Remote Sensing based rapid watershed health appraisal – a case study of NWDPRA watersheds of Rajasthan

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Abstract
Eight watersheds under NWDPRA (National Watershed Development Project for Rain-fed Areas), distributed across different agro climatic zones of Rajasthan were studied for rapid appraisal of their health conditions over a span of 8 years after treatment for long term policy decision. Major remote sensing based indicators studied include land cover, overall biomass, vegetation along drainage buffer and increase in the number and extent of water bodies. Distribution of land cover, and biomass has been analyzed for individual watersheds and the changes over the years have also been quantified. An effort was made to quantify various change parameters to derive a crisp value, which expresses the overall development index for watershed health. For comparative evaluation of performance, area weighted spatial averaging of the land cover and vegetation index was performed and ranked accordingly. Finally the ratio of weighted spatial average values of land cover and vegetation index was used from pre (1988) and post treatment (1996) years for all the watersheds. Positive change was noticed from all the watersheds except one for land cover, whereas only 4 watersheds showed positive change in terms of biomass development. The ephemeral biomass is highly dynamic over time due to short life cycle and is a function of rainfall amount and distribution. To be more specific vegetation density along the drainage line was analyzed which could be used as an indicator qualifying drainage line treatments. Only 4 watersheds had positive biomass development along the drainage buffer zone and rest had negative. All of them showed better performance in comparison to overall biomass of the watersheds as a whole. All the weighted values were finally averaged to derive remote sensing based watershed health index (RSWHI) and ranked accordingly. Mewanagar watershed performed the best among 8 but Birathai kalan, Kamli and Syala performed poorly.

Introduction

Dry land farming accounts for more than 60% of the cultivated lands which suffers from the vagaries of climate, resulting in periodic crop failure and acute shortage of water. Government of India has accorded highest priority to these areas for holistic development in the form of National Watershed Development Project for Rain fed Areas (NWDPRA). The project aims at *in situ* moisture conservation, primarily through vegetative measures to conserve as much rain water as possible, controlling soil erosion and regeneration of green biomass both on arable and non-arable lands. As the development process is an integrated approach and synchronized activities of various departments, there is need to monitor the development activities and assess their performance in terms of performance indicators. Conventional ground data collection in pre and post treatment period for monitoring is indeed a costly and time-consuming affair and subjected to human bias. However, synoptic viewing from space through multi-spectral capability is a cutting edge technology to provide information about various subtle biophysical parameters. Having suitably selected spectral bands sensitive towards vegetation pigment and cell structure, the image acquired over land surface gives spatial details of vegetation condition along with types and dynamics. Satellite data analysis before and after watershed treatment can provide valuable baseline information towards direction of change and its overall impact on biophysical environment.

Eight micro-watersheds, distributed over different agro climatic zones of Rajasthan, India, were studied for their performance in terms of biomass gain, landuse change and changes along drainage line, if any. The satellite data prior to treatment year (1988) was compared with post-treated year (1996), to reveal the noticeable changes over a span of 8 years. Visible surface manifestations due to watershed treatments were recorded in terms of increase in number and extent of water bodies, forest/horticultural plantation, and agro-forestry. For comparing the performance of the watersheds located at different agro climatic set up a comprehensive rating procedure was adopted for quantification and parametric evaluation of the changes, which considers all the visible impacts discernible in the data. The ratio of performance of watersheds in the year 1996 over base year i.e. 1988 gives the remote sensing based watershed health index (RSWHI). How the watersheds have performed at different agro-ecological set up has been described in details.

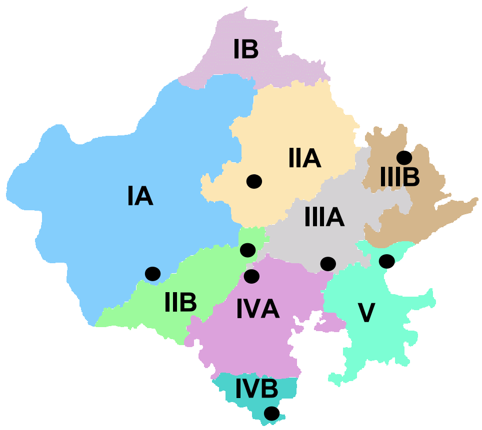

Fig. 1: Map of the study area

Study area

The study area is distributed across 8 agro-climatic zones (Figure 1) ranging from desertic western plain to humid southern and south-eastern plain. There is large variation in rainfall from 270 mm in the west to as high as 922 mm in the south. The annual and diurnal temperature variations are also very high. Mean monthly temperature goes below 7^{o}C during winter and rises above 42^{o}C during summer. The watersheds along with area, geographic locations and climate pattern are given in Table 1.

Table 1: Location, area, agro-climatic zones and associated climatic variables of the watersheds

Water Shed	Watershed (District)	SOI toposheet	Area (ha)	Agro climatic zone	Rainfall (mm)	Tmax (^{o}C)	Tmin (^{o}C)
w1	**Ambali** (Nagaur)	45I/8	6320	**IIA:** Transitional plain of inland drainage.	383	40.7	6.3
w2	**Bawliya pada** (Banswara)	46I/12	3820	**IVB:** Humid southern plain.	922	41.5	7.8
w3	**Birathai kalan** (Pali)	45J/4	9019	**IIB:** Transitional plain of Luni basin.	472	40.2	9.5
w4	**Kamli** (Rajsamand)	45G/14	5862	**IVA:** Sub-humid southern plain and Aravalli hills.	650	38.6	7.8
w5	**Kharkhari** (Alwar)	54A/13,14	5581	**VIIB:** Flood prone eastern plain.	577	40.6	8.3
w6	**Kheri** (S. Madhopur)	54C/5	12208	**V:** Humid south-eastern plain.	684	42.2	7.1
w7	**Mewanagar** (Barmer)	45C/1,2	8408	**1A:** Arid western plain.	270	39.5	7.7
w8	**Syala** (Tonk)	45O/9,13	6538	**IIIA:** Semi-arid eastern plain.	613	39.5	7.3

Materials and methodology

Indian Remote Sensing Satellite, LISS II data of 1988 and 1996 (post monsoon period), with a spatial resolution of 36.25 m was used for the study. Data selection was done based on crop window, crop calendars and vegetation dynamics of the region. For baseline mapping Survey of India (SOI) topomaps in 1:50,000 scale and watershed maps with demarcated treatment areas were procured. Besides data on watershed activities, base line data for various development activities etc were also collected. For supervised landuse classification, ground truth from homogeneous areas were collected and used as training sites in digital landuse classification. Besides data collection, discussion was also made with the farmers and soil conservation officials.

Satellite data of both the years were normalized for minimizing the changes in spectral responses due to seasonal variation in atmospheric effects, sensor characteristics, sun illumination etc. that is necessary in change detection study, to capture subtle changes. Scene statistics is used to normalize band by band for bringing the mean and standard deviation of two dates at par with each other. Data processing was performed using both Digital Image Processing Software (EASI/PACE) and Geographic Information System (ARC/INFO).

Grid base generation, toposheet registration, mosaicing of scenes and image registration

Watershed wise geographic grid base of 5 minutes interval was generated and output projection was defined in Lambert Conformal Conic C, which is suitable for small area analysis. The purpose is to register the scanned maps into real world coordinate system. For registration of maps with georeferenced grid vectors, GCPworks function of PCI software was used, following nearest neighborhood resampling and affine transformation model. Once a registered database with topomaps was created the uncorrected raw satellite images were also registered in reference to the registered topomaps with minimum permissible rms errors (less than half of a pixel). Wherever single image does not cover the entire watershed, mosaicing was done with the adjoining scenes and then registration was performed. From the toposheets the watershed boundaries were digitized and saved as a vector segment, which was subsequently rasterized and used for watershed mask preparation.

Landuse/landcover

Landuse classification was done following maximum likelihood classifier (which classifies each pixel based on their probability of being in a class). Training sites with known landuse classes were interactively applied for training the classifier, which subsequently classifies the whole image along with the training sets for a classified landuse output. Homogeneous training areas excluding bordering pixels, uniformly spread throughout the scene are collected for all the landuse types, which are spectrally separable. The spectral separability was also checked statistically by computing divergence matrix/confusion matrix. The statistics of training sets thus obtained are used for classifying the image. Using multivariate sample mean vector and inter band variance covariance matrix the probability of each pixel is calculated for each class and the pixel is assigned to that class which has the highest probability. The classified output was then verified in the field for 95% classification and overall accuracy. Broadly the lands are classified into agricultural lands, forestlands, wastelands and water body and their sub-classes.

Vegetation vigour

The spectral response curve of healthy green vegetation is characterized by strong absorption in the red region together with a higher reflection in the NIR region of electromagnetic spectrum. Vegetation vigour is assessed through vegetation indices, which is a real number that is generated by linear combination of spectral bands of satellite predominantly the red and infrared band. Cell structure and plant architecture serve as effective scatters in the optical portion of electromagnetic spectrum due to large contrast in the refractive index between turgid cells of leaf tissues and the intercellular air space. One of the most common used indices is Normalized Difference Vegetation Index (NDVI), which is highly correlated with vegetation parameters such as green leaf biomass and leaf area. NDVI is given as the ratio of reflectance of (IR-R) and (IR+R). The index value varies between –1 and +1. In the present study the vegetation index values were grouped into 5 classes of same class interval based upon the maximum and minimum values. The groups were named as very poor, poor, moderate, good and very good respectively.

Change detection

For detection of positive and/or negative changes in landuse and vegetation vigour, weights were assigned to various classes of landuse and NDVI independently. Then each pixel of 1996 scene is compared with the corresponding pixel of 1988 and the difference is noted. Positive difference in landuse gives an indication of better management practices. Both the overall changes and the degree of changes are recorded for estimating the degree of criticality. A programme was written in EASI/PACE digital image processing software, for change detection, which makes use of landuse/NDVI values of 1988 and 1996 using a logic table (look up table). The difference image was finally classified into no change, positive change and negative change categories.

Composite scoring for remote sensing based watershed health index

To evaluate relative performance of various watersheds in terms of landuse and biomass change the watershed quality indicators (derived through landuse and NDVI) were scaled and weights were assigned depending upon the impact of the health parameter on watershed. For various landuse types and vegetation vigour the weights were assigned as follows (Table 2 and 3).

Table 2: Weights assigned to various landuse classes

WB	AP	FP	AF	GF	MF	CL	F	LWIS	SF	PF	LWOS	SA	B/R	R/G
150	140	130	120	110	100	90	80	70	60	50	40	30	20	10

Where, W B = water body, AF = agricultural plantation, FP = forest plantation, GF = good forest, MF = moderate forest, CL = crop land, F = fallow, LWIS = land with scrub, SF = scrub forest, PF = poor forest, LWOS = land without scrub, SA = sandy area, B/R = barren/rocky, R/G = ravenous/gullied.

Table 3: Weights assigned to various vegetation vigour classes

Very poor	Poor	Moderate	Good	Very good
10	20	30	40	50

The area weighted spatial averaging was done for each watershed for both the years as follows.

$$\mathbf{Wav = [\sum a_i w_i / A] \times 100}$$

Where, Wav = average weight, Ai = area under landuse ‘i’, wi = weight of the landuse ‘i’, A = area of the watershed.

Database generation in ARC/INFO GIS

On line digitization was performed for transport network, settlement location, notified forest boundaries, drainage lines and other features of interest. The arc coverage of drainage layer was used for buffer across it length to visualize the change along the drainage lines which is most critical from run-off and erosion point of view. A threshold of 50 m on either side of the drain was considered for buffer generation. This buffer coverage was subsequently used as mask to extract information through buffer window. These vector coverages in ARC/INFO were exported to image processing environment. The masks generated from forest boundaries, stony wastes etc. were used for *apriori* knowledge in classification of image. Overall methodology for watershed monitoring is given in Figure 2.

Results and Discussion

Landuse/landcover

The percent distribution of various landuse types during pre and post treatment years (1988 and 1996) are given in Table 4 and 5 respectively. Based upon the predominant landuse types watersheds could be classified into 3 types viz. agricultural watersheds (w1, w3, w5 and w8), wasteland watersheds (w2, w4, and w7), and forested watershed (w6). The physiography and land characteristics have fabricated the existing landuse with varying degree of biodiversity. The watersheds viz. w1, w5 and w8 are almost flat in topography but in w3 almost half of the area is under hilly undulated terrain interspersed with cultivated lands confined along the valley and channel fills. On the other hand watersheds viz. w2 and w4 are hilly with hardly any soil cover to support intensive agriculture, whereas w7 is almost flat except the central steep ridges, but due to climatic and moisture constraints the cultivation is limited. Only one watershed (w6) is forested, characterized by hilly terrain and sitting over humid south-eastern plain. Large areas of this watershed are under protected forest, besides intensive social forestry programme is evident through large patches of plantation, discernible in satellite image. The valley fills are intensively cultivated which gives high productivity due to better sediment deposit and soil moisture availability.

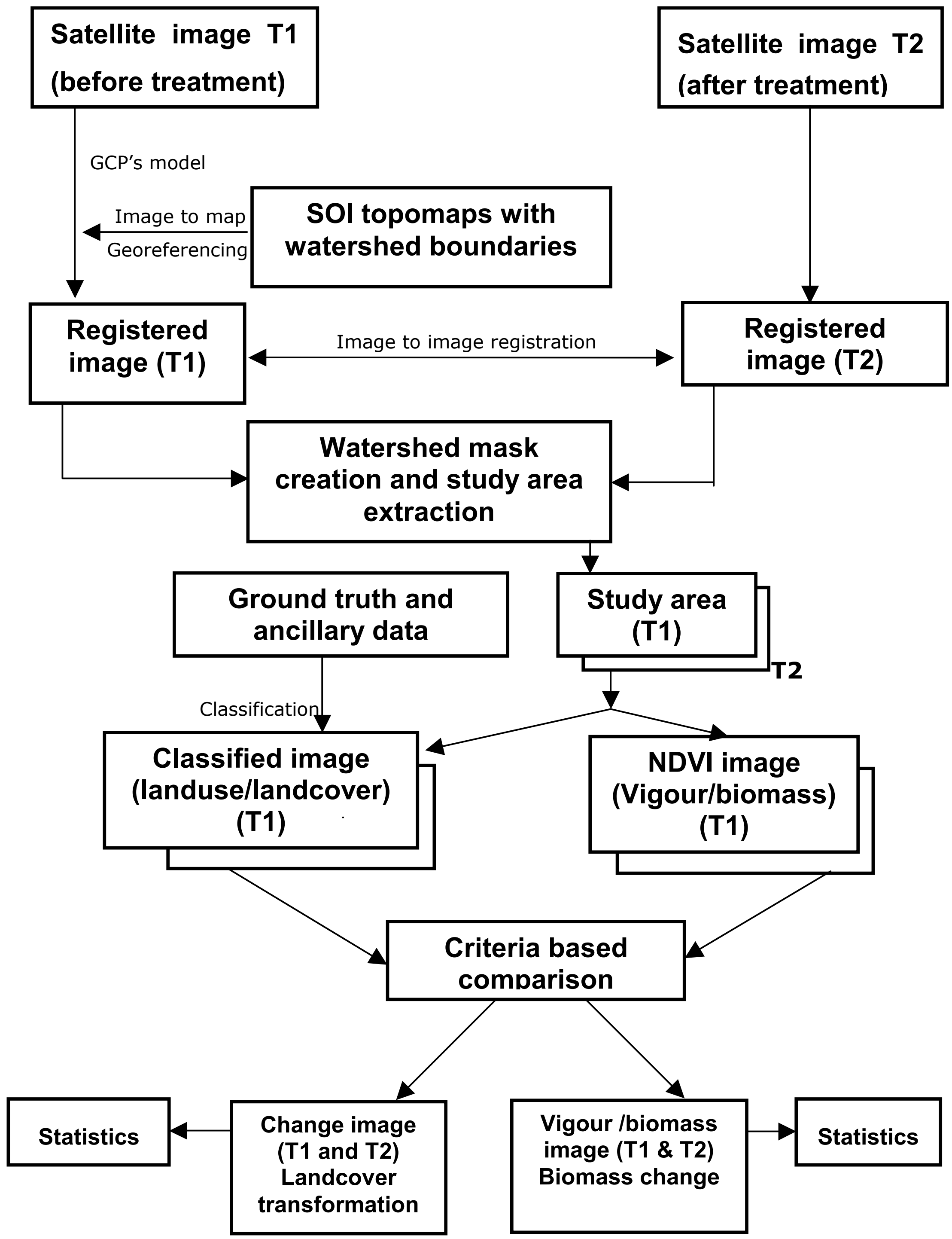

Fig. 2: Flow chart for watershed monitoring

One of the foremost indicators of the watershed development is the increase in the area and number of the water bodies. The extent of water bodies has increased in 4 watersheds viz. w2, w4, w5 and w6 but has decreased in w3 and w8 (Table 6). Out of 6 watersheds (contain water bodies), significant increase in aerial spread was observed in w4 and decrease in w3. The decrease in the extent could be due to less rainfall in the year of 1996 in comparison to 1988. The comparison between 1988 (pre treatment) and 1996 (post treatment) reveals that there is an increase in agricultural activity in w1, w2, w3, w6, w7 and w8 whereas decrease in w4 and w5 (Fig. 3 and Table 6). This increase in agriculture area has been possible as a result of bringing more and more marginal and wastelands under cultivation. Considerable increase in forestlands is also noticeable in w1, w5 and w7 due to large area put under social and farm forestry and allowing natural regeneration in the arid forest. In all the watersheds, wastelands have decreased significantly due to soil conservation, gully plugging and land reclamation. However, in w4 there is a marginal increase, which could be due to mixing of signatures of wastelands with long fallow (both of which appear similar in the image) while interpreting the satellite data.

Table 4: Percent distribution of various landuse types in 1988

Landuse	**w1**	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**
Crop land	37.78	7.85	43.16	30.89	6.36	20.56	2.29	37.03
Fallow	40.16	3.66	9.16	-	43.33	13.64	-	34.38
Long fallow	11.29	-	-	-	-	-	-	-
Agroforestry	-	-	-	-	-	-	30.7	-
Agril. Plantation	-	-	-	0.44	-	-	-	-
Good forest	-	-	1.34	-	-	1.38	-	-
Moderate forest	-	-	-	-	-	27.02	-	4.70
Poor forest	-	-	-	-	-	13.55	-	0.004
Scrub forest	-	-	-	-	25.10	-	3.31	-
Forest plantation	0.84	0.68	-	-	-	-	-	-
Land with scrub	9.93	76.49	31.48	46.07	-	7.92	47.21	20.41
Land without scrub	-	9.51	12.64	-	2.17	-	4.96	-
Barren/rocky	-	-	-	20.06	19.76	1.09	11.49	-
Sandy	-	-	0.21	-	3.28	-	0.04	1.36
Gullied	-	-	-	-	-	13.81	-	-
Water body	-	1.81	2.01	2.54	0.009	1.03	-	2.12

Table 5: Percent distribution of various landuse types in 1996

Landuse	**w1**	**w2**	**w3**	**w4**	**w5**	**w6**	**w7**	**w8**
Crop land	32.13	12.08	34.49	5.69	22.59	25.60	8.15	31.79
Fallow	23.98	0.36	20.46	-	18.36	14.36	-	56.69
Long fallow	20.79	-	-	-	-	-	-	-
Agroforestry	15.62	-	-	-	-	-	31.75	-
Agril. Plantation	-	-	-	20.48	-	-	-	0.24
Good forest	-	-	1.26	-	-	0.16	-	1.01
Moderate forest	-	-	-	-	-	27.97	-	3.69
Poor forest	-	-	-	-	-	10.34	-	0.002
Scrub forest	-	-	-	-	44.53	-	8.54	-
Forest plantation	7.48	3.36	-	-	-	3.43	-	-
Land with scrub	0	72.97	38.61	44.89	11.32	9.33	27.52	3.68
Land without scrub	-	9.40	3.41	18.64	0	-	17.02	-

Barren/rocky	0.002	-	-	4.02	0.36	0	6.56	-
Sandy	-	-	1.03	-	2.79	-	0.46	1.74
Gullied	-	-	-	-	-	7.66	-	-
Water body	-	1.83	0.74	6.28	0.05	1.15	-	1.16

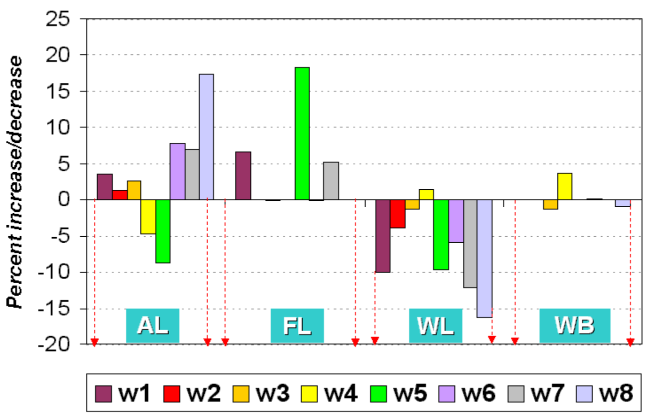

Fig. 3: Per cent changes in landuse between 1988 and 1996

Table 6: Percent changes in various landuse types between 1988 and 1996

Wshed	AL	FL	WL	WB
w1	+3.5	+6.64	-9.93	-
w2	+1.29	-	-3.93	+0.02
w3	+2.63	-0.08	-1.28	-1.27
w4	-4.72	-	+1.42	+3.74
w5	-8.74	+18.43	-9.74	+0.04
w6	+7.76	-0.05	-5.83	+0.12
w7	+6.91	+5.23	-12.14	-
w8	+17.33	0	-16.35	-0.96

Vegetation vigour:

Percent distribution of various vigour types is given in Table 7 and 8. Significant increase in the moderate and good vigour (NDVI) is apparent in w2 and w5, whereas significant decrease in both these types is noticed in w3 and w4. The decrease in the moderate to very good vigour in agricultural watersheds (w1, w3, w8) could be due to crop harvesting or more area kept under fallow. Whereas in forested watershed (w6) the decrease in good and very good type is due to degradation of forest and/or the deficient rainfall year in 1996. Among the wasteland watersheds only w4 has got deterioration in vegetative cover, however, w2 and w7 exhibits better vigour condition. Overall observation indicates that for 5 watersheds (w1, s2, w5, w6 and w8) the dominant category has remained same for both the years (Fig. 4 and Table 9) but in w3 and w4 the moderate vigour type is changed to poor, whereas as a sign of little improvement in w7, the dominant types change to poor from very poor.

Table 7: Percent distribution of vegetation vigour types in 1988

Vigour type	w1	w2	w3	w4	w5	w6	w7	w8
Very poor	0.06	1.25	0.46	1.11	5.84	1.71	52.91	1.91
Poor	17.70	34.44	34.06	26.18	65.52	45.58	46.97	60.85
Moderate	53.62	60.22	62.38	56.23	25.51	35.89	0.12	31.13
Good	25.17	4.08	3.10	16.46	2.86	15.37	0	6.11
Very good	3.45	0.01	0.002	0.02	0.27	1.45	0	0

Table 8: Percent distribution of vegetation vigour types in 1996

Vigour type	w1	w2	w3	w4	w5	w6	w7	w8
Very poor	0.11	0.39	2.30	2.10	8.50	4.64	17.41	5.76
Poor	14.83	3.47	68.41	51.40	44.81	45.55	81.89	59.44
Moderate	50.22	75.26	27.14	45.08	42.06	37.43	0.66	32.69
Good	32.76	20.61	1.93	1.41	4.63	12.19	0.04	2.09
Very good	2.08	0.27	0.22	0.01	0.004	0.19	0	0.01

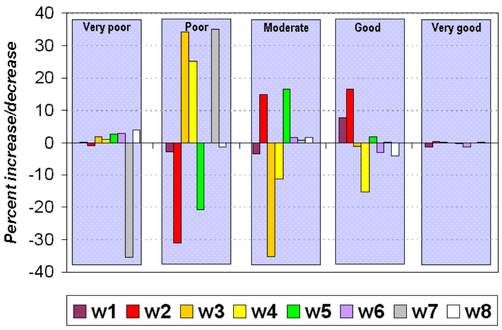

Fig. 4: Percent changes in vegetation vigour between 1988 and 1996

Table 9: Percent changes in vegetation vigour types between 1988 and 1996

Wshed	VP	P	M	G	VG
w1	+0.05	-2.87	-3.40	+7.59	-1.37
w2	-0.89	-30.97	+15.04	+16.53	+0.26
w3	+1.84	+34.35	-35.24	-1.17	+0.22
w4	+0.99	+25.22	-11.15	-15.05	-0.01
w5	+2.66	-20.71	+16.55	+1.77	-0.26
w6	+2.93	-0.03	+1.54	-3.18	-1.26
w7	-35.50	+34.92	+0.54	+0.04	0
w8	+3.85	-1.41	+1.56	-4.02	+0.01

Drainage line performance

In desert regions most of the streams are eroded and devoid of any vegetation. As the soil is mostly sandy with poor moisture retention capacity, following storm incidence run-off water flows with a very high kinetic energy, resulting in bank erosion and sediment transport. With every storm incidence these drains bulges in their dimension and turns to deep gullies. Any conservation measure to stabilize these gullied lands would be manifested through better moisture retention in the gully beds and surrounding zones. Due to moisture retention and sediment deposition good vegetation comes up in due course of time and helps in reducing the impact of rain drop, providing safer velocity of flood water through the channels and helps in better soil and water conservation. Keeping these in view, a buffer mask of the drainage lines with 50 m either side was created to glance through the buffer window what is the vegetation status at various level of drainage line treatment. Different vigour types and their relative distribution are given in Table 8 and 9 for the year 1988 and 1996 respectively.

Table 10: Vegetation vigour along drainage buffer in 1988

Vigour type	w1	w2	w3	w4	w5	w6	w7	w8
Very poor	0.07	0.70	1.21	2.70	2.66	2.79	64.33	2.49
Poor	36.71	3.51	33.35	34.24	46.28	57.09	35.46	65.21
Moderate	51.56	70.56	63.36	47.98	37.45	36.65	0.21	28.18
Good	11.48	25.02	2.08	14.99	12.35	3.39	-	4.15
Very good	0.18	0.21	-	0.09	1.26	0.08	-	-

Table 11: Vegetation vigour along drainage buffer in 1996

Vigour type	w1	w2	w3	w4	w5	w6	w7	w8
Very poor	0.18	2.51	2.40	5.28	2.43	4.82	18.15	4.25
Poor	30.07	24.86	58.37	45.15	35.40	42.37	80.56	52.87
Moderate	51.81	65.48	37.68	47.60	58.91	41.42	1.14	37.71
Good	16.71	7.12	1.50	1.97	3.26	11.25	0.15	5.16
Very good	1.29	0.03	0.05	-	-	0.14	-	0.01

Comparative study of two years performance of the watersheds reveals that the condition of vegetation around the streams/drains are improved in w1, w6, w7 and w8 (Fig. 5 and Table 12). In all these watersheds the proportion of moderate, good and very good types have increased substantially and contributes 6.59%, 12.69%, 1.08% and 10.55% respectively. There is also a decrease in poor or very poor type over the years. This have been possible due to better moisture availability, along drain vegetation which comes up naturally due to favourable soil hydrology. Although the development is slow but is stable. However, significant decrease in vigour type is observable in w2, w3, w4 and w5. There is a very large decrease in moderate to good vegetation type due to anthropogenic activities and the decrease accounted to be 23.16%, 26.31%, 13.49% and 31.81% respectively. The proportion of decrease is more than the increase in vigour. Annual rainfall distribution in the watersheds (district average) indicates that annual rainfall was higher in 1996 than 1988 for w1, w2, w3, w4, w5 and w8 whereas less rainfall was recorded in w6 and w7. Hence out of eight, 4 watersheds (w1, w6, w7 and w8) performed well in terms of drainage line stabilization. In w6 and w7 the vigour was found to be better even if the rainfall was less in 1996 than 1988. For w2, w3, w4 and w5 the major reason for poor performance could be due to less rainfall year.

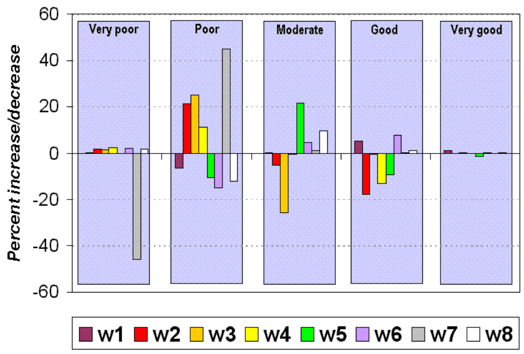

Fig. 4: Percent changes in vegetation vigour along drain between 1988 and 1996

Table 12: Percent changes in vegetation vigour along drain between 1988 and 1996

Wshed	VP	P	M	G	VG
w1	+0.11	-6.64	+0.25	+5.23	+1.11
w2	+1.81	+21.35	-5.08	-17.90	-0.18
w3	+1.19	+25.02	-25.68	-0.58	+0.05
w4	+2.58	+10.91	-0.38	-13.02	-0.09
w5	-0.23	-10.88	+21.46	-9.09	-1.26
w6	+2.03	-14.72	+4.77	+7.86	+0.06
w7	-46.18	+45.10	+0.93	+0.15	-
w8	+1.76	-12.34	+9.53	+1.01	+0.01

Composite ranking for RSWHI

Table 13 represents the composite average weight received by different watersheds. These indicators give overall relative performance during 1996 over the base year 1988. The relative ranking is also given in Table 13 separately for landuse, overall biomass and biomass along the drainage line.

Individual ranking wise Ambali performed best both in terms of landuse and biomass change. Broadly the rank remained same for Ambali, Syala and Kharkhadi in terms of landuse but better performance is noticeable in Kamli and Kheri. Ambali, Kheri, Syala and Mewanagar remained same in terms of ranking for overall watershed vegetation status. Improvement in rank is found in Bawliya pada, and Kharkhadi. Drainage line vegetation is an important indicator for the erosion control measures and in the present study improvement is found in Ambali, Kharkhadi Kheri and Syala. However the rank remained the same for Mewanagar. Marginal negative performance in landuse practice was found in Bawliya pada and Bhirathai Kalan.

Table 13: Weighted performance values and ranking

WS	Landuse				Watershed NDVI				NDVI of drain buffer			
	Wav 1988	Wav 1996	Rank 1988	Rank 1996	Wav 1988	Wav 1996	Rank 1988	Rank 1996	Wav 1988	Wav 1996	Rank 1988	Rank 1996
Ambali	83.58	93.20	1	1	31.42	32.18	1	1	27.50	28.90	3	1
B. pada	70.93	73.11	6	7	26.71	31.69	5	2	32.05	27.73	1	2
B. kalan	77.81	78.60	4	5	26.81	22.93	4	7	26.63	23.84	4	7
Kamli	68.49	82.89	7	3	28.81	24.58	2	4	27.55	24.62	2	5
Kharkhadi	61.26	70.57	8	8	22.62	24.28	7	5	26.33	26.30	5	3
Kheri	73.42	81.32	5	4	26.93	25.77	3	3	24.09	25.95	6	4
M. nagar	78.23	78.08	3	6	14.72	18.33	8	8	13.59	18.33	8	8
Syala	83.41	83.94	2	2	24.14	23.10	6	6	23.40	24.38	7	6

To analyse the overall performance of the watersheds in terms of landuse, vegetation vigour and drainage line vegetation density all the individual index values were summed and averaged (Fig. 5 and Table 14) to better represent the effect of watershed treatment. In developing such composite index the values less than 1 indicate negative performance and more than 1 indicates positive performance. In the present study 5 watersheds showed overall positive performance in health and three showed negative health performance. The degree of positive change in higher only in Mewanagar but for rest 4 the performance is only marginally improved and remained almost unchanged. The watersheds showed negative performance include Bhirathai kalan, Kamli, and Syala. However in Syala and Kamli the performance is marginally negative where as in Birathai kalan it is considerable. Hence from this study it can be concluded that only watershed showed good performance is Mewanagar having located in arid western plain and the poor performance was found in Birathai kalan, which is largely attributed to large area devoid of vegetation.

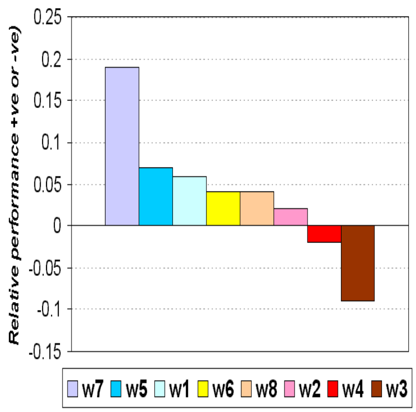

Fig. 5: Watershed health index and composite ranking

Table 14: Watershed health index and composite ranking

Wshed	**Luse W96 /w88**	**Wshed NDVI W96/ w88**	**Buffer NDVI W96/w88**	**Composite index (SBWHI) ∑(w96/w88)/3**	**Performance** (RSWHI – 1.00)*
w1	1.11	1.02	1.05	1.06	0.06 (2)
w2	1.03	1.18	0.86	1.02	0.02 (5)
w3	1.01	0.85	0.89	0.91	-0.09 (8)
w4	1.21	0.85	0.89	0.98	-0.02 (7)
w5	1.15	1.07	0.99	1.07	0.07 (3)
w6	1.11	0.95	1.07	1.04	0.04 (4)
w7	0.99	1.24	1.35	1.19	0.19 (1)
w8	1.00	0.95	1.04	0.99	0.04 (6)

+ Means positive performance, - means negative performance

Conclusion

Eight watersheds distributed across different agro climatic zones of Rajasthan were studied for rapid appraisal of their health condition after 8 years of treatment. Major remote sensing based indicators studied include landuse, overall biomass, vegetation along drainage buffer zone and number and extent of water body. Distribution of landuse, and biomass have been analysed and their change over the years have also been calculated. For comparative performance evaluation area weighted spatial averaging of the landuse and vegetation index were performed and ranked accordingly. Finally the ratio of the weighted spatial average values of landuse and vegetation index was calculated for all the watersheds. Positive change was noticed from all the watersheds except one for landuse, whereas only 4 watersheds showed positive change in terms of biomass development. The biomass especially the ephemerals are highly dynamic as a function of rainfall amount and distribution and hence more precisely the vegetation along the drainage line was analysed which could be used as an indicator due to impact of drainage line treatment. Only 4 watersheds had good biomass along the drainage buffer zone and rest had negative. All of them showed better performance in comparison to overall biomass of the watershed. All the weighted values were finally averaged to derive the RSWHI and ranked accordingly. Mewanagar watershed performed the best among 8 but Birathai kalan, Kamli and Syala performed poorly.

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