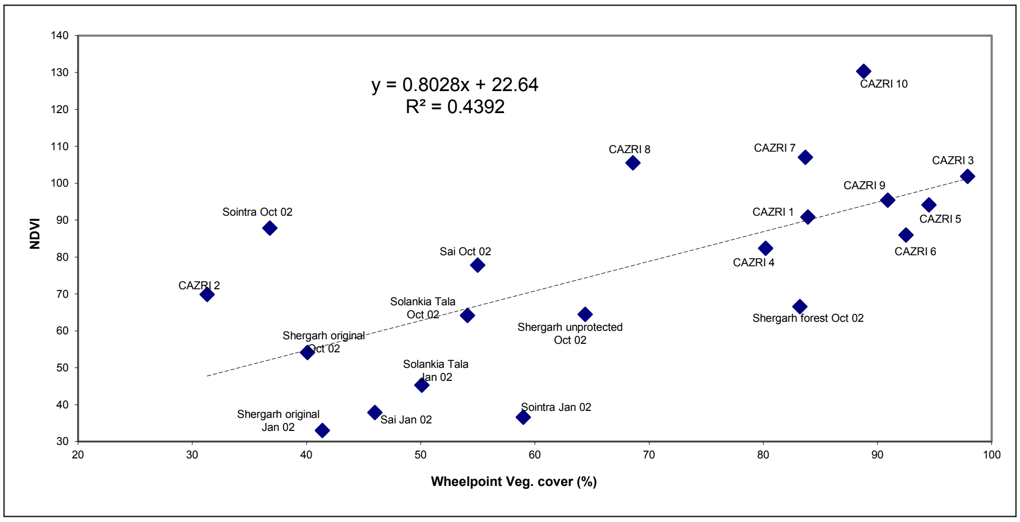

Fig. 5. Final plot of NDVI values at selected sites of different vegetation cover.

receiving low rainfall. It supported the earlier finding that NDVI cannot detect vegetation with less than 5% surface cover (Townshend and Justice, 1986). Holben (1986) opined that the observed NDVI is perhaps due to water vapour and aerosols and not vegetation growth. In sub Sahara zone, biomass zones less than 400-500 kg ha^{-1} year^{-1} cannot be detected by NDVI (Friedel and Shaw, 1987a). In view of limitations of NDVI in deserts, different approaches which have been developed as alternative to the NDVI include: (1) Adjustment for the effects

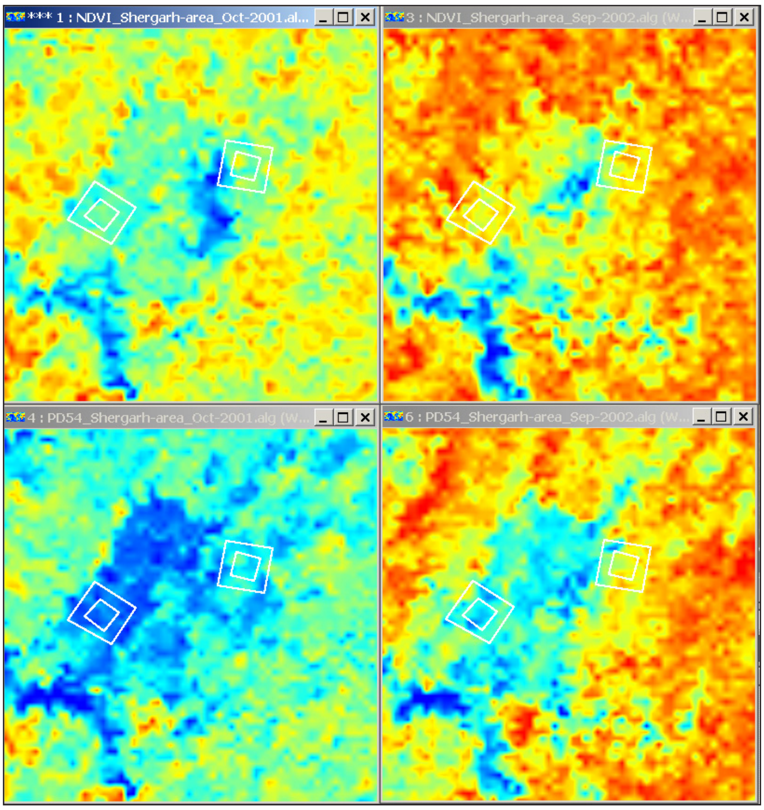

Fig. 6. NDVI and PD54 outputs of protected and unprotected sites after good rainfall (Oct. 2001) and poor rainfall (Sept. 2002) at Shergarh. The inner polygon refers to the area sampled through wheelpoint method while outer polygon refers to area sampled through bitterlich method (not reported in this paper)

of pixel darkening (Wilson and Tueller, 1987), (2) Use of spectral information from the red band (Ringrose and Matheson, 1987), (3) The approach of spectral mixture modeling (Smith *et al*., 1990a; Smith *et al*., 1990b), (4) The methods using the spatial autocorrelation function (ACF), and mean and variance plots of Landsat Multi-Spectral Scanner (MSS) bands 5 and 7 to separate the cover response obtained in years of good, medium and poor rainfall (Pickup and Foran, 1987). But the PD54 index (Pickup *et al*., 1993) is superior to all these methods. The index was found to be robust across many arid-zone vegetation types, including variable soil color background, where developed in central Australia. Equally important, index values were found to be largely independent of greenness allowing vegetation cover to be monitored reliably through time (Tucker *et al*., 1986). The stability of PD54 index with changing phenology means that it provides a more accurate measure of cover than the commonly used normalized difference vegetation index (Tucker *et al*., 1986). NDVI produces high index values when the vegetation is green during a growth phase and low values when the vegetation is dry. Knowing area of abundance and scarcity of natural grazing resources especially during drought, using this index, PD54, can assist the administrators in planning routes of livestock migration and transhumance.

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