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MONITORING ECOLOGICAL HEALTH OF DOHAN WATERSHED IN ARAVALI HILLS OF RAJASTHAN AND HARYANA*

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Abstract

The present study aims to investigate the ecological health of the Dohan watershed which spreads across Haryana and Rajasthan states. Landsat 5 TM and Landsat 7 ETM+ imageries of 1989 and 2009 pertaining to the pre and post treatment periods of watershed has been used and analyzed. In order to examine the ecological changes both natural (vegetative index, water index, bare land index, moisture index, aridity index and standard precipitation index as climatic index) and anthropogenic (land use/ cover change) factors have been considered. The study reveals an increase in the area under cultivation, water bodies, plantation and tree cover and decrease in fallow land as a result of watershed management programmes. Interestingly, Rajasthan part of the watershed has sound ecological health due to community level watershed management practices, whereas Haryana part displayed relatively poor ecological health in the absence of such programmes.

Introduction

The watershed as a planning unit for development of rain-fed agriculture has gained importance over the years (Shanwad et al., 2012). It has been observed that watershed development approach improves livelihoods in a holistic manner by enhancing agricultural productivity, minimizing environmental degradation, reducing regional disparities and generating reliable employment opportunities for the poor (Bosch and Hewlett, 1982; Singh et al., 1989; Kallur, 1991; Randhir and Ravichandran, 1991; ISRO,1998; Dutta et al., 1999; Kumar, 1999; Batchelor et al., 2003; Gallart and Llorens, 2003; Shanwad et al., 2008; Shanwad et al., 2012).

During the pre-independence period, due to lack of policy framework the attempts to conserve soil and water resources were sporadic. During 1950s, agricultural development strategy relied heavily on intervention programmes aimed at developing irrigated areas. Participatory watershed management was institutionalized in government policies during 1990s. This has led to the emphasis on many projects shifting from technological to social interventions. In the wake of this, the Ministry of Rural Development and Ministry of Agriculture, India brought a number of area development programmes such as Drought-Prone Area Programme (DPAP), Desert Development Programme (DDP), Integrated Watershed Development Programme (IWDP) and

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National Watershed Development Programme for Rain fed Areas (NWDPRA) under the ambit of watershed development. It has also established a common set of operational guidelines, objectives, strategies and expenditure norms for all these programmes. The revised watershed guidelines in 2001 framed a uniform and clear commitment for integrated land and water management using participatory approaches. However, the new approach suffered from a continuous lack of inter-departmental coordination (Wilson et al., 2003). The new *Hariyali* guidelines issued by the Government of India in 2003 addresses the problem by giving more emphasis to local government bodies such as village panchayats in watershed development and management programmes.

Integrated watershed management implies both the amalgamation of different activities and the collation of relevant information to evaluate the cause and effect of all the proposed actions which would consider hydrological, demographic and socio-economic parameters within a geo-hydrological unit (Singh et al., 1989; Kallur, 1991; Suo et al., 2008; Jones et al., 2009). Most of above mentioned watershed implementing agencies (DPAP, DDP, IWDP, NWDPRA etc.) claim that the results due to implementation of the watershed programmes were positive and highly productive (ISRO, 1998; Yadav and Singh, 2000; NCHSE, 2002; Milne, 2007; Sharma and Thakur, 2007; Singh, 2008; Shanwad et al., 2008; Shanwad et al., 2012). Therefore, there is a need for holistic approach to assess and evaluate the progress of implementation and achievements of such projects through reliable methods. Holistic approach besides seeking inputs from related domain combines geospatial tool which provides an excellent methodology to monitor the land resources and evaluation of ecological changes (Hernandez, 1995; Malczewski et al., 2003; Turner and Boner, 2004; Suo et al., 2008; Zha et al., 2008; Jones et al., 2009). The integration of GIS and remote sensing data with the field data and collateral information gives the most accurate assessment of the actual work done in the field by the project implementing agencies.

More recently, monitoring and assessing ecological changes by using geospatial technology has emerged an important research field all over the world (Malczewski et al., 2003; Lichtenberg and Ding 2008; Shanwad et al., 2008; Suo et al., 2008; Zha et al., 2008; Shanwad et al., 2012) and reveals that the land use change is one of the most important factors in understanding the ecological and environmental dynamics (Lambin and Ehrlich, 1997; Dutta et al., 1999; Kumar, 1999; Sujatha et al., 2000; NCHSE, 2002; Jabbar et al., 2006; Jones et al., 2009). Therefore, the studies monitoring the ecological health of watersheds raise an intellectual curiosity all over the globe. In addition, this becomes further important particularly, for all those watersheds which have been taken-up under the aegis of the national watershed development programmes for rain-fed agricultural regions. Dohan watershed which has been a part of the watershed development programme (Government of Rajasthan, 2011), has also experienced many geo-physical and ecological changes during the last two decades and calls for a close academic investigation of its ecological health. However, watershed development programmes initiated in Haryana part could not achieve the desired results. Thus, the present study is an endeavour to monitor the changes in ecological health of Dohan watershed due to implementation of various watershed development programmes.

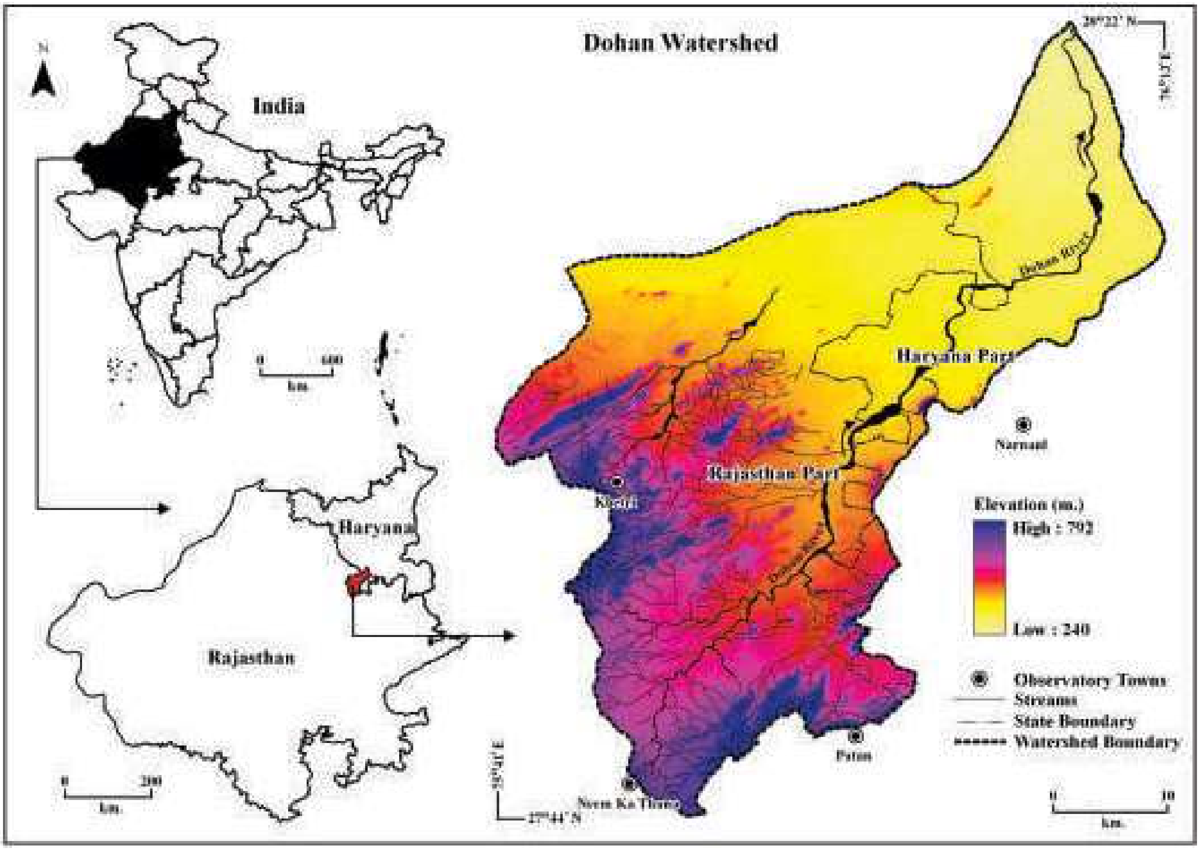

Fig. 1

Geo-environmental setting of the Study Area

The Dohan watershed is located between 27° 44' to 28° 22' N latitudes and 75° 41' to 76° 13' E longitudes sprawling in the states of Rajasthan and Haryana (Fig. 1). It covers an area of about 1517 km^2 comprising 1086 km^2 in Rajasthan and 431 km^2 in Haryana. Dohan River originates from Shri Madhopur hills. There are two tributaries namely Chandrawati and Sukh Nadi which are ephemeral in nature and flow in response to heavy precipitation during monsoon season. The watershed is bounded on the north-west by Jhunjhunu and south by Sikar districts of Rajasthan state and on the north-east by Mahendergarh district of Haryana state. The general slope of the area is from south-west to north-east. The elevation varies between 240 to 792 m above mean sea level (Fig. 1).

The watershed is characterized by semi-arid climatic conditions having average annual rainfall of 473 mm mainly received during the south-west monsoon season (June to September).The mean annual temperature remains about 23°C (Singh, 2005). The air is generally dry during the summer season and the potential evapo-transpiration rates are quite high, especially during May and June. The major part of the watershed is covered by recent to sub-recent windblown sand dunes. Watershed is characterized by summer sand storms, drought conditions, inland streams, fixed or fossil sand dunes, dissected upland tract and barren denuded rocky hill ranges. However, the western part of the watershed is occupied exclusively by the rocks of Delhi super groups. Most of the streams that originate or enter the watershed gradually shrink and lose water by high rate of evaporation and excessive percolation in sandy material.

Objective

Major objective of the present study is to examine the ecological health of Dohan watershed over time and space by monitoring both natural (vegetative, water, bare land, moisture, aridity and standard precipitation index) and anthropogenic changes such as land use/ cover in the study area.

Material and Methods

Data Base

The United States Geological Survey (USGS) satellite data of Landsat 5 TM and Landsat ETM+ sensor with a spatial resolution of 28.5 m have been used for the study. The data were downloaded from Global Land Cover Facility (GLCF) website (http://landsat.gsfc.nasa.gov/?page_id=9). Landsat 5 (Path: 147 Row: 40 and 41) TM (dated October 6, 1989) and Landsat 7 (Path: 147 Row: 40 and 41) ETM+ (dated October 10, 2009) imageries covering the watershed were assembled and analyzed to highlight the changes that have occurred in land use/cover, biomass and moisture contents over a period of 21 years. Ancillary data were also procured from Survey of India (SOI) topographic map of 1:50,000 scale. The watershed is covered in the Survey of India topographic maps 44P/12, 44P/16, 45M/9, 45M/13, 45M/14, 53D/3, 53D/4 and 54A/1. The elevation data at 30 m resolution have been taken from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM). The meteorological data (rainfall and potential evapo-transpiration) for a period of 21 years have been collected from India Meteorological Department (IMD) for four stations namely Khetri, Neem-Ka-Thana and Patan in Rajasthan and Narnaul in Haryana.

Methods

The thematic layers were generated using remote sensing data and GIS technology. The ERDAS IMAGINE 9.1, Arc/Info 9.3 softwares have been used for processing the data and generating the requisite information for analysis.

(i) Pre-processing of Images

The pre-processing for the dataset included image registration, radiometric calibration, and radiometric normalization. Rectification and registration of Landsat 5 TM and Landsat 7 ETM+ imageries were based on control points collected from geo-referenced Survey of India topographical maps using more than 50 ground control points (GCP). The remotely sensed dataset were geometrically corrected with appropriate projection parameters (UTM Zone N 43 and datum WGS 84) using the first order polynomial equation. The nearest neighbour rectification resampling method was applied in order to preserve the radiometry and spectral information in the imagery. Image-to-image registration was performed to register the Landsat 7 ETM+ image (2009) with geo-coded Landsat 5 TM image of 1989. The total Root Mean Square (RMS) error of the images was observed to be 0.17. The Landsat imageries were radiometrically calibrated for sensor differences, converted into spectral radiance and normalized for illumination properties.

(ii) Post-processing of Images

Two interaction goals have been followed in the present study. In the first stage, remote-sensing techniques were used in evaluation of surface changes and determination of the type of land use/land cover classes. In the next stage, the area was evaluated for ecological health change by using the various prominent indicators like NDVI, NDMI, NDBaI, Aridity Index and Standard Precipitation Index followed by analysing the impacts of land use/ land cover class expansion on ecological change in the watershed. The

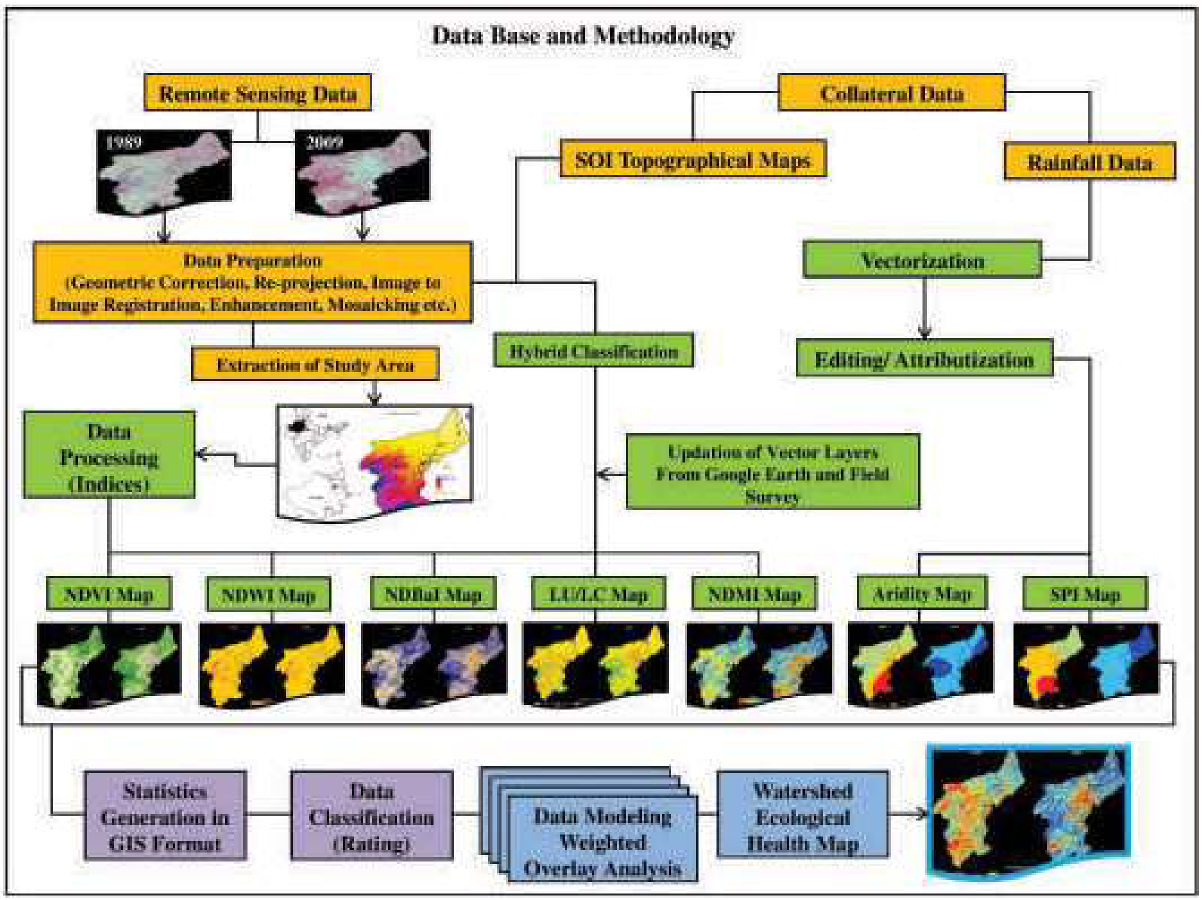

Fig. 2

Landsat 5 TM, Landsat 7 ETM+ bands 1, 2, 3, 4, and 5 have been used to derive the selected indices. The methodologies adopted for calculating the ecological health index have been summarized in Fig. 2.

The hybrid classification method (supervised and un-supervised classification based on radiometry and on screen digitized mask) and the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Bare Land Index (NDBaI) have been employed for evaluating the land use/ land cover classification. In order to study the ecological health of watershed, six closely related indices namely NDVI, NDWI, NDBaI, Normalized Difference Moisture Index (NDMI), Aridity Index (AI) and Standard Precipitation Index (SPI) have been computed using the following equations:

- NDVI: It is the most common form of vegetation index (Tucker, 1979) which is basically the difference between the red and near-infrared band combination divided by the sum of the red and near-infrared band combination (Rouse et al., 1973) or:

  $NDVI = (NIR - R) / (NIR + R)$

  where R and NIR stand for the red and near-infrared bands of Landsat images.
- NDWI: It is developed to delineate open water feature (Mcfeeters, 1996). Investigators have developed several methods to map water features with the visible/infrared imagery i.e. thematic classification method (Lira, 2006),

single-band thresholding method (Jain et al., 2005), and spectral water index method (Sakamoto et al., 2007):

NDWI = (Green- NIR)/ (Green+ NIR)

where, Green and NIR represent the spectral bands of the Landsat images.

- NDBaI: A new index NDBaI has been used to retrieve bare land from the Landsat imagery advocated by Jamalabad and Abkar (2004) as

  NDBaI = (SWIR-Red)-(NIR-Blue)/ (SWIR+ Red) + (NIR+Blue)+1

  where, SWIR, NIR, Red and blue represent the spectral bands of the Landsat images.
- NDMI: It analyzes the spectral characteristics of different land use/cover types based on moisture content (Wilson and Sader, 2002). This index contrasts the near-infrared (NIR), which is sensitive to the reflectance of leaf chlorophyll content to the mid-infrared (MIR), sensitive to the absorbance of leaf moisture (Gao, 1996):

  NDMI = (NIR-MIR)/ (NIR+MIR)

  where NIR and MIR are bands of the Landsat TM and ETM+ images.
- AI: It is also called an index of moisture deficit indicating a lack of moisture under average climatic conditions (Perry, 1986).The degree of aridity is inversely related to the magnitude of the aridity index. Here, aridity index has been computed as suggested by Hare, 1993.

  AI = Precipitation amount (mm)/ amount of potential evapotranspiration (mm)
- SPI: It is a tool derived by McKee et al., (1993). In the output index, positive SPI values indicate greater than median precipitation (wet condition), while negative values indicate less than median precipitation (drought conditions). A drought event is defined when SPI value reach 1 or lower and a station suffers an extreme drought situation, if the SPI value is below 2 (Edwards and McKee, 1997).

  SPI = Rainfall (mm) - mean rainfall/ standard deviation

The ecological health index of a watershed is an indication of the extent of management and developmental activities taken up in the watershed. In order to have more comprehensive idea about the improvement of watershed over the years, comparative weightage has been given to each type of land use/ land cover classes. Based on possible negative impacts on land, a rating has been given to assess land use changes. Water bodies are put under highest weightage category followed by agricultural land, dense vegetation cover, sparse vegetation cover, settlements and fallow land which being on the lowest side of weightage. Higher sum total of actual marks better is the ecological health of a watershed in a given time-frame and vice versa. For assessing the final ecological change in the watershed, all the thematic maps (NDVI, NDMI, NDBaI, AI and SPI) were reclassified into five categories using the suitable threshold value and converted into raster format (.img) for both the time periods and superimposed by weighted overlay method. The output of NDWI map has not been used for calculating the weightage value and ratio for both the periods. The output of NDWI map has been used in the land use/land cover map to increase its precision level for identification of surface water bodies. This helped to avoid misinterpretation of land use/land cover classes. In order to get spatial pattern of aridity and drought conditions, interpolation of AI and SPI map was also done. The ordinary Kriging in

Spatial Analysist tool of ArcGIS 9.3 isopleths maps were prepared for both the periods. All these required layers have been integrated using Raster Calculator given in Spatial Analyst extension and finally ecological change index has been derived as given below:

Ecological Change Index= $\sum [(Map_1 \times W_1/A) \times 100 + (Map_2 \times W_2/A) \times 100 \ldots\ldots (Map_n \times W_n/A) \times 100]$.

where, Map_1 = Area under land use $type_1$

W = Weight / score assigned to the $type_1$

A = Total area of the watershed

In order to assess the changing pattern of overall ecological health of Dohan Watershed five categories of ecological health index which include very good, good, moderate, poor and very poor have been identified.

To obtain the overall changes (positive or negative) in watershed ecology, ratio of composite map value, for the year 2009 and 1989 has been generated using following formula.

Ratio= Total weightage value of 2009/ Total weightage value of 1989.

If the ratio value is more than 1.0, then it has been assumed that the situation of the watershed has improved (excluding bare land index) after taking up the watershed management practices. The value less than 1.0 indicates that the ecological situation has not improved much. The degree of improvement is proportional to the value of the ratio. Finally, the Microsoft excel was utilized for statistical, graphical and trend analysis.

Results and Discussion

Land Use/ Land Cover Change

Table 1 reveals the area of the watershed under different land use/land cover classes and their transformations during the reference period 1989-2009. These changes are vividly noticeable in Fig. 3 and can be attributed to the implementation of different watershed management schemes of the government and through the efforts of a non-government organization (NGO) known as *Traun Bharat Sangh*. These agencies constructed check dams, *nala bunds*, boulder checks and percolation tanks in the watershed resulting, an increase in the cropped area and reduction in fallow land. The comparison of land use/ land cover maps of 1989 and 2009 clearly demonstrates that agricultural land has increased substantially in the watershed during this period (Fig. 3). Of the total land, agricultural land in pre-development phase (1989) was observed to be 25.86 and 18.08 per cent in Rajasthan and Haryana parts, respectively, while it demonstrated a discernible increase in Rajasthan part (32.19 per cent) and minuscule decrease in Haryana part (17.69 per cent) in 2009. Interestingly, only Rajasthan part has registered an increase in agricultural land (96 km^2) whereas, the Haryana part has witnessed a minuscule decline in agricultural land (6 km^2). The fallow land (sand dunes and unused land) has decreased by about three times in Rajasthan part, whereas it remained almost stagnant (7 per cent) in Haryana part (Table 1). Such a phenomenal decline in fallow land in Rajasthan part is due to the improvements in vegetation growth in rocky barren hills and expansion of agricultural activities in the western and north-western parts of the watershed. In addition, an overall increase in vegetation cover of the watershed has been noticed (Table 1 and Fig. 3; Photo 1 and 2). The area under settlements has also increased by 23.15 km^2 in study area. This change was due to construction of new houses/buildings, water harvesting and storage structures etc associated with increase in population. Also, the number of water bodies in the area has demonstrated a perceptible change (0.55 km^2). It indicates the growing awareness and attention of the implementing agencies and villagers towards the management of water resources. The calculated weightage average value for land use/ land cover in 1989 was 264.37 which increased to 310.11 in 2009 (Table 2). The study reveals that the overall land use/ land cover weighted value was 1.0 in 1989 which increased up to 1.17 in 2009. The land use/ land cover weighted value has been observed higher (1.26) in Rajasthan part, whereas it was found stagnant (0.99) in Haryana part after the implementation of soil and water conservation measures in Dohan watershed..

Indicators of Ecological Health

I) Vegetal Cover

The results of the NDVI computed for Dohan watershed are shown in Fig 4 and Fig. 5. Fig 5 reveals that vegetation cover in the watershed was about 900 km^2 (59.31 per cent) in the year 1989, which significantly increased to about 1180 km^2 (77.77 per cent) in 2009. Rajasthan part exhibited a significant change (18.68 per cent point) in vegetal cover during the study period, while the vegetal cover in Haryana part didn't experience any apparent change. This can be attributed to non-compliance of in situ soil and water conservation measures in Haryana part of the watershed. The spatial analysis of NDVI shows that it has a significant association with moisture index map (Fig 4 and Fig 8). The composite weightage of vegetation cover map of the watershed has been found to be 258.29 in 1989 and 333.71 in 2009, their ratio being 1.29. This clearly indicates that the vegetation cover has improved in Rajasthan part whereas it remained almost constant in parts of Dohan

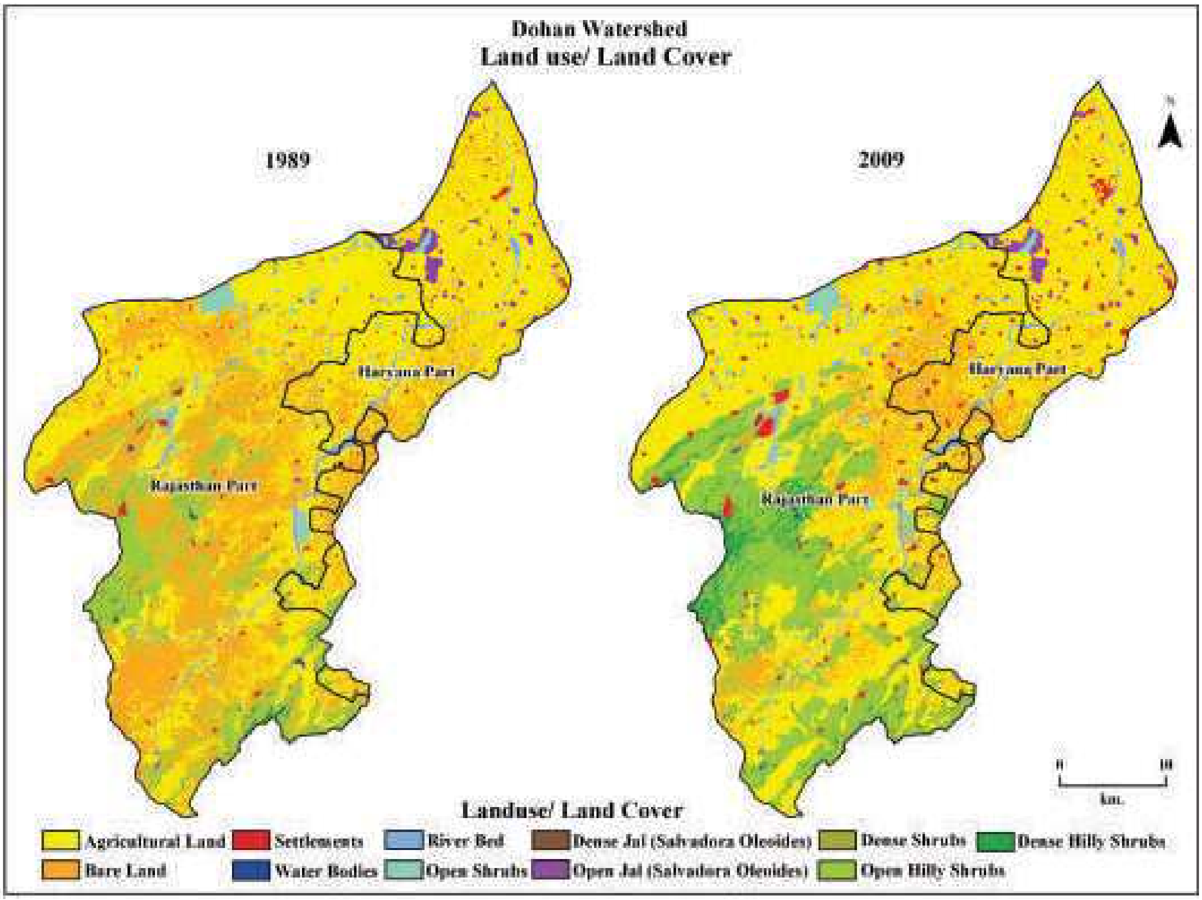

Fig. 3

Table 1
Dohan Watershed: Per cent Change in Area under Various Land use/ Land Cover Classes, 1989-2009

Land use/Cover Classes	Rajasthan Part						Haryana Part					
	1989		2009		Change		1989		2009		Change	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Change (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Change (%)
Agricultural Land	392.60	25.86	488.70	32.19	96.10	24.48	274.55	18.08	268.55	17.69	-6.00	-2.19
Open *Jal* (Salvadora Oleoides)	0.07	0.00	0.07	0.00	0.00	0.00	14.67	0.97	13.89	0.91	-0.78	-5.32
Dense *Jal* (Salvadora Oleoides)	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.56	0.04	0.49	700.00
Open Shrubs	28.13	1.85	34.20	2.25	6.07	21.58	3.06	0.20	3.06	0.20	0.00	0.00
Dense Shrubs	0.09	0.01	1.48	0.10	1.39	1544.44	0.07	0.00	0.07	0.00	0.00	0.00
Open Hilly Shrubs	173.34	11.42	296.48	19.53	123.14	71.04	8.70	0.57	11.50	0.76	2.80	32.18
Dense Hilly Shrubs	5.08	0.33	61.75	4.07	56.67	1115.55	0.04	0.00	0.24	0.02	0.20	500.00
Settlements	12.73	0.84	27.05	1.78	14.32	112.49	8.17	0.54	17.00	1.12	8.83	108.08
Bare Land (Fallow Land)	458.95	30.23	162.73	10.72	-296.22	-64.54	112.79	7.43	108.45	7.14	-4.34	-3.85
Water Bodies	1.71	0.11	2.08	0.14	0.37	21.64	0.01	0.00	0.19	0.01	0.18	1800.00
River Bed	14.14	0.93	12.3	0.81	-1.84	-13.01	9.26	0.61	7.88	0.52	-1.38	-14.90
Total	**1086.84**	**71.59**	**1086.84**	**71.59**	**0.00**	**0.00**	**431.39**	**28.41**	**431.39**	**28.41**	**0.00**	**0.00**

Source: Compiled by Author

Table 2
Dohan Watershed: Weighted Composite Ratio of Ecological Parameters, 1989-2009

Parameters	Rajasthan Part			Haryana Part			Dohan Watershed		
	1989	2009	Ratio	1989	2009	Ratio	1989	2009	Ratio
Land use/cover Map	177.17	223.92	1.26	87.2	86.19	0.99	264.37	310.11	1.17
Normalized Difference Vegetation Index	154.83	226.06	1.46	103.46	107.65	1.04	258.29	333.71	1.29
Normalized Difference Bare Land Index	260.13	196.81	0.76	107.97	101.70	0.94	368.1	298.51	0.81
Normalized Difference Moisture Index	166.32	273.06	1.64	106.78	112.10	1.05	273.1	385.16	1.41
Aridity Index	175.90	302.03	1.72	70.75	122.83	1.74	246.65	424.86	1.72
Standard Precipitation Index	135.91	288.91	2.13	76.53	135.40	1.77	212.44	424.31	2.00
Ecological Health Map	178.37	251.79	1.41	92.12	110.97	1.20	270.49	362.76	1.34

Source: Compiled by Author; Ratio = Map composite value of 2009/map composite value of 1989.

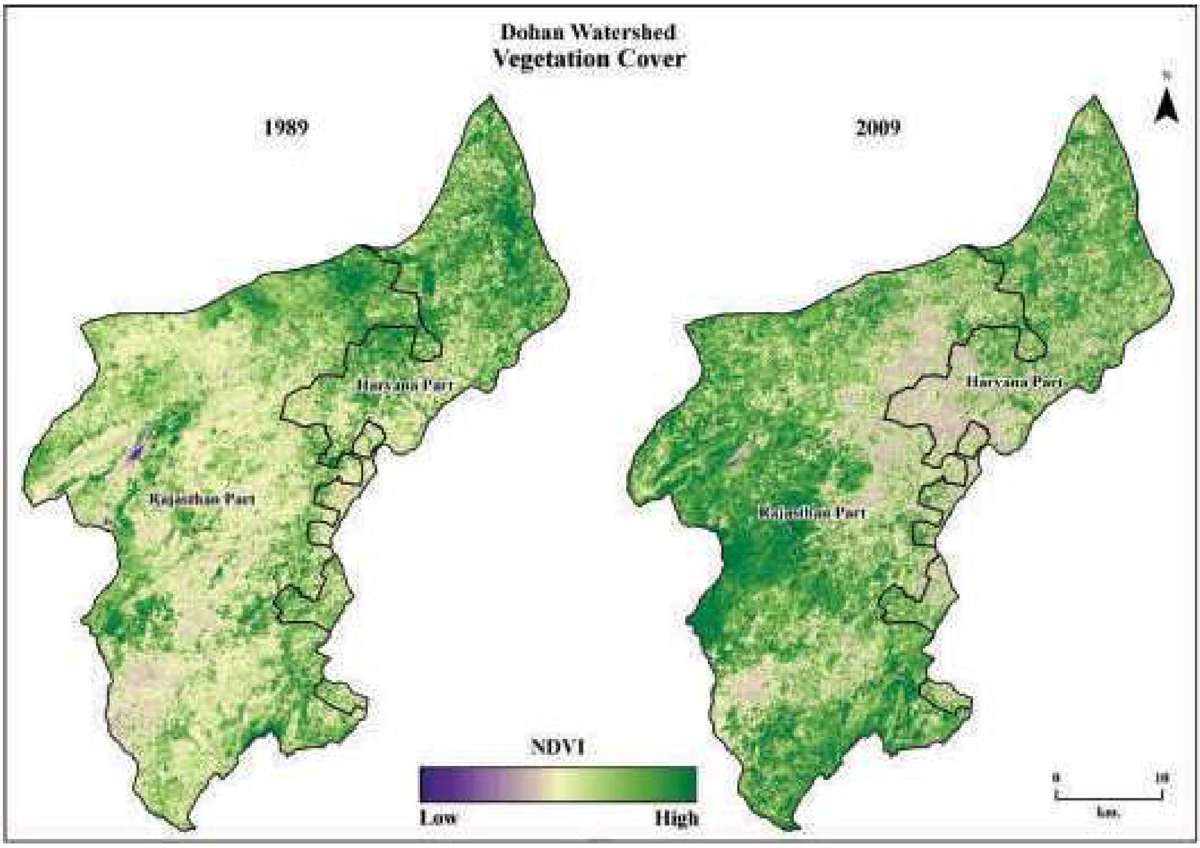

Fig. 4

Watershed in Haryana (Table 2). These observations have been corroborated from the changes noticed in land use/land cover maps of 1989 and 2009.

ii) Surface Water Bodies

The NDWI used to investigate the status of surface water bodies in the Dohan watershed reveals that there was a significant increase in the area under surface water bodies during the study period. The surface water cover was 1.72 km^2 in 1989 which increased to 2.27 km^2 in 2009 (Fig. 6). Both Rajasthan and Haryana parts witnessed increasing trend in surface water coverage. Initially, Rajasthan part had 1.71 km^2 area under water bodies which increased to 2.08 km^2 in 2009. This can be attributed to construction of water harvesting and runoff retention structures such as, *nala bunds*, boulder checks and gully checks in the depressions of Rajasthan part (Photo 3 and 4). Haryana part also exhibited an increase in the area under surface water bodies from 0.01km^2 in 1989 to 0.19 km^2 in 2009 but it was much less than that of Rajasthan part.

iii) Bare Land

The results (Table 1 and Fig. 7) show a general decrease in the fallow land in the study area. It clearly indicates that there was an effective implementation of land resource conservation planning in the area (Photo 1 and 2). The calculated composite weightage values of the NDBaI map of the watershed was 368.1 in 1989 which declined to 298.51 in 2009. The ratio of the composite values of NDBaI between 2009 and 1989 is 0.81 (in case of fallow land) which shows improved ecological health of watershed. The ratio value noticed in Rajasthan part was 0.76 while for Haryana it was almost equal to unity (0.94) (Table 2). This indicates that the watershed management

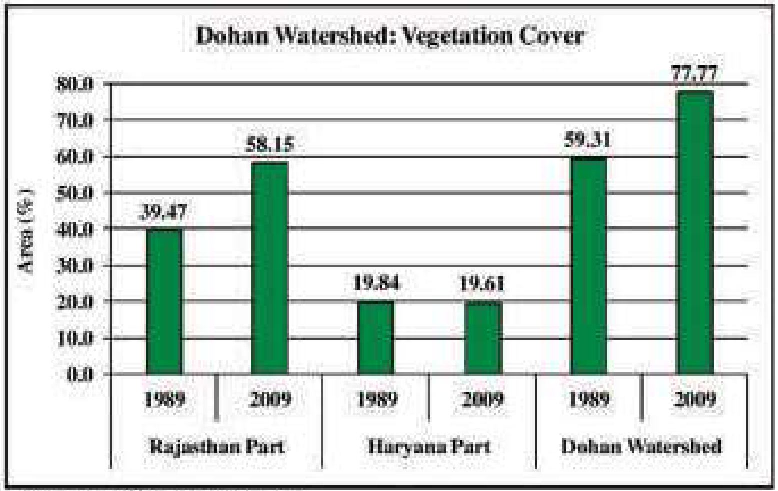

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Fig. 5

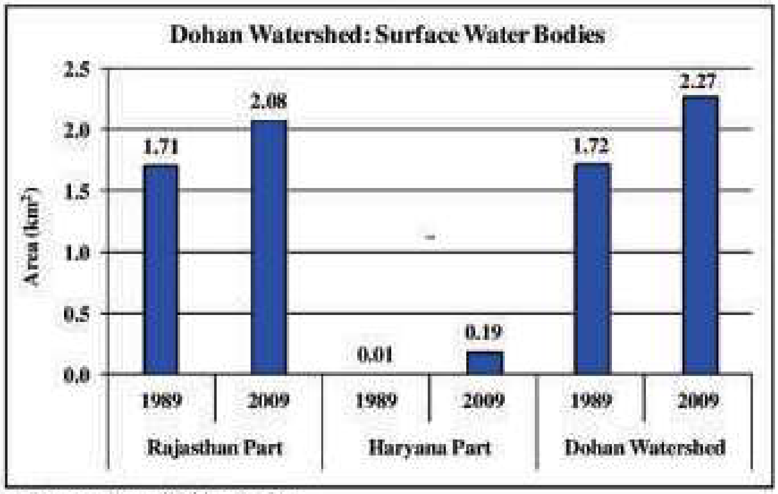

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Fig. 6

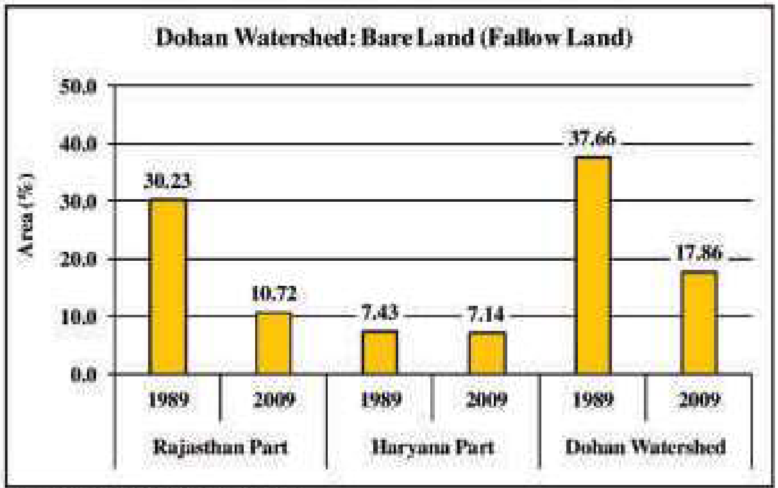

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Fig. 7

Bare hills, stressed vegetation and dry course of Dohan River

Photo 1

Lush green hills, improved vegetation cover and perennial channel of Dohan watershed

Photo 2

practices have not yielded any significant positive changes in the fallow land of eastern part of watershed which lies in the state of Haryana.

iv) Moisture Level

Likewise, the NDMI obtained for Dohan watershed indicates that there has been a significant increase in the moisture content within the watershed during the study period (Table 2 and Fig. 8). Initially, the western hilly tract and north-eastern part along the riverbed of the watershed moderated to high moisture content, whereas south-western, north-western and central part except a few isolated pockets, showed the deficit in moisture content mostly in Rajasthan part of the study area (Fig. 8). During 2009, the watershed condition improved except few patches where the moisture content declined. The Haryana part along the boundary of Rajasthan also witnessed decrease in moisture content and it is associated with the decrease in the vegetation cover in Haryana part of the watershed. The computed moisture content map weightage values were found to be 273.1 and 385.16 for the year 1989 and 2009 respectively, indicating an improvement in moisture content in Dohan watershed. The Rajasthan part of the watershed exhibited a higher ratio value (1.64), whereas in Haryana part the moisture index remained close to 1.0 showing no change in the moisture content (Table 2).

v) Aridity Index

The aridity analysis revealed that the annual aridity index was increasing with time at Patan and Neem-Ka-Thana stations (Fig. 9), while it has decreased at Narnaul and Khetri stations in the watershed. However, minimum aridity index values are found during June and October, when the rainfall is low and evapo-

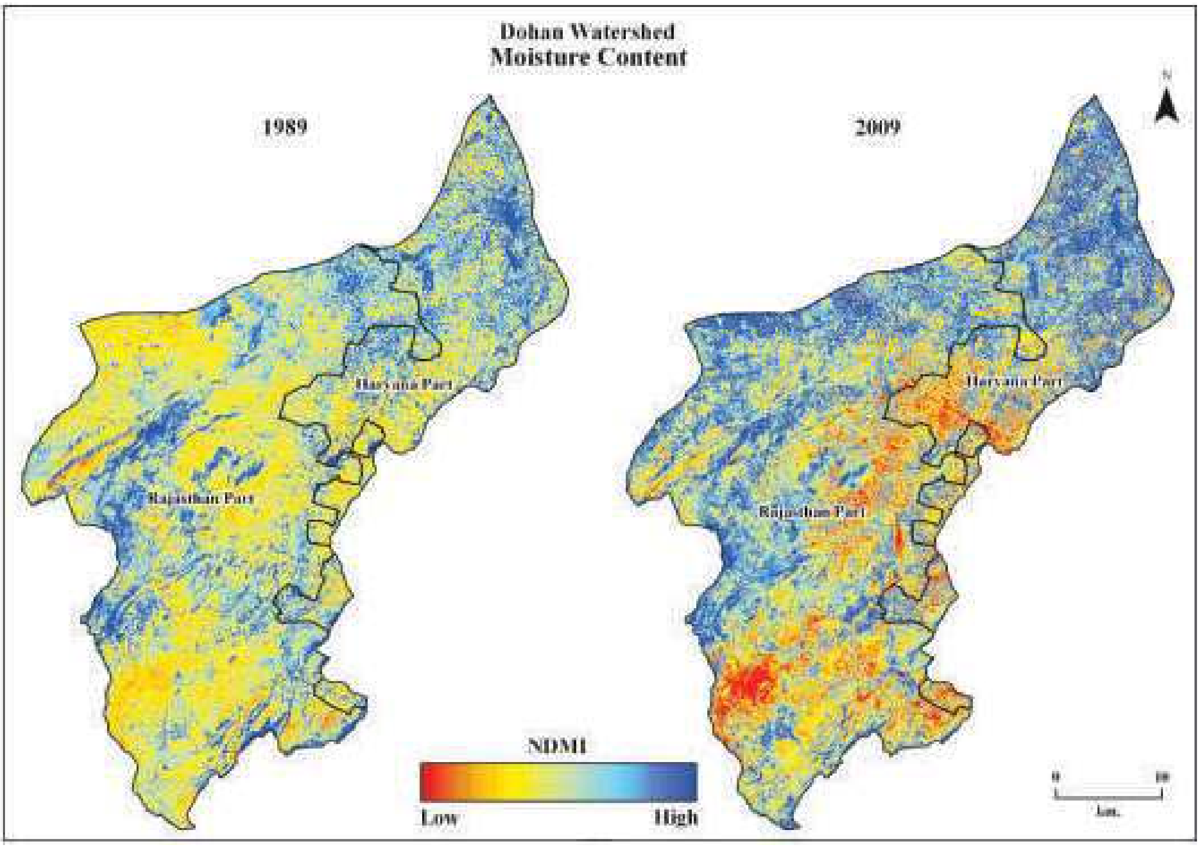

Fig. 8

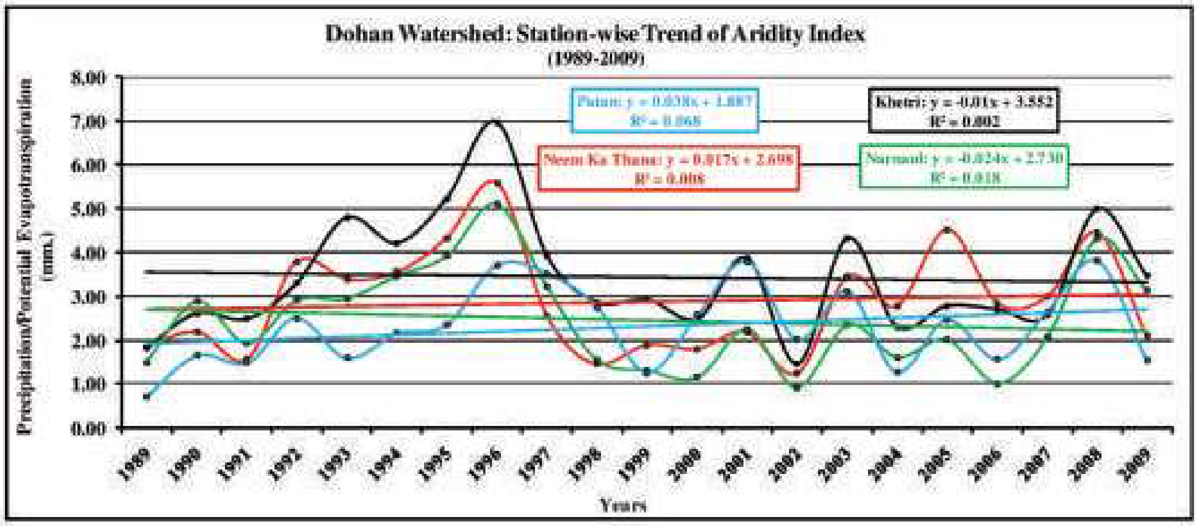

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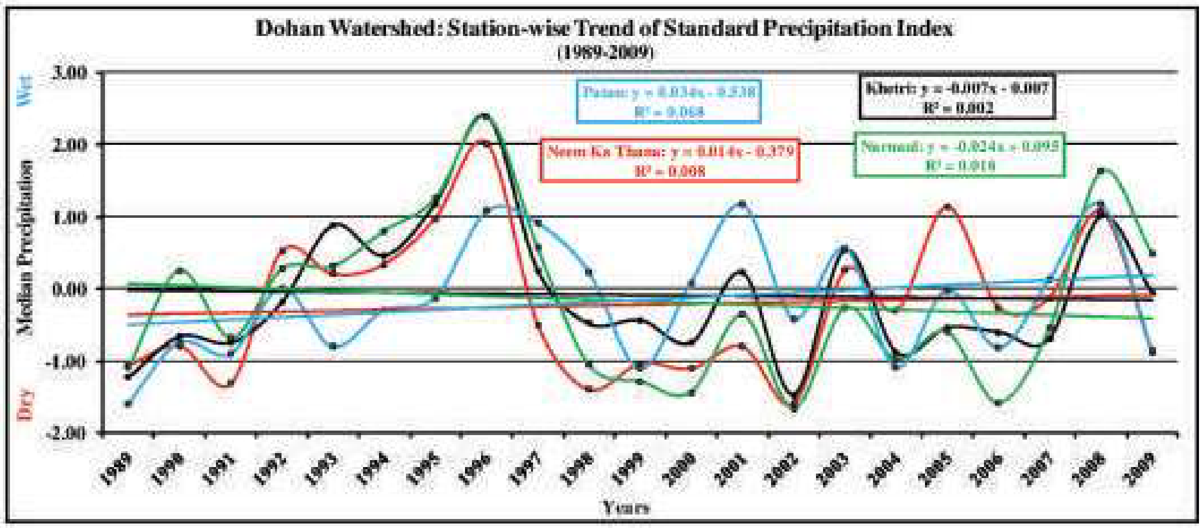
Fig. 9



Source: Compiled by Author

Fig. 10

transpiration is high. The aridity index was observed to be lower during 1997 than 2007 while the area experienced dry conditions during the years 2002 and 2006. During dry years, the aridity index values for each of the rain gauge station moved to the next lower zone, which indicates a change in the local climatic conditions. A perceptible wet period is clearly noticeable during the period 1993-1996 and subsequently during the years 2003, 2005 and 2008 (Fig. 9). The composite weightage of aridity classes of the watershed were observed to be 246.65 and 424.86 during 1989 and 2009, respectively resulting into a ratio value of 1.72 (Table 2). This clearly indicates that the aridity in the watershed has declined significantly which can be attributed to the improvement of vegetal cover and occurrence of reliable rainfall over the watershed area during study period.

vi) Standard Precipitation Index

The SPI trend has not shown any significant changes during the study period in Dohan watershed areas (Fig. 10). The obtained SPI values for Patan and Neem-Ka-Thana stations have shown rising trend whereas Khetri and Narnaul stations demonstrated a decreasing trend. However, extreme drought conditions occurred in year 2002, whereas extreme wet conditions have been observed during the years 1996 and 2008. The composite weighted ratio value of SPI for the watershed clearly shows an improvement in distribution of rainfall mainly during 1989 and 2009 (Table 2). Moreover, the adequate amount of rainfall helped in the ecological nourishment of the watershed areas.

Ecological Health of the Watershed

In order to assess the changing pattern of overall ecological health of Dohan watershed five categories of health index have been identified (Fig. 11) The spatial changes in area of ecological health for both time periods have been observed and the same has been summarized in Table 3. The analysis revealed that about one-fifth area of the watershed was falling under the category of good and very good ecological health during the year 1989, whereas these two categories registered more than half of the watershed area (55 per cent) during next two decades i.e. 2009. It could be attributed to sound conservation practices adopted in the Dohan watershed during the study periods (Photo 3 and 4). The spatial distribution of these areas is highly associated with vegetation cover, moisture content and

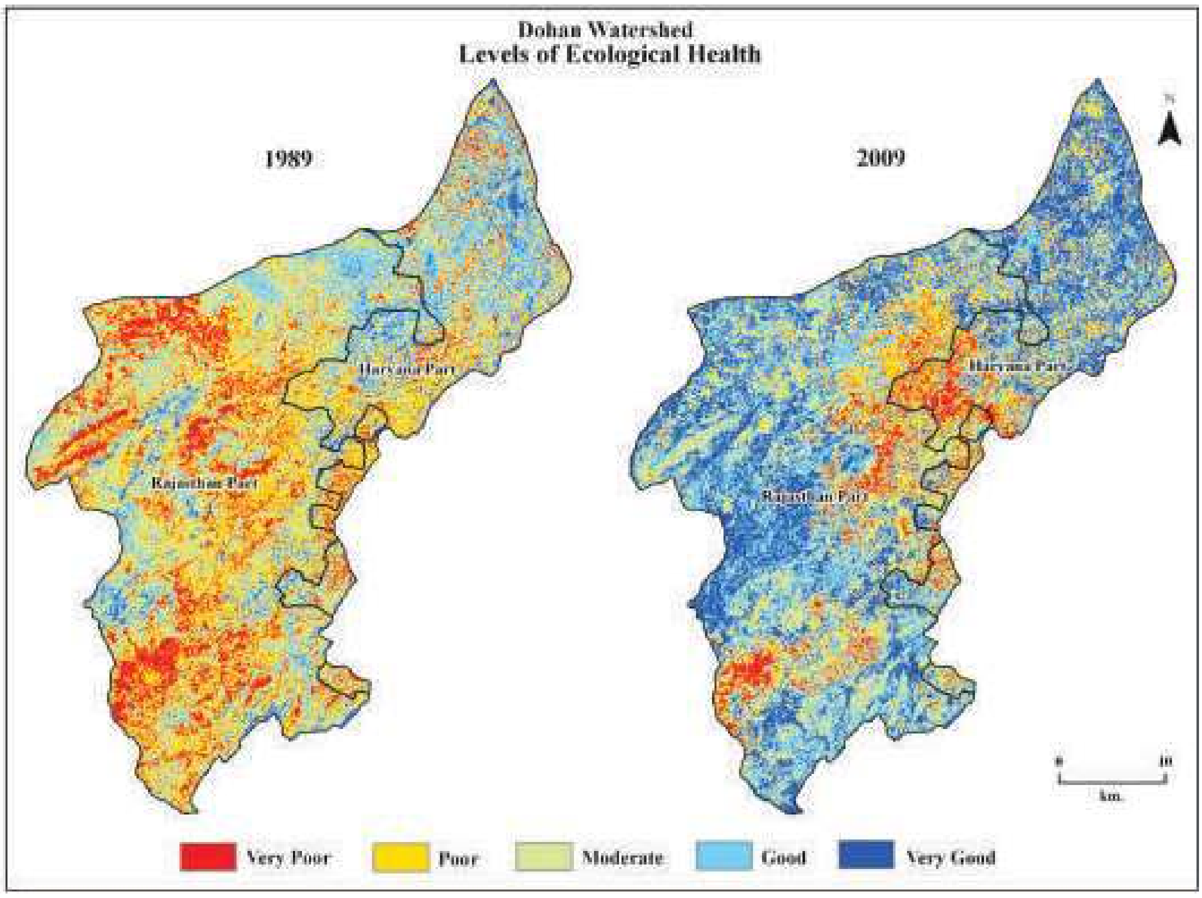


Fig. 11

Groundwater recharge structure leading to percolation and soil conservation

Photo 3

Community usage of water from built-up water harvesting structures

Photo 4

Table 3
Dohan Watershed: Per cent Change in Area (km^2) under Various Levels of Ecological Health

Unit	Year	Classes				
		Very Good	Good	Moderate	Poor	Very Poor
Rajasthan Part	1989	22.22 (1.46)	151.04 (9.95)	386.25 (25.44)	302.46 (19.92)	224.87 (14.81)
	2009	209.03 (13.77)	380.35 (25.05)	291.62 (19.21)	132.31 (8.71)	73.53 (4.84)
	Change	186.81 (840.73)	229.31 (151.82)	-94.63 (-24.50)	-170.15 (-56.26)	-151.34 (-67.30)
Haryana Part	1989	26.08 (1.72)	122.49 (8.07)	151.96 (10.01)	83.41 (5.49)	47.45 (3.13)
	2009	97.10 (6.40)	139.43 (9.18)	77.46 (5.10)	77.74 (5.12)	39.65 (2.61)
	Change	71.02 (272.32)	16.94 (13.83)	-74.50 (-49.03)	-5.67 (-6.80)	-7.80 (-16.44)
Dohan Watershed	1989	48.30 (3.18)	273.53 (18.02)	538.21 (35.45)	385.87 (25.42)	272.32 (17.94)
	2009	306.13 (20.16)	519.78 (34.24)	369.08 (24.31)	210.05 (13.84)	113.18 (7.45)
	Change	257.83 (533.81)	246.25 (90.03)	-169.13 (-31.42)	-175.82 (-45.56)	-159.14 (-58.44)

Source: Compiled by Author; Figures in parentheses are the percentages to the total area and change.

inversely with fallow lands (Fig. 4 and Fig. 8). It is further observed that there has been a remarkable increase in the area under very good and good health condition in Rajasthan part of watershed (Fig. 11).

However, due to sluggish growth of vegetal cover, slight improvements in ecological health have been observed in the Haryana part of the watershed (Fig. 11). The calculated weightage average ratio value for ecological health map in 1989 was found to be 270.49 which increased to 362.76 in 2009 (Table 2) indicating towards successful watershed implementation programmes. Interestingly in Rajasthan part higher ecological health was observed (1.41) than Haryana part (1.20), while for the water shed as a whole it was found to be 1.34 (Table 2).

Conclusions

The most important findings of the present study are perceptible increase in area under vegetation cover, surface water bodies and improvements in moisture content. As a result, a noticeable decline in fallow land and aridity conditions has been observed. The overall ecological health index ratio of Dohan watershed has increased from 1.0 during 1989 to 1.34 during the year 2009. The rate of ecological regeneration is much more pronounced in Rajasthan part as a result of successful construction of check dams, n*ala bunds*, boulder checks and percolation tanks which subsequently resulted an increase in the cropped area, vegetation cover, moisture contents and reduction in fallow land. However, Haryana part could not achieve the desired improvements in cropped area, vegetation cover, moisture content and improvement of fallow lands.

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