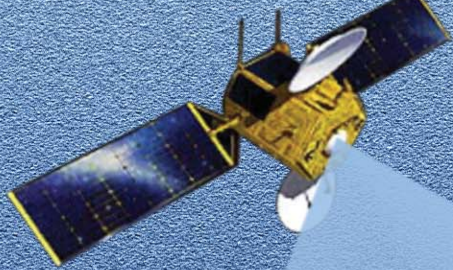
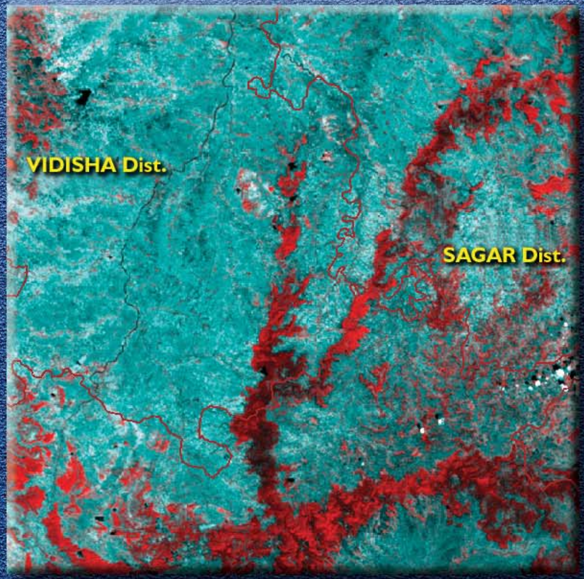
Global Theme 3: Water, Soil, and Agrobiodiversity
Management for Ecosystem Health

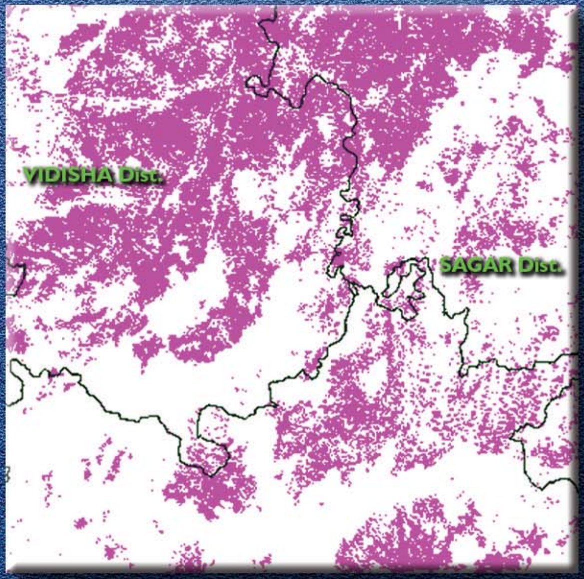
Report no. 3



Spatial Distribution of Rainy Season Fallows in Madhya Pradesh: Potential for Increasing Productivity and Minimizing Land Degradation

S P Wani, R S Dwivedi, K V Ramana, A Vadivelu,
R R Navalgund, and A B Pande





International Crops Research Institute for the Semi-Arid Tropics
National Remote Sensing Agency
Asian Development Bank
BAIF Development Research Foundation

Citation: Wani, S.P., Dwivedi, R.S., Ramana, K.V., Vadivelu, A., Navalgund, R.R., and Pande, A.B. 2002. Spatial distribution of rainy season fallows in Madhya Pradesh: Potential for increasing productivity and minimizing land degradation. Global Theme 3: Water, Soil, and Agrobiodiversity Management for Ecosystem Health. Report no. 3. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

Abstract

Madhya Pradesh in Central India is endowed with Vertisols and associated soils along with assured rainfall (700–1200 mm yr^{-1}). The Vertisols contain high (40–60%) montmorillintic clay and exhibit typical swelling and shrinking characteristics under moist and dry conditions. Vertisols have poor hydraulic conductivity and consequently, are frequently poorly drained. Traditionally farmers grow a secured postrainy season crop on stored soil moisture and keep the fields fallow during rainy season. The most dense region of rainy season fallowing in semi-arid tropical India covers areas endowed with Vertisols.

Realizing the potential of Vertisols in supporting a short-duration crop during rainy season, which otherwise is left fallow, a pilot study was taken up by ICRISAT to delineate the rainy season (kharif) fallows in Madhya Pradesh. The Indian Remote Sensing Satellite (IRS-IC/-ID/-P3) Wide Field Sensor (WiFS) data acquired during peak kharif, post-kharif, and mid-rabi cropping season was used. The analytical approach employed involves geo-referencing and radiometric normalization of multi-temporal WiFS data, and delineation of kharif fallows in a Silicon Graphic Work Station using ERDAS/IMAGINE software and a per-pixel Gaussian maximum likelihood algorithm and limited field check. While mid-kharif and post-kharif season WiFS data enabled detection of lands that remain fallow during kharif season, mid-rabi season WiFS data allowed further verification of the delineation since such lands have been found supporting mostly wheat crop during rabi season. An estimated area of 2.02 million ha, accounting for 6.57% of the total area of the state is lying fallow. Utilization of kharif fallows for short-duration pulse crops like soybean may help not only to boost agriculture production but also to improve the sustainability of the agro-ecosystem and minimize land degradation.

This publication is part of the research project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" (RETA # 5812) funded by the Asian Development Bank (ADB) to ICRISAT.

Global Theme 3: Water, Soil, and Agrobiodiversity Management for Ecosystem Health

Report no. 3

Spatial Distribution of Rainy Season Fallows in Madhya Pradesh: Potential for Increasing Productivity and Minimizing Land Degradation

S P Wani, R S Dwivedi, K V Ramana, A Vadivelu,
R R Navalgund, and A B Pande

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

National Remote Sensing Agency
Balanagar, Hyderabad 500 037
Andhra Pradesh, India

Asian Development Bank
0401 Metro Manila
0980 Manila, The Philippines

BAIF Development Research Foundation
Arera Colony, Bhopal 462 016
Madhya Pradesh, India

2002

Authors

S P Wani Principal Scientist and Regional Coordinator, Water, Soil and Agrobiodiversity Management for Ecosystem Health (GT 3), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India (email: s.wani@cgiar.org).

R S Dwivedi Head, Sustainable Agriculture Division, National Remote Sensing Agency (NRSA), Department of Space, Government of India, Balanagar, Hyderabad 500 037, Andhra Pradesh, India (email: dwivedi_rs@nrsa.gov.in).

K V Ramana Senior Scientist, NRSA, Department of Space, Government of India, Balanagar, Hyderabad 500 037, Andhra Pradesh, India (email: rvk_nrsa@sify.com).

A Vadivelu Consultant, ICRISAT, Patancheru 502 324, Andhra Pradesh, India (email: vadivelu26@rediffmail.com).

R R Navalgund Director, NRSA, Department of Space, Government of India, Balanagar, Hyderabad 500 037, Andhra Pradesh, India (email: director@nrsa.gov.in).

A B Pande Program Coordinator, BAIF Development Research Foundation, Arera Colony, Bhopal 462 016, Madhya Pradesh, India (email: baifmp@sify.com).

Acknowledgments

This study is a part of the research project "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" supported by the Asian Development Bank (ADB) through RETA # 5812. We acknowledge the help of Mr P Pathak, Dr T J Rego, Mr G D Nageswara Rao of ICRISAT; Sri S Senthil Kumar of NRSA; and Dr Somnath Roy, Mr S Rao, and other staff of BAIF Research Foundation, Bhopal who contributed in discussions and also assisted in data collection for facilitating the work covered in this report. We also thank Dr K Sailaja and Mr Habeeb who helped in processing data. Financial support provided by the ADB through RETA # 5812 is gratefully acknowledged.

Contents

Executive summary

The practice of fallowing the Vertisols in Madhya Pradesh, Central India during the rainy season (kharif) and growing crops on residual soil moisture thereafter (postrainy season or rabi) has been in vogue for several years. After the successful introduction of soybean in the state, which accounts for 87% of the area and 83% production of the crop in the whole country, it was assumed that rainy season fallow has declined. To delineate rainy season fallows in the state, data obtained from the Indian Remote Sensing Satellite were analyzed.

A deductive approach including delineation of agricultural land and forests from temporal satellite data was employed to identify kharif fallow. Three sets of satellite data corresponding to three periods, namely mid-kharif, late kharif, and rabi season were used. While mid-kharif season satellite data provides the information on agricultural lands, which were lying unutilized along with those agricultural lands that have been supporting crops, the satellite data of rabi season, on the other hand, exhibits the spatial distribution pattern of the land supporting rabi crops. These lands include the areas, which were lying fallow during kharif season, and are now supporting crops. In contrast, the satellite data acquired during late kharif season showed the agricultural lands that were lying fallow during kharif season and the areas where kharif crops were planted.

It was estimated that 2.02 million ha accounting for 6.57% of the total area of the state were under fallowing. Madhya Pradesh is endowed with well distributed rains ranging from 700 to 1200 mm. Vertisols with good moisture holding capacity can be used to grow short-duration soybean by adopting sound land management practices. This will help increase income to the farmers besides preventing land degradation due to runoff erosion.

Introduction

Information on land use is becoming increasingly important for overcoming the problems of unsustainable and uncontrolled development, deteriorating environmental quality, loss of prime agricultural lands, destruction of important wetlands, and loss of wild life. Land use data are needed in the analysis of environmental processes for its improvement. To meet the growing demands for food, fuel, and fiber for an ever increasing population, cropping intensity and productivity should be improved in agricultural lands, and additional land lying otherwise unutilized should be brought under cultivation. For better use of land, information on existing land use patterns and changes in land use through time is a prerequisite. Madhya Pradesh in Central India is endowed with Vertisols and associated soils along with assured rainfall (700 to 1200 mm yr^{-1}) and is considered the heartland of dryland agriculture. In the semi-arid tropics (SAT) where rainfall is often extremely erratic and execution of tillage operations can be difficult, yield from rainy season crops can be precariously lower than the potential yield. The threats of mid-season drought, and other weather-induced losses at critical plant growth stages contribute to the risks involved in growing a rainy season crop. Consequently, farmers achieve stable but small harvests by sowing a postrainy season crop on known quantities of residual soil moisture (Michales 1982). Rainy season (kharif) fallowing results in underutilization of land, water, and human resource and when monsoons arrive in the form of sporadic, high intensity showers, a significant portion of the annual rainfall is lost through surface runoff causing soil erosion.

The economic problem confronting farmers in SAT relates to intra- and inter-seasonal land, water, and human resource allocation to maximize farm-household welfare, subject to resource management constraints. As a farming system, monsoon fallowing presumably evolved as a rational strategy for maximizing household welfare over time. In years when weather conditions are favorable for monsoon cropping, farmers forego the chance for above-average incomes. By following the same strategy, however, they are apparently able to avoid catastrophic losses while meeting minimal nutritional requirements.

Krantz and Quackenbush (1970) cited three fundamental barriers to rainy season cropping in black soil regions: (i) difficulty of soil preparation prior to the monsoon for timely sowing of a rainy season crop; (ii) threat of flooding of the rainy season crop due to heavy rains; and (iii) reduction in available soil moisture for the postrainy season crop (due to high transpiration by the rainy season crop) and consequent reduction in yields. Jodha (1979) stated that "given the uncertainty of rainy season cropping in these deep black soils and the extreme difficulty of raising two rainfed crops on these lands with the traditional technology, the farmer perhaps makes a rational choice in leaving the deep black soils fallow in the monsoon". Kampen (1975) explained that high rainfall areas exhibit large tracts of rainy season fallow due to drainage problems, difficulties in cultivation and weed control, and the absence of viable rainy season crop technologies.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has demonstrated the technical and economic feasibility of double cropping on dryland with Vertisols where annual rainfall exceeds 750 mm (ICRISAT 1987). Estimates on the size of the production environment where double cropping is technically feasible range from 5 to 12 million ha (Ryan et al. 1982).

To fully utilize these lands during kharif season, short-duration crops, which mature before sowing of postrainy season (rabi) crops can be cultivated. Timely and reliable information on the extent and spatial distribution of fallow lands during kharif season is a prerequisite for their effective utilization.

Though the area estimates for kharif fallow in Madhya Pradesh are available from the Revenue Department, Government of Madhya Pradesh, the spatial distribution is not available and the available data are not updated appropriately. Furthermore, it takes at least six months after the inventory of land use pattern for the report to be made available to the Government.

The most dense region of rainy season fallowing in SAT of India covers areas endowed with soils of the Vertisol order. The high percentage (40–60%) of motmorillintic clay present in the Vertisols results in significant swelling and shrinking under moist and dry conditions. During the hot, dry post-monsoon seasons the Vertisols become very hard, shrink, and develop wide deep cracks. Under moist conditions during monsoon season, these soils swell and have a sticky, plastic consistency. Under tropical temperature regimes, the Vertisols are generally low in organic matter. Deficiencies in nitrogen and phosphorus but adequate levels of calcium, magnesium, and potassium are present. The Vertisols have poor hydraulic conductivity, and consequently, are frequently poorly drained.

The qualities of the Vertisols in terms of clay content and profile depth are significant in conditioning the practice of rainy season fallow for several reasons:

- The moisture holding capacity (200 mm) of the Vertisols is sufficiently high to make a postrainy season crop feasible. On more shallow or more permeable soils, with lower moisture retention capacity, an unirrigated postrainy season crop is not a feasible alternative; so rainy season cropping is virtually predetermined.
- The consistency and weight of the soil under moist or dry conditions makes tillage and weeding operations extremely difficult. Given the uncertainty in timing and amount of initial monsoon rainfall, conditions may change quickly from extremely dry to extremely wet, disrupting preparatory tillage and sowing operations.
- Rainy season fallowing is itself a technique of soil and water management, and in the low rainfall areas, it may be the most suitable soil water management technology. However, in areas where drainage would appear to be a binding constraint on rainy season cropping, particularly in higher rainfall areas, the potential for more efficient use of the rainfall endowment through improved technologies would appear to be high. Within the broad rainfall zones discussed, the relative urgency of the drainage issue will be further conditioned by the in situ topographical and soil characteristics of the particular watershed. The a priori expectation is that plots occupying a low position in the toposequence and with little slope would have more severe drainage problems than plots with similar soils occupying a higher position in the toposequence with greater slope. Consequently, even in regions where rainfall endowments are relatively low, drainage problems still occur with some frequency in particular locations.

The farmer's decision to sow a rainy season crop or keep the land fallow is based on several factors such as ability to take risk, availability of technologies, and existing biophysical and socioeconomic conditions. Michales (1982) has studied climatic and agronomic determinants for leaving the lands fallow during the rainy season. Based on the results of Vertisol technology evaluation trials at ICRISAT, Patancheru, Andhra Pradesh, India on-farm trials to cultivate Vertisols with double cropping in Begumgunj area of Madhya Pradesh were undertaken.

Background

The micro-watershed in the Milli watershed in Lateri block in Madhya Pradesh is one of the benchmark sites for the Asian Development Bank (ADB) supported project on "Improving Management of Natural Resources for Sustainable Rainfed Agriculture" (RETA # 5812). In partnership with BAIF Research Foundation on-farm evaluation and monitoring the impact of various improved soil, water, and nutrient management options were undertaken since 1998/99 seasons through integrated watershed management. During the initial participatory survey we observed that considerable portion of cultivable land was kept fallow during the rainy season.

In spite of available technology for double cropping in Vertisols since 1982, during baseline survey of ICRISAT's work in Milli watershed, initiated in 1999, large areas of rainy season fallows were observed. To determine the extent of fallows in rainy season in this watershed, a detailed survey was undertaken.

Rainy season fallow in Milli watershed

Objectives of the study

- To investigate the extent of rainy season fallow in the Milli watershed, Lateri block and analyze the possible reasons.
- To identify areas for further research.
- To suggest possible future intervention strategies.

Methodology

Primary data were collected from 47 farm households in six villages of Milli watershed for 2000–01 rainy season and postrainy season.

Hypothesis of the study

1. The dryland is largely under fallow during the rainy season as farmers feel that growing the soybean crop would be a risky proposition as it would delay sowing of the more assured postrainy season crop (wheat, chickpea).
2. Waterlogging is a major constraint, which strengthens the risk-aversive behavior of the poorer dryland farmers whose risk-coping mechanisms are weak; therefore, they prefer to grow the more assured postrainy season crop.

Table 1. Total landholding (ha) of the sampled farmers in Milli watershed.

Description	Area (ha)	Area (%)
Total area	228.1	-
Dryland area	187.5	82.2
Irrigable area	40.6	17.8

Table 2. Average landholding and land cultivated during rainy and postrainy seasons in Milli watershed.

Description	Average dryland (ha)	Average irrigable land (ha)	Total average (ha)
Overall landholding	4.04	0.86	4.90
Land cultivated in rainy season	0.96	0.25	1.21
Land cultivated in postrainy season	3.81	0.46	4.27

Table 3. Land cultivated in rainy season and postrainy season in Milli watershed.

Season	Dryland (ha)	% of the total dryland cultivated	% of the dryland left fallow	Irrigable land (ha)	% of irrigable land cultivated	% of irrigable land left fallow
Rainy	45.75	24.36	75.64	11.25	27.69	72.31
Postrainy	178.87	95.27		21.50	52.92	

Table 4. Correlation between different variables (land size, family size, and livestock) and fallow land.

Description	Land size	Family size	Livestock
Rainy season, dry	0.21	–0.02	0.39
Rainy season, irrigable	0.29	0.13	0.34
Postrainy season, dry	0.91	0.03	0.16
Postrainy season, irrigable	0.87	0.07	0.29

Table 5. Cropping intensity during rainy and postrainy seasons.

Season	Cropping intensity (%)
Rainy season, dry	21
Rainy season, irrigable	29
Postrainy season, dry	91
Postrainy season, irrigable	87

The extent of fallow is given in Tables 1–5.

Reasons for rainy season fallow

In the rainy season, there is not much difference in the extent of fallow in dryland (75.64%) and irrigable land (72.31%). Similarly, there is not much difference in cropping intensity in dryland (23.85%) and in irrigated land (29.23%). There are two hypothetical reasons for this based on the following:

- Since the probability of the occurrence of waterlogging is perceived as high (1999 rainy season had waterlogging problem), risk-averse farmers would tend to fallow the land (both dry and irrigable) to reduce the risks. However, the land on which they cultivate soybean would to a great extent be irrigable land (see evidence for 1999 rainy season in Vadivelu et al. 2001).

- Competitive with the more assured postrainy season crop, growing of soybean would lead to delay in the sowing of the more assured crop. The study by Pandey (1986) reveals that inadequate moisture conditions for a postrainy season crop following the rainy season crop has a high probability (21 of the 29 years).
- The correlation results indicate that normally predicted relationship of higher fallow due to a higher landholding does not exist (Table 4). In the rainy season, the correlation is positive for dryland at 0.21 but not significant; similarly for irrigable land at 0.29 (it is higher in the case of irrigable land, as these lands are kept fallow for the postrainy season crop).
- It is hypothesized that there is an active water market in the postrainy season and the farmer gains more by selling the water to his neighboring farmers (this needs to be further investigated in the study villages).
- Since there is an active land lease-market in the study villages (Vadivelu et al. 2001)[1] the share croppers have to cultivate the landlord's land despite the riskiness of the rainy season crop. Since credit is taken both in kind (wheat) and cash, the necessity for the more-assured wheat crop is even more greater. Hence, the share croppers leave their land fallow during the rainy season.
- It is hypothesized that there is greater fallow land in the dryland areas; however, the data indicates that there is not much difference in fallow land between dryland and the irrigable land.[2] The problem is not availability of irrigation in the rainy season when the average rainfall is normal. The problem is excess rainfall and not deficit. The variation within the crop cycle is a problem and given that the two plots topographically have a lesser chance to be waterlogged, the farmer would prefer the irrigable plot as in the case of a deficit in the rainfall, irrigation remains an option. So the decision on the plot to fallow during rainy season is more determined by the topographical location of the plot and its potentiality for waterlogging and not the irrigability factor.

Reasons for postrainy season fallow

While 95.27% of the dryland is cultivated during postrainy season, only 52.92% of the irrigable lands are cultivated (Table 3). The rationale for this could be that the farmer prefers to cultivate the dryland, which is traditionally kept fallow during the rainy season, and grow a postrainy season crop making use of stored soil moisture along with a supplemental irrigation. The land size-extent of fallow is found positively correlated at 0.91 for dryland and 0.87 for irrigable land (Table 4).

Analysis of the correlation results

The correlation between family size and rainy season dry fallow is negative at –0.02, which means that as family size increases the extent of rainy season dry fallow decreases to a marginal extent. The correlation for rainy season irrigable land shows that as family size increases the extent of fallow increases but is not statistically significant. For postrainy season dryland and irrigable land, as family size increases the fallow also increases but is not statistically significant.

1. See data for Jaoti, Kherkhedi, and Kundhankhedi villages in Lateri watershed; for Vidisha district, 74.8% of the land cultivated is classified as 'leased in'.
2. The data pertains to 2000 rainy season. However, the data for 1999 rainy season reveals that the greater proportion of the land was sown on irrigable land. Further investigation could be done on these plots to answer the following question: Was the plot selected because it is irrigable or it has a lesser potential for waterlogging? See Vadivelu et al. (2001) for details of the farmers in Jaoti, Kherkhedi, and Kundhankhedi villages in Lateri watershed.

The correlation between livestock and the rainy season dryland and irrigable land is positive at 0.39 and 0.34 respectively which means that as livestock population increases the extent of fallow also increases. The same is the case with postrainy season dryland and irrigable fallow which has a weaker correlation at 0.16 and 0.29 respectively; however, none of the above correlations are statistically significant.

Constraints to double cropping and intercropping in Milli watershed area based on the Begumgunj intervention

Dry sowing

Double cropping as envisaged in improved Vertisol technology requires that various variables have to be suitable for optimizing the returns and reducing the risks. During the rainy season, sowing should be done as early as possible. Dry sowing of crops such as sorghum, maize, pigeonpea, mung bean, and black gram should be done before onset of the rainy season. However, for soybean dry seeding is not recommended. For other crops which are grown to a lesser extent in the study area (Begumgunj) farmers perceive it a risky proposition because the seeds could be lost due to lack of rains and re-sowing has to be done. Sowing of the postrainy season crop should also be done as soon as the soybean crop is harvested, but in the current situation in Milli watershed, Lateri block there is a lag due to the longer duration of soybean crop. Therefore, a short-duration crop could be a possible 'best-bet' in tackling the problem. Possibility of minimum tillage for a postrainy season crop could be a better option. The availability of labor is also a problem as during October, it is peak time and wage rates could reach up to Rs 75 to Rs 100 per day.

Riskiness of sequential cropping

Studies reveal that sequential cropping is a difficult and risky proposition (Heinrich and Sangle 1983). In Begumgunj losses of more than Rs 1000 have been reported in 4 of the 17 plots.

Non-acceptance of soybean-pigeonpea intercrop

The problem of non-acceptability of this cropping pattern despite its demonstrated higher benefits have been mentioned earlier. To reiterate the importance of the postrainy season crops, chickpea and wheat (particularly wheat as it meets both subsistence needs and is the commodity of lending by the share croppers), for the farmers, particularly the dryland farmers who traditionally fallow the rainy season land (and to a high extent enter into share cropping contracts), makes the above combination an unviable proposition. This is also the case with the bigger farmers who meet their needs for wheat through the postrainy season crop, although they are economically in a better position to purchase it from the market. Another major constraint is the higher probability for waterlogging which can reduce the yield of both the crops and increase the risks. The risk-aversive farmer therefore finds this combination (although with a potentially higher profit) unacceptable.

Use of satellite images for estimating extent of rainy season fallows

The results of detailed survey on Milli watershed in Lateri block demonstrated that about 70–75% of arable land was kept fallow during the rainy season 2000. Fallowing of good quality lands to such a large extent in areas with dependable rainfall is definitely a cause of worry when the need of the day is to increase farmers' incomes through increasing productivity and also minimizing soil erosion which is the main cause of land degradation in the region. To assess the extent of land fallowed during the rainy season in Madhya Pradesh, a detailed study using remotely sensed satellite data was undertaken.

Spectral response pattern

The spectral response pattern refers to a set of spectral measurements made in different regions of the electromagnetic spectrum, which directly or indirectly leads to the identification of an object or feature. In a terrain, natural vegetation cover in the form of forests, shrubs, crops, grasses, fallow lands, settlements, and water bodies constitute the major land use/land cover features. Low reflectance by leaves in the blue and red regions corresponds to two chlorophyll absorption bands centered at 0.45 and 0.65 µm (Fig. 1). The lack of absorption of incident radiation in the green region allows normal vegetation to appear green. In the near infrared region, there is a high reflectance (around 45%), transmittance of similar magnitude, and absorption of only 5%. The internal structure of leaves contributes to higher reflection observed in the infrared region. At longer wavelengths in the shortwave infrared region, reflectance peaks at 1.6 and 2.2 µm. The total incident solar radiation absorbed in this region is directly proportional to the total leaf water content. The major water absorption regions are centered around 1.45 µm, 1.95 µm, and 2.6 µm (Fig. 1). The response of leaves in this region is generally used as an indicator of moisture stress.

Fallow land/bare soils show an increasing trend with respect to spectral response pattern from 0.5 to 2.5 µm (Fig. 2). However, such a trend is likely to be modified by the moisture content, presence of crop stubble, etc. Contrastingly, water bodies exhibit maximum absorption in the infrared region, and reflect the incident solar radiation in the blue region, which allows their easy detection from other natural features (Fig. 2).

Role of remote sensing and GIS

By virtue of providing synoptic coverage of a fairly large area at regular intervals, spaceborne multispectral measurements have been operationally used for deriving information on current land use/land cover at scale ranging from 1:250,000 to 1:12,500 scale (Landgrebe 1979, Thomas et al. 1980, Raghavaswamy et al. 1992). In addition, such data have also been used for preparing urban land use and sprawl maps (Gaydos and Wray 1978), and wasteland maps (Nagaraja et al. 1992) at operational level. Nation-wide land use/land cover mapping on 1:250,000 scale using Indian Remote Sensing (IRS-1A/1B) Linear Imaging Self-scanning Sensors (LISS-I) data is the testimony of the potential of spaceborne multispectral data for land use/land cover mapping (NRSA 1995). The level of information on land use/land cover that could be derived from different remote sensing datasets along with the scale of mapping and the minimum mappable area are given in Tables 6 and 7,

Table 6. Remote sensing data used in multi-level classification.

Level	System	Image scale
I	Landsat MSS and TM images; AVHRR images	Smaller than 1:250,000
II	High-altitude aerial photographs; TM and SPOT images; AVHRR images (with ancillary data)	1:80,000 to 1:250,000
III	Medium-altitude aerial photographs	1:20,000 to 1:80,000
IV	Low-altitude aerial photographs	Larger than 1:20,000

Source: Modified from Anderson et al. (1976).

Table 7. The level of land use/land cover classification and mapping scale.

Level	Scale	Minimum mappable unit	Area on the ground (ha)
I	1:1 M	3 × 3 mm	900.00
II	1:250,000	3 × 3 mm	56.25
III	1:50,000	3 × 3 mm	2.25

Source: NRSA (1990).

respectively. Additionally, the multi-temporal nature of spaceborne multispectral measurements allows monitoring the changes in land use/land cover, if any, over a period of time. Beginning with the Landsat-Multispectral Scanner System (MSS) data with a 60 × 80 m spatial resolution and four spectral bands spanning from green to near infrared in early 1970s, the Landsat-Thematic Mapper (TM) data with a 30 m spatial resolution and seven spectral bands spanning from blue to thermal infrared region of the electromagnetic spectrum became available with the launch of Landsat-4 in early 1980s, which helped further refining the information on land use/land cover at a larger scale. Further, high spatial resolution data from High Resolution Visible (HRV)-Multispectral Linear Array (MLA) and Panchromatic Linear Array (PLA) sensors with 20 m and 10 m spatial resolution, respectively from Systeme Probatoire d'Observation de la Terre (SPOT) satellite in later half of 1980s supplemented the effort.

The indigenous efforts on design and development of satellites and sensors led, initially, to the launch of the Indian Remote Sensing Satellite, IRS-1A and IRS-1B, carrying Linear Imaging Self-scanning Sensors (LISS-I and II) with the spatial resolution comparable with those of Landsat MSS and TM, respectively in late 1980s and early 1990s. Further developments in the sensor technology had resulted in the launch of the state-of-the-art satellite (IRS-1C) in December 1995 with a unique combination of the following three sensors (Table 8):

- **Wide Field Sensor (WiFS)** with 188 m spatial, two spectral bands, red and near infrared, 810 km swath and a repetivity of 5 days.
- **Linear Imaging Self-scanning Sensor (LISS-III)** with 23.5 m spatial resolution in the green, red and near infrared region, and 70.5 m in the middle infrared region, and 140 km swath.
- **Panchromatic (PAN) camera** with 5.8 m spatial resolution, 70 km swath, and stereo capability.

Table 8. IRS-1C/1D instrumentation characteristics.

Band description	Band width (μm)		
	LISS-III	PAN	WiFS[1]
Band 1	0.45–0.52	0.50-0.75 (Single band)	-
Band 2	0.52–0.59	-	
Band 3	0.62–0.68	-	0.62–0.68
Band 4	0.77–0.86	-	0.77–0.86
Band 5	1.55–1.75	-	
Ground IFOV (m)	23.5 m for bands 1 to 4; 69.5 m for band 5	5.8 m	188 m
Data rate (Mbps)	35.794 (VNIR)[2] 1.3906 (SWIR)[3]	84.903	2.0616
Quantization level	128	64	128

1. IRS-P3 WiFS characteristics are same as above.
2. VNIR = Visible and near infrared bands.
3. SWIR = Shortwave infrared band.

Source: Joseph et al. (1996).

While WiFS with 5-day repetivity and large swath provides the capability of regional level assessment and monitoring of crop condition, etc., LISS-III multispectral sensor with 140 km swath provides detailed level crop area estimation and crop condition assessment. The IRS-1C WiFS data have been used for regional-level inventory of land use/land cover (Rao et al. 1996). PAN data with 5.8 m spatial resolution and stereo capability enables appreciation of terrain's relief. Merging LISS-III data with PAN offers additional advantage of exploiting both spectral information from LISS-III and high spatial resolution from PAN for deriving information on land use/land cover. The uniqueness of these sensors is due to the fact that all the sensors with regional and local level coverage are mounted on the same platform, and collect data under similar illumination conditions avoiding thereby the need for radiometric normalization. The IRS-1D with similar payload as IRS-1C was launched in March 1997 as a backup of the latter.

Further, the development of launch vehicles, especially Polar Satellite Launch Vehicle (PSLV) has enabled India to launch three experimental satellites, namely IRS-1E in September 1993, IRS-P2 in October 1994, and IRS-P3 in March 1996. The IRS-P3 has two payloads namely WiFS, similar to the one aboard IRS-1C/1D, and Modular Electro-optical Scanner (MOS) with 13 channels spanning from blue to middle infrared region of the electromagnetic spectrum.

Geographic information system (GIS) offers the capability of integrating spatial and attribute data and subsequent generation of derivative information. The GIS has been used in various applications, namely database development and changes in the aquatic environment (Remillard and Welch 1993), modeling of non-point source pollution (Welch et al. 1993), database design for a multi-scale spatial information system (Jones et al. 1996), assessment of surface and zonal models of population (Martin 1996), military housing management (Forgionne et al. 1996), multiple criteria group decision making (Malczewski 1996), etc. Further, remote sensing and GIS have been used conjunctively in several studies for addressing issues related to developmental planning (Smith and Blackwell 1980, Hellden et al. 1982, Welch et al. 1993). The GIS permits the integration of agroclimatic data, and information on soils with the kharif fallow, which in turn helps identifying parcels of land wherein specific oilseed crops suitable to local conditions could be raised. While generating the information on rice fallows from spaceborne multispectral measurements, Subba Rao et al. (2001) used GIS to create the overlay of pedo-climatic variables along with these fallow lands, which was used to derive national-level spatial and temporal variations in soil water availability parameters.

Study area

Covering a geographical area of 30.8 million km^2, Madhya Pradesh is situated on Deccan trap, and bound by geo-coordinates 21°05' to 26°52' N and 74° 02' to 82°49' E, bordered by Uttar Pradesh and Rajasthan in the North, Chhatisgarh in the East, Maharastra in the South, and Gujarat in the West. The state forms part of peninsular India (Fig. 3). Physiographically, the state could be divided into the following four regions: (i) *Gird Region:* covers areas North and Northeast of Gwalior; (ii) *Malwa Plateau:* includes the region between the Vindhyan ranges and the point just south of Gwalior; (iii) *Satpura Ridge:* stretches across the state from Maikala range in the east towards Nimar in the west; and (iv) *Narmada Valley:* lies between Satpura range on the south and Vindhyans on the north (Raychaudhary and Govindarajan 1971). Due to heterogeneity in the parent material and physiography, there is a large variation in soils of the state. The major soils, encountered include black soils, mixed red and black soils, red and yellow soils, skeletal soils, and alluvial soils. Forest cover an estimated 31% of geographical area which varies from semi-xerophytic type in Gird Region and Malwa plateau to deciduous types in Vindhyans, Satpura, and other hill ranges (Table 9). The kharif fallow area ranged from 5.2 to 5.6 million ha between 1971–72 and 1977–78 (% of net area sown ranged from 28 to 31%). In 1962–63, 5.0 million ha were fallowed during kharif, representing 31% of the net area sown. The climate of this area, in general, is temperate in Malwa region with 800 to

Table 9. Land use statistics of Madhya Pradesh during 1999–2000.

Particulars	Area ('00,000 ha)
Geographical area	307.50
Forest	86.13
Not available for cultivation	32.00
Land put to non-agricultural uses	18.35
Barren and uncultivable land	13.65
Other uncultivable land excluding fallow land	16.73
Permanent pastures and grazing land	16.58
Land under miscellaneous tree crops and groves	0.15
Cultivable wasteland	11.70
Fallow land	10.24
Current fallow	4.86
Old fallow	5.38
Cropped area	204.19
Net area sown	150.70
Area sown more than once	53.49
Cropping intensity (%)	135

Source: www.mp.nic.in/agriculture/land_use.htm

1200 mm annual rainfall, and dry in Gird Region with about 700 mm rainfall. The maximum temperature ranges between 37.5°C and 43°C, and the minimum temperature between 26.5°C and 37.5°C during summer (April–May). During winter, the maximum temperature ranges between 21°C and 31°C, and the minimum temperature ranges between 7.2°C and 12.8°C.

Database

The state of Madhya Pradesh is covered by two WiFS images. Owing to the presence of persistence cloud cover during kharif season, the availability of cloud-free spaceborne multispectral data has been the major problem. However, very short repetivity and tandem operation of the IRS-1C and IRS-1D satellites, along with the IRS-P3 satellite, enabled acquiring virtually cloud-free WiFS data of September from IRS-1D and IRS-P3 satellites (Table 10). Furthermore, the situation remains more or less same even during post-monsoon period too. Consequently, cloud-free WiFS data were not available and out of two images covering the former state of Madhya Pradesh, one image for October was to be used. Satellite data acquired during peak growing period of rabi crops, help identification of lands where rabi crops have been taken. The digital multispectral data from WiFS aboard IRS-1D/-P3 over the area acquired during the kharif season of 1999–2000 and rabi season of 2000–01 was utilized for deriving information on kharif fallow lands (Table 10). In addition, Survey of India topographic maps at 1:250,000 scale were also used.

Table 10. The details of remote sensing data used.

Satellite/Sensor	Path/row nos.	Date of acquisition
IRS-1C WiFS	97-56	1-2-2000
	103-58	2-3-2000
IRS-1D WiFS	98-55	28-9-2001
	104-57	19-9-2001
IRS-P3 WiFS	98-55	6-10-2000
	104-57	12-10-2000

Approach

The approach essentially involves preparation of the mosaic of WiFS digital data covering entire state, preliminary digital analysis, ground truth collection, map finalization, and generation of area statistics (Fig. 4).

Preliminary digital analysis

Basically, a deductive approach was employed for delineation of fallow lands. Based on past experience, initially areas akin to fallow lands were identified after displaying the digital multispectral data onto color monitor of Silicon Graphics work station. Besides, topographic maps were used for exclusion of the areas with rock outcrops, scrubs, hills, etc. Furthermore, other categories like forestland, cropland, wasteland, water, and settlements were also broadly delineated. Doubtful areas were located in the topographic maps of 1:250,000 scale for further verification in the field.

Ground truth collection

Field visits were made to establish the relationship between image elements, namely color, texture, shape, size, shadow or pattern, association, etc. of WiFS data, and fallow lands and other land use and land cover categories. Initially, a reconnaissance traverse of the area was made to assess the "trafficability" of the terrain and to locate the sample points precisely. Subsequently, the points where observations were to be made were marked precisely on the topographic maps and the observations with respect to current land use/land cover, and cultivation practice followed in the past were made.

Final digital analysis

After displaying the digital WiFS data onto color monitor of the Silicon Graphics work station, the areas where field observations were made were identified. The spectral response patterns of fallow lands and other land use/land cover categories were generated. In addition, class separability analysis was also carried out by computing the transformed divergence (TD) values. Furthermore, the forest mask portraying the areas with forest cover was also used to delimit the area for digital analysis, which helped exclusion of forestland. The exercise has enabled avoiding the mixing of spectral response pattern of forestland with that of cropland. The WiFS data covering entire state were classified using per-pixel Gaussian maximum likelihood classifier and a color-coded digital output depicting the spatial distribution pattern of fallow lands along with other associated land use/land cover categories, was generated on an ink jet printer model Tectronics Phaser 560.

Results

The results of the study have been reported in three sections. The first section deals with the concept of land use/land cover and definition of various land use/land cover categories, the second with the delineation of fallow lands and other land use/land cover categories from satellite data, and the third with the spatial extent and distribution of fallow lands.

Land use/land cover

Land use can be defined as the use of land by humans, usually with the emphasis on the functional role of land in economic activities. In contrast, land cover in its narrowest sense, often designates only the vegetation, either natural or man-made, on the earth's surface. In a much broader sense, land cover designates the visible evidence of land use to include both vegetative and non-vegetative features; dense forest, plowed land, urban structures, and paved parking lots constitute land cover. Digital analysis of IRS-1C/-1D and IRS-P3 WiFS data has permitted the delineation of five major land use/land cover categories, namely cropland, fallow land, forestland, wasteland, water, and urban or built-up land. For generating information on land use/land cover of the area, the classification system (Table 11) proposed by Anderson et al. (1976) was followed. The definition of land use/land cover categories are given below:

Fallow land refers to agricultural land which is used for cultivation but is temporarily allowed to rest, un-cropped for one or more seasons, but less than a year (NRSA 1990).

Table 11. Land use and land cover classification system.

Level 1	Level II	Level III
100 Urban built-up	110 Residential	111 Single unit, low density (less than 2 DUPA)[1]
		112 Single unit, medium density (2 to 6 DUPA)
		113 Single unit, high density (greater than 6 DUPA)
		114 Mobile homes
		115 Multiple dwelling, low rise (2 stories or less)
		116 Multiple dwelling, high rise (3 stories or more)
		117 Mixed residential
	120 Commercial and services	121 Retail sales and services
		122 Wholesale and services (including trucking and warehousing)
		123 Offices and professional services
		124 Hotels and motels
		125 Cultural and entertainment
		126 Mixed commercial and services
	130 Industrial	131 Light industrial
		132 Heavy industrial
		133 Extractive
		134 Industrial, under construction
	140 Transportation	141 Airports, including runways, parking areas, hangars, and terminals
		142 Railroads, including yards and terminals
		143 Bus and truck terminals
		144 Major roads and highways
		145 Port facilities
		146 Auto parking facilities (where not directly related to another land use)
	150 Communications and utilities	151 Energy facilities (electrical and gas)
		152 Water supply plants (including pumping stations)
		153 Sewage-treatment facilities
		154 Solid waste disposal sites
	160 Institutional	161 Educational facilities, including colleges, universities, high schools, and elementary schools
		162 Religious facilities, excluding schools
		163 Medical and health care facilities
		164 Correctional facilities
		165 Military facilities
		166 Governmental, administrative, and service facilities
		167 Cemeteries
	170 Recreational	171 Golf courses
		172 Parks and zoos
		173 Marinas
		174 Stadiums, fair grounds, and race tracks
	180 Mixed	
	190 Open land and other lands	191 Undeveloped land within urban areas
		192 Land being developed; intended use not known

continued

Table 11. *continued.*

Level 1	Level II	Level III
200 Agriculture	210 Cropland and pasture	211 Row crops
		212 Field crops
		213 Pasture
	220 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas	221 Citrus orchards
		222 Non-citrus orchards
		223 Nurseries
		224 Ornamental horticultural
		225 Vineyards
	230 Confined feeding operations	231 Cattle
		232 Poultry
		233 Hogs
	240 Other agriculture	241 Inactive agricultural land
		242 Other
300 Rangeland	310 Grassland	
	320 Shrub and brushland	321 Sagebrush prairies
		322 Coastal scrub
		323 Chaparral
		324 Second growth brushland
	330 Mixed rangeland	
400 Forestland	410 Evergreen forest	411 Pine
		412 Redwood
	420 Deciduous forest	421 Oak
		422 Other
		423 Other hardwood
	430 Mixed forest	
	440 Clear cut areas	
	450 Burned areas	
500 Water	510 Streams and canals	
	520 Lakes and ponds	
	530 Reservoirs	
	540 Bays and estuaries	
	550 Open marine waters	
600 Wetlands	610 Vegetated wetlands, forested	611 Evergreen
		612 Deciduous
		613 Mangrove
	620 Vegetated wetlands, non-forested	621 Herbaceous vegetation
		622 Freshwater marsh
		623 Saltwater marsh
	630 Non-vegetated wetlands	631 Tidal flats
		632 Other non-vegetated wetlands
700 Barren land	710 Dry lake beds	
	720 Beaches	
	730 Sand and gravel other than beaches	
	740 Exposed rocks	
800 Tundra		
900 Perennial snow or ice	910 Perennial snow fields	
	920 Glaciers	

1. DUPA = Dwelling units per acre.

Source: Modified from Anderson et al. (1976) and from Florida Bureau of Comprehensive Planning (1976).

Cropland is agricultural land, and includes the lands with standing crops. The crop may be either kharif or rabi or both, and/or *zaid* (summer crop).

Forests have a tree-crown areal density (crown closure percentage) of 10% or more, and are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate and water regime (Anderson et al. 1976)

Wasteland is defined as that land which is degraded and is presently lying unutilized except as current fallow due to different constraints (NWDB 1986).

Urban or built-up land is comprised of areas of intensive use with much of the land covered with structures.

Water includes all areas within the landmass that persistently are covered with water.

Delineation of fallow lands

As pointed out earlier, a deductive approach including delineation of agricultural land and forests from temporal satellite data was employed to identify kharif fallow. Three sets of satellite data corresponding to three periods, namely mid-kharif, late kharif, and rabi season were used. While mid-kharif season satellite data provides the information on agricultural lands, which were lying unutilized along with those agricultural lands that have been supporting crops, the satellite data of rabi season, on the other hand, exhibits the spatial distribution pattern of the land supporting rabi crops. These lands include the areas which were lying fallow during kharif season, and are now supporting crops. Contrastingly, the satellite data acquired during late kharif season show the agricultural lands that were lying fallow during kharif season and the areas where kharif crops were planted.

The mean digital number (DN) values of wastelands are maximum in the red as well as near infrared bands of WiFS data for all the three periods (Table 12). Contrastingly, water shows the lowest DN values in these bands. Owing to near-total absorption of near infrared energy, the DN value of water in this region has been observed to be only 2 during mid-kharif season while the values are higher in the late kharif and rabi seasons probably due to the presence of suspended sediments therein. The reflected energy from the kharif fallow land is lower than croplands and wastelands.

In forestland and cropland, due to higher reflectance of near infrared energy by leaf chlorophyll and absorption in the red region, the reflected energy in terms of DN values is higher in near infrared region as compared to red region. The spectral response pattern of the urban land is similar to that of kharif fallow. To objectively assess the separability of kharif fallow with other land use/land cover

Table 12. Mean DN values of various land use/land cover categories in the WiFS bands.

	Mid-kharif		Late kharif		Rabi	
Land use	Red	Near infrared	Red	Near infrared	Red	Near infrared
Water	45	2	35	22	42	30
Cropland	85	125	82	130	85	140
Forest	55	135	55	130	75	95
Kharif fallow	71	76	72	87	65	95
Wasteland	150	111	135	137	132	130
Urban	82	65	82	95	80	78

Table 13. Transformed divergence (TD) values of various land use/land cover categories.

Category	No.	1	2	3	4	5	6
Urban land	1	0	1998	2000	2000	2000	2000
Kharif fallow	2	1998	0	2000	2000	2000	2000
Forestland	3	2000	2000	0	2000	2000	2000
Cropland	4	2000	2000	2000	0	2000	2000
Wasteland	5	2000	2000	2000	2000	0	2000
Water	6	2000	2000	2000	2000	2000	0

categories, as mentioned earlier, TD values were generated. A close look at Table 13 indicates that except for urban land and kharif fallow pair, the TD values for other land use/land cover categories are maximum (2000) indicating thereby an excellent spectral separability. Though the TD value for urban land and kharif fallow is less than 2000, it is much above the threshold value of 1700, which means these two categories are also spectrally separable.

Apart from kharif fallow, as indicated earlier, cropland, forestland, urban or built-up land, wastelands, and water have been delineated. Forestland includes dense forest (more than 40% crown density), open forest (20–40% crown density), and scrubs (less than 20% crown density).

Sample images of different periods show the situation during mid-kharif, late kharif, and peak rabi cropping seasons (Fig. 5). The blue color in mid-kharif image indicates kharif fallow while red color indicates vegetation/crops (Fig. 5). The WiFS image acquired during peak kharif and rabi seasons enable identification of agricultural lands.

Spatial extent and distribution

The WiFS images corresponding to mid-kharif, late kharif, and rabi seasons are shown in Figures 6, 7, and 8 respectively. The land use/land cover map is shown in Figure 9 and the map showing only fallow lands is depicted in Figure 10. Fallow lands can be seen as cyan color in the mid-kharif and late kharif images. During mid-rabi season, these lands are seen supporting healthy rabi crops. Cyan color in the late kharif season represents kharif fallow as well as harvested kharif crops. It is amply clear from the map in Figure 9 that the forestland is confined mostly to hilly terrain, cropland/fallow land to valleys and plains, and wastelands are encountered in the undulating plains and pediments.

Agriculture being mainstay of the people, an estimated 13.2 million ha land are under cropland (Table 14), whereas dense forests cover an estimated 2.9 million ha. The area under open forests has been estimated as 5.0 million ha. Fallow lands cover an estimated area of 1.83 million ha. Water bodies and settlements are two other important land use/land cover categories which cover an estimated 0.1 and 0.2 million ha, respectively. For a fairly large area (0.1 million ha), information on land use/land cover could not be derived owing to presence of cloud cover in satellite image.

Table 14. Spatial extent of various land use/land cover categories in Madhya Padesh.

Category	Area ('00,000 ha)
Cropland	131.61
Fallow	18.29
Wastelands	50.20
Open forest	46.43
Dense forest	29.20
Waterbody	0.98
Settlements	0.16
Cloud cover	0.98
Scrubs	4.42
Others	20.35

The district-wise spatial distribution of fallow land (kharif fallow) is shown in Figure 10 and spatial extent is given in Table 15. Fallow lands are more concentrated (240,739 ha) in Vidisha district followed by Sagar (280,649 ha) and Guna (184,100 ha) districts. Balaghat district accounts for the minimum area under fallow lands (Table 15). This data is supplemented by the spatial distribution pattern of fallow lands in these districts (Fig. 10).

Table 15. Spatial extent of rainy season fallow lands in Madhya Padesh.

District	Area (ha)
Balaghat	272
Betul	46424
Bhind	8705
Bhopal	25589
Chhatarpur	79736
Chhindwara	32548
Damoh	99886
Datia	11024
Dewas	28855
Dhar	64768
East Nimar	31583
Guna	184100
Gwalior	18976
Hoshaangabad	13615
Indore	30399
Jabalpur	80556
Jhabua	11395
Mandla	5061
Mandsaur	10373
Morena	2085
Narsimhapur	56971
Panna	67786
Raisen	182845
Rajgarh	11960
Ratlam	2898
Rewa	78269
Sagar	240739
Satna	118385
Sehore	42148
Seoni	46131
Shahdol	18110
Shajapur	2902
Shivpuri	20871
Sidhi	18930
Tikamgarh	11653
Ujjain	1679
Vidisha	280649
West Nimar	2813

Optimal utilization of rainy season fallows

To utilize rainy season fallow lands and prevent them from further degradation, extensive field experiments have been carried out by several Indian Council of Agricultural Research (ICAR) institutions, agricultural universities, and ICRISAT. A few interventions developed by ICRISAT are discussed.

Sustaining productivity of Vertisols: ICRISAT's long-term study analysis

ICRISAT long-term operational scale experiments validated the hypothesis that improved systems increased crop growth, crop production, and the carrying capacity of the land, and soil quality and carbon sequestration (Wani 2000, Wani et al. 2000). The components of the improved watershed management technology are:

- Dry season tillage.
- Land and water management through grassed waterways and storage of runoff water in the farm ponds and tanks.
- Land configuration: broad-bed and furrow (BBF) on grade.
- Dry sowing ahead of the rainy season.
- Improved cropping systems.
- Use of high-yielding and stress-tolerant crop varieties.

- Improved fertility management.
- Improved pest management.

Sustainable increased productivity

Crop yields were improved by following intercropping or sequential double cropping and these are sustained by better land and water management practices. In an improved system in which sorghum was intercropped with medium-duration pigeonpea, the average yield of sorghum and pigeonpea together was 4.7 t ha^{-1} and in the traditional system with rainy season fallow followed by postrainy season sorghum, the average yield of sole sorghum was only 0.9 t ha^{-1}.

Increased yields in improved system are mainly due to increased rainfall use efficiency; 67% of the rainfall is used by the crops, only 14% is lost as runoff, and 19% is lost as evaporation and deep percolation. Under the traditional system, only 30% of the rainfall is used by crops, 25% is lost as runoff, and 45% as soil evaporation and deep percolation. The soil loss in the improved system is only 1.5 t ha^{-1} compared to 6.4 t ha^{-1} in the traditional system (Table 16) (Wani et al. 2001).

Table 16. Water balance and soil loss (t ha^{-1}) for traditional and improved technologies in Vertisol watersheds, ICRISAT Center, Patancheru, India.

		Water-balance component[1]			
Farming system technology	Annual rainfall (mm)	Water used by crops (mm)	Water lost as surface runoff (mm)	Water lost as bare-soil evaporation and deep percolation (mm)	Soil loss (t ha^{-1})
Improved system[2] (double cropping on broad-bed and furrow)	904	602 (67)	130 (14)	172 (19)	1.5
Traditional system[3] (single crop in postrainy season, and cultivation on flat land)	904	271 (30)	227 (25)	406 (45)	6.4

1. Values in parentheses are amounts of water used or lost expressed as percentage of total rainfall.
2. Improved system received 60:20 kg N and P ha^{-1}.
3. Traditional system received 10 t ha^{-1} farmyard manure once in every two years; during the rainy season the land was kept as cultivated fallow (cultivated in rainy season to keep weed-free).

Source: Wani et al. (2001).

Soybean-chickpea sequential and intercropping system

The total productivity of the soybean-chickpea sequential system in Vertic Inseptisols ranged from 2.5 to 2.8 t ha^{-1} and that of soybean/pigeopea intercropping system from 2.5 to 2.8 t ha^{-1}. These yields are higher than the current soybean yields (<1.0 t ha^{-1}).

Using weather records from 1975 to 1996 for ICRISAT Center in Patancheru, long-term simulations of water balance and productivity of soybean-chickpea rotation were performed for

4 treatments using crop simulation model DSSATv3 (Singh et al. 2001). The long-term simulation studies showed that total productivity of soybean-chickpea crop rotation system in 70% of the years exceeded 3000 kg ha^{-1} (range 3000–4150 kg ha^{-1}) for the shallow soil and 3450 kg ha^{-1} (range 3450–4700 kg ha^{-1}) for the medium deep soil. This multi-year simulation results showed that greater runoff and drainage on Vertic Inceptisols in assured rainfall environments, provide opportunity for water harvesting in surface ponds as well as for recovering deep drainage water. The analysis shows that crop yields can be substantially improved by increasing rainfall-use efficiency through appropriate land and water management practices in a watershed framework.

Begumgunj intervention

For three years starting from 1982/83, ICRISAT and the Madhya Pradesh Department of Agriculture jointly evaluated and field-level tested dryland double cropping in Begumgunj, 120 km east of Bhopal on the Bhopal-Sagar Road. The village soils are Vertisols and the average rainfall is about 1300 mm. But these abundant soil and rainfall resources were not effectively utilized and almost all the dry cropland was rainy season fallowed prior to 1982.

Vertisol technology

The new technology based on water management in a small watershed (drainage, infiltration, and conservation), improved varieties, soil fertility improvement, pest control, and other practices was evaluated. The verification trials were undertaken in a small watershed to enable farmers to improve the management of soil, water, and crop (Ryan et al. 1982). Broad-beds and furrows were developed across the slope (0.4 to 0.8% gradient) to improve the in situ drainage and moisture conservation so that the farmer could grow two crops under sequential cropping or add three months to the growing season with intercropping.

The results from the 1982–83 trials showed that the average profitability of the improved technology was lower in the Begumgunj watershed than in other field trial sites in India. This relative poor performance was partly attributed to the drought between June 19 and July 9, the first time in 30 years that it did not rain during this period. However, the improved cropping system of soybean/pigeonpea intercrop performed well with profits exceeding Rs 3300 ha^{-1} while the farmer's benchmark or traditional practices had a profit of only Rs 800 ha^{-1}. Significantly, farmers trying to grow in sequence with chickpea and/or wheat as second crop without irrigation found it difficult, if not impossible, to establish those crops (Heinrich and Sangle 1983).

Results from the 1983/84 studies showed considerably improved profits over those of 1982/83 despite problems of frost and wilt in the pigeonpea crop. Unlike in 1982/83, rainfall was copious in 1983/84 and its distribution was exceedingly favorable for sequential cropping (Sangle and Sharma 1985). Sequential cropping systems generated profits of Rs 2500 ha^{-1} in the watershed and in the neighboring farmer's fields. The improved technology continued to perform well in 1984/85.

The economic attractiveness of the improved technology was largely derived from the high profitability of the soybean/pigeonpea intercrop in the three cropping years and to a lesser extent by the sequential cropping systems in 1983/84. Watershed farmers attempted sequential cropping in 1982/83 and 1984/85 which were unfavorable to sequential crops. Neighboring farmers only sequentially cropped in the 1983/84 season, characterized by late rains, which were conducive to the establishment of the postrainy season crop (Foster et al. 1987).

The improved soybean/pigeonpea intercrop and sequential cropping system also intensively utilized both men and women labor compared to the farmer's traditional practice of fallowing in the rainy season and planting wheat or chickpea on residual moisture in the postrainy season. The labor use doubled and sequential cropping appeared to be even more intensive than the soybean/pigeonpea intercrop.

The analysis revealed that:

- Traditional rainy season fallow-postrainy season cropping system gives a low return. Low risk activity as profits from 50 of the 63 fields range from Rs 1 to Rs 1000 per ha^{-1}.
- The improved soybean/pigeonpea intercrop also involved little risk as losses were not incurred in any of the 65 sample fields.
- Returns were much more dispersed with sequential cropping and rainy season sole crop-postrainy season fallow alternatives. Sequential cropping was particularly risky as losses of more than Rs 1000 were incurred on 4 of the 17 sample plots.

It is argued by Foster et al. (1987) that "farmers' unwillingness to take risk could certainly be a source of friction to the adoption of sequential cropping system, but risk aversion could not impede the diffusion of the low risk, highly profitable soybean/pigeonpea inter-crop". The initial acceptance of the suggested practice and the decline in interest is examined later.

Seventy-two per cent of the watershed farmers and more than half the traditional farmers cultivated soybean on dryland with soybean in the rainy season. The crop combination soybean-pigeonpea recommended as most profitable during the field trials was grown by four (all watershed) farmers. Adding another five watershed farmers who sequential cropped after soybeans, half the farmers tried double cropping compared to one of the 'traditional' farmers (Table 17).

An important recommendation of the study is that the problem should be addressed by focusing on increasing the yield of postrainy season crops so that farmers would be willing to allocate less land to assured subsistence crops, thereby releasing more land for profitable double cropping.[3]

Future research interventions

In Madhya Pradesh early sowing of soybean could increase the yields by 3-fold as observed from the crop simulation studies using SOYGRO model and historical weather data sets (Singh et al. 2001). In 7 out of 10 years farmers can undertake early sowing; however, farmers continue to sow soybean in mid-July. Some future research interventions are suggested below:

- There is an urgent need to develop capability for localized prediction of onset of rainy season along with the demonstration of benefits of early sowing to farmers.
- Farmers perceived that waterlogging could damage their crops severely and there is a genuine concern on deep black cotton soils (Vertisols) and the associated problems of low-infiltration rates. In such a case appropriate landform treatments to alleviate waterlogging, need to be employed and their effectiveness demonstrated.

3. For a survey conducted in 1997 in Begumgunj, see Wani et al. (1997).

Table 17. Utilization of cropland by farmers in Begumgunj, Madhya Pradesh, 1984/85 and 1986/87 (expressed as percentage of farmers).

Type of use	Watershed farmers in 1984/85[1]	Watershed farmers in 1986/87[2]	Traditional farmers in 1986/87[2]
Dryland[3]			
Rainy season cropping	100	72	57
Rainy season cropping with pigeonpea	73	22	0
Sequential cropping	10	28	14
Total double cropping	83	50	14
Rainy season single cropping	27	22	43
Postrainy season single cropping	38	89	86
Irrigable land[4]			
No. of farmers	10	9	4
Rainy season only cropping	0	0	0
Postrainy season only cropping	44	0	0
Double cropped pigeonpea	11	0	0
Other double cropping	89	100	100

1. Watershed land only.
2. All operated land.
3. Number of dryland farmers: 45 watershed in 1984/85; 18 watershed in 1986/87; and 7 traditional in 1986/87.
4. Number of farmers with irrigable land: 10 watershed in 1984/85; 9 watershed in 1986/87; and 4 traditional in 1986/87.

Source: Foster et al. (1987).

- Use of short-duration crops/varieties need to be demonstrated and evaluated. Techno-economic feasibility of using appropriate crop management options need to be evaluated and demonstrated to the farmers. Along with short-duration crops/varieties appropriate sequential cropping ensuring the farmers' choice for wheat and chickpea also need to be developed.
- Technological options such as minimum tillage for these self-mulching soils due to their swelling and shrinking nature resulting in deep cracking also need to be developed and evaluated particularly for postrainy season crop. Such options would cut down the land preparation time by 2 weeks at least after harvest of the rainy season crop and also could make use of residual soil moisture to establish a good postrainy season crop.

References

Anderson, J.R., Hardy, E.E., Roach, J.T., and **Witmer, R.E.** 1976. A landuse and land cover classification for use with remote sensor data. US Geological Survey Professional Paper 964. Washington, DC, USA: Government Printing Office. 28 pp.

Florida Bureau of Comprehensive Planning. 1976. The Florida land use and cover classification system. Report DSP-BCP-17-76. Tallahassee, FL, USA: Florida Bureau of Comprehensive Planning.

Forgionne, G.A., Lane, R.F., and **Armstrong, T.C.** 1996. A geographic information system to facilitate military housing management. International Journal of Geographic Information Systems 10(8):991–1007.

Foster, J.H., Kshirsagar, K.G., Bhende, M.J., Bhaskar Rao, V., and **Walker, T.S.** 1987. Early adoption of improved Vertisol technology options and double cropping in Begumgunj, Madhya Pradesh. Progress Report no. 77, Economic Group, Resource Management Program. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 78 pp.

Gaydos, L., and **Wray, J.R.** 1978. Land cover map from Landsat 1973, with place names (Map 1-858E) and with census tract (Map 1-858F), 1978. Reston, VA, USA: US Geological Survey.

Heinrich, G.M., and **Sangle, R.D.** 1983. Report of work for the Vertisol technology test site in Begumgunj, Raisen district, Madhya Pradesh (1982/83). Patancheru, Andhra Pradesh 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Hellden, U., Olsson, L., and **Stern, M.** 1982. Approaches to desertification monitoring in Sudan. Pages 131–144 *in* Satellite Remote Sensing in Developing Countries (Lery, Longman G., ed.). Paris, France: European Space Agency.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Farming systems research at ICRISAT. Pages 23–28 *in* International agricultural research centers: proceedings of the Workshop on Farming Systems Research, 17–21 February 1986, ICRISAT Center, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Jodha, N.S. 1979. Some dimensions of traditional farming systems in semi-arid tropical India. Presented at the Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, 19–23 February 1979, ICRISAT Center, Patancheru, India.

Jones, C.B., Kidner, D.B., Luo, L.Q., Bundi, G.L., and **Ware, J.M.** 1996. Data base design for a multi-scale spatial information system. International Journal of Geographic Information Systems 10(8):901–920.

Joseph, G., Iyengar, V.S., Rattan, R., Nagchenchaiah, K., Kiran Kumar, A.S.S., Aradhye, B.V., Gupta, K.K., and **Samudraiah, D.R.M.** 1996. Cameras for Indian Remote Sensing Satellite IRS-1C. Current Science 70(7):510–515.

Kampen, J. 1975. Soil and water conservation and management in farming systems research for the semi-arid tropics. Pages 3–43 *in* International Workshop on Farming Systems, 18–21 Nov 1974, ICRISAT, Hyderabad, India (Krantz, B.A., and Kampen, J., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Krantz, B.A., and **Quackenbush, T.H.** 1970. A proposal for increasing crop production through improved water management and utilization in rainfed agriculture. Unpublished discussion paper. New Delhi, India: The Ford Foundation.

Landgrebe, D. 1979. Monitoring the earth's resources from space - Can you really identify crops by satellites? Presented at the National Computer Conference, New York, USA, 7 Jun 1979.

Malczewski, J. 1996. A GIS-based approach to multiple criteria group decision-making. International Journal of Geographic Information Systems 10(8):955–971.

Martin, D. 1996. An assessment of surface and zonal models of population. International Journal of Geographic Information Systems 10(8):973–990.

Michales, G. 1982. The determinants of rainy season fallowing on the Vertisols in semi-arid tropics of India. PhD dissertation, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota, USA. 191 pp.

Nagaraja, R., Gautam, N.C., Rao, D.P., and **Raghavaswamy, V.** 1992. Application of Indian Remote Sensing Satellite (IRS) data for wasteland mapping. Pages 170–174 *in* Natural resources management: A new perspective (Karale, R.L., ed.). Bangalore, India: National Natural Resources Management System (NNRMS), Department of Space, Government of India.

NRSA (National Remote Sensing Agency). 1990. Description and classification of land use/land cover. Hyderabad, India: NRSA, Department of Space, Government of India. 81 pp.

NRSA (National Remote Sensing Agency). 1995. Technical report on area statistics of land use/ land cover generated using remote sensing techniques. Hyderabad, India: NRSA, Department of Space, Government of India.

NWDB (National Wasteland Development Board). 1986. Wastelands: Definition and classification. Technical Task Group Report, New Delhi, India: Ministry of Environment and Forestry, Government of India.

Pandey, S. 1986. Economics of water harvesting and supplementary irrigation in the semi-arid tropics of India: A systems approach. Armidale, Australia: University of New England. 312 pp.

Raghavaswamy, V., Gautam, N.C., Rao, D.P., and **Nagaraja, R.** 1992. Land use/land cover mapping and monitoring urban sprawl using IRS data - A few examples. Pages 120–127 *in* Natural resources management: A new perspective (Karale, R.L., ed.). Bangalore, India: National Natural Resources Management System (NNRMS), Department of Space, Government of India.

Remillard, M.M., and **Welch, R.A.** 1993. GIS technologies for aquatic macrophyle studies: Modeling applications. Landscape Ecology 8(3):163–175.

Rao, D.P., Gautam N.C., Nagaraja, R., and **Ram Mohan, P.** 1996. IRS-1C applications in land use mapping and planning. Current Science 70(7):575–581.

Raychaudhary, S.P., and **Govindarajan, S.V.** 1971. Soils of India. Technical Bulletin No. 25. New Delhi, India: Indian Council of Agricultural Research.

Ryan, J.G., Virmani, S.M., and **Swindale, L.D.** 1982. Potential technologies for deep black soils in relatively dependable rainfall regions of India. Pages 41–62 *in* Proceedings of the Seminar on Innovative Technologies for Integrated Rural Development, 15–17 April 1982, New Delhi, India. New Delhi, India: Indian Bank.

Sangle, R.D., and **Sharma, D.** 1985. On-farm testing of improved Vertisol management technology at Begumgunj in Raisen District of Madhya Pradesh. Concluding Project Report. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Singh, P., Vijaya, D., Chinh, N.T., Ponkanjana, A., Prasad, K.S., Sreenivas, K., and **Wani, S.P.** 2001. Potential productivity and yield gap of selected crops in the rainfed regions of India, Thailand, and Vietnam. Natural Resource Management Program Report no. 5. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

Smith, A.Y., and **Blackwell, R.J.** 1980. Development of an information data base for watershed monitoring. Photogrammetric Engineering and Remote Sensing 46:1027–1038.

Subba Rao, G.V., Kumar Rao, J.V.D.K., Kumar, J., Johansen, C., Deb, U.K., Ahmed, I., Krishna Rao, M.V., Venkataratnam, L., Hebbar, K.R., Sai, M.V.R.S., and **Harris, D.** 2001. Spatial distribution and quantification of rice-fallows in South Asia – Potential for legumes. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Thomas, I.L., Benning, B.M., and **Bennetts, R.L.** 1980. Land-use applications of Landsat. New Zealand Agricultural Science 14(4):169–184.

Vadivelu, G. Ananda, Wani, S.P., Bhole, L.M., Pathak, P., and **Pande, A.B.** 2001. An empirical analysis of the relationship between land size, ownership, and soybean productivity – new evidence from the semi-arid tropical region in Madhya Pradesh, India. Natural Resource Management Program Report no. 4. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 50 pp.

Wani, S.P. 2000. Integrated watershed management for sustaining crop productivity and reduced soil erosion in Asia. Proceedings of the 5th MSEC Steering Committee Meeting, 9 November 2000, Semarang, Indonesia.

Wani, S.P., Pathak, P., Tam, H.M., Ramakrishna, A., Singh, P., and **Sreedevi, T.K.** 2001. Integrated watershed management for minimizing land degradation and sustaining productivity in Asia. Pages 207–230 *in* Integrated land management in dry areas: proceedings of a Joint UNU-CAS International Workshop, 18–13 September 200, Beijing, China (Zafar Adeel, ed.). Tokyo, Japan: United Nations University.

Wani, S.P., Singh, Piara, Pathak, P., and **Rego, T.J.** 2000. Sustainable management of land resources for achieving food security in the semi-arid tropics. Lead paper presented at the International Conference on Land Resource Management for Food, Employment and Environmental Security, 9–13 November 2000, New Delhi, India.

Welch, R.A., Fernandes, N., and **Jordan, T.** 1993. GIS modeling of non-point source pollution with remotely sensed data. Proceedings of the 1993 Georgia Water Resources Conference, 21–22 April 1993, University of Georgia, USA (Hatcher, K.J., ed.). Athens, Georgia, USA: Institute of Natural Resources, The University of Georgia.

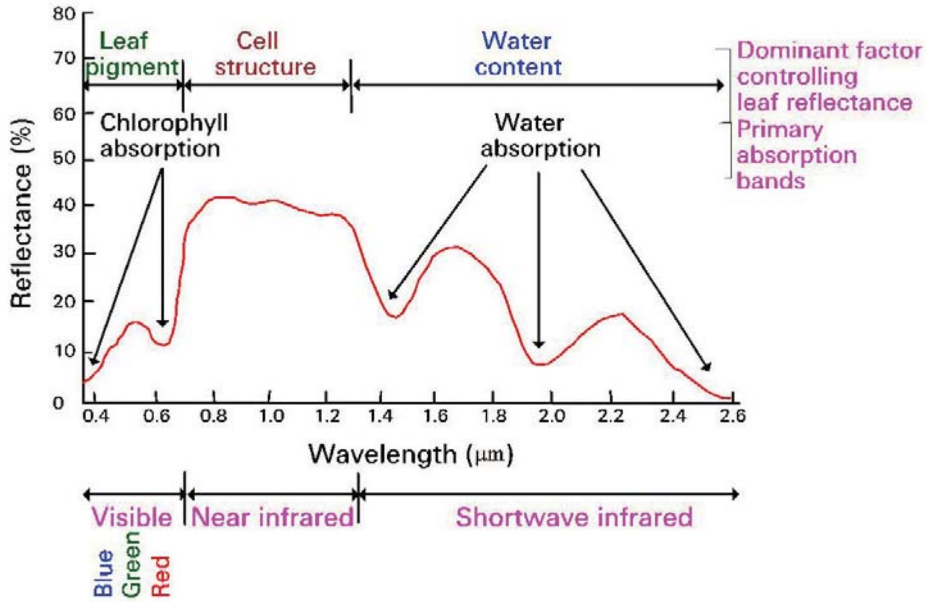


Figure 1. Typical spectral response of green vegetation.

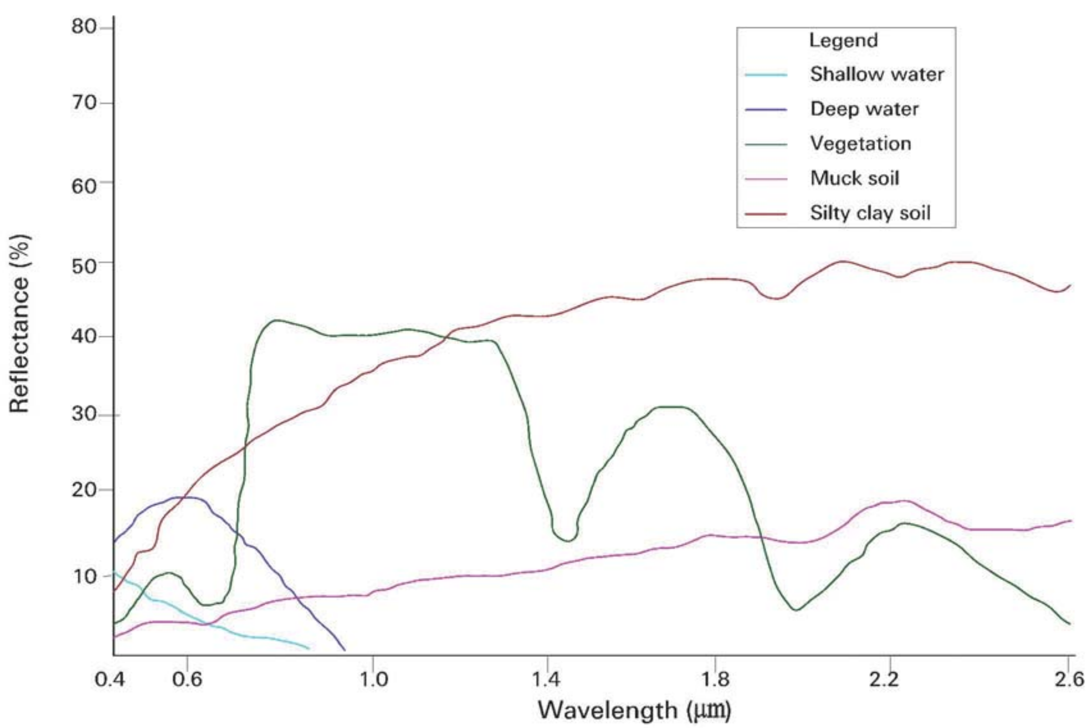


Figure 2. Typical spectral reflectance curves.

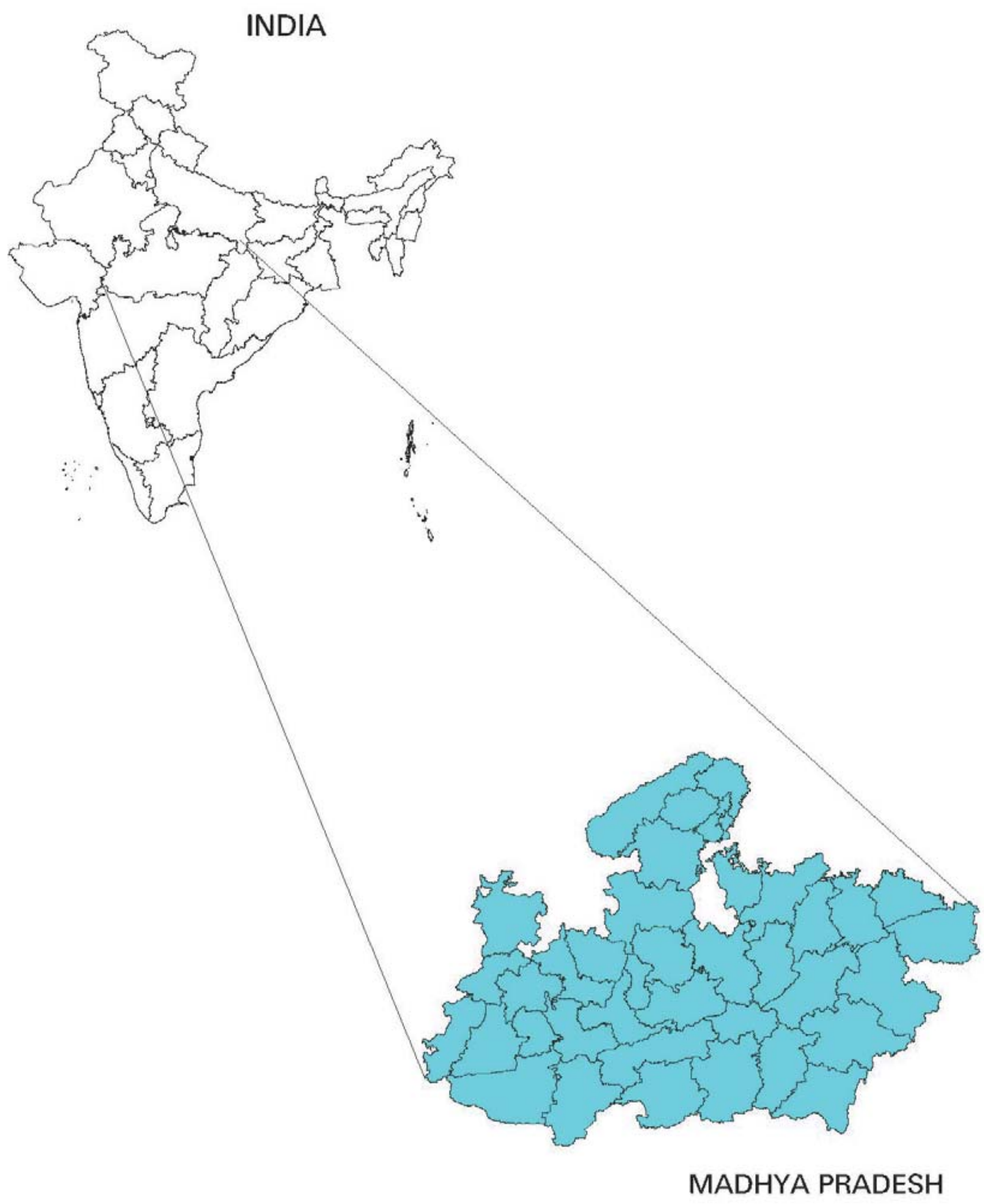


Figure 3. Location map of the study area.

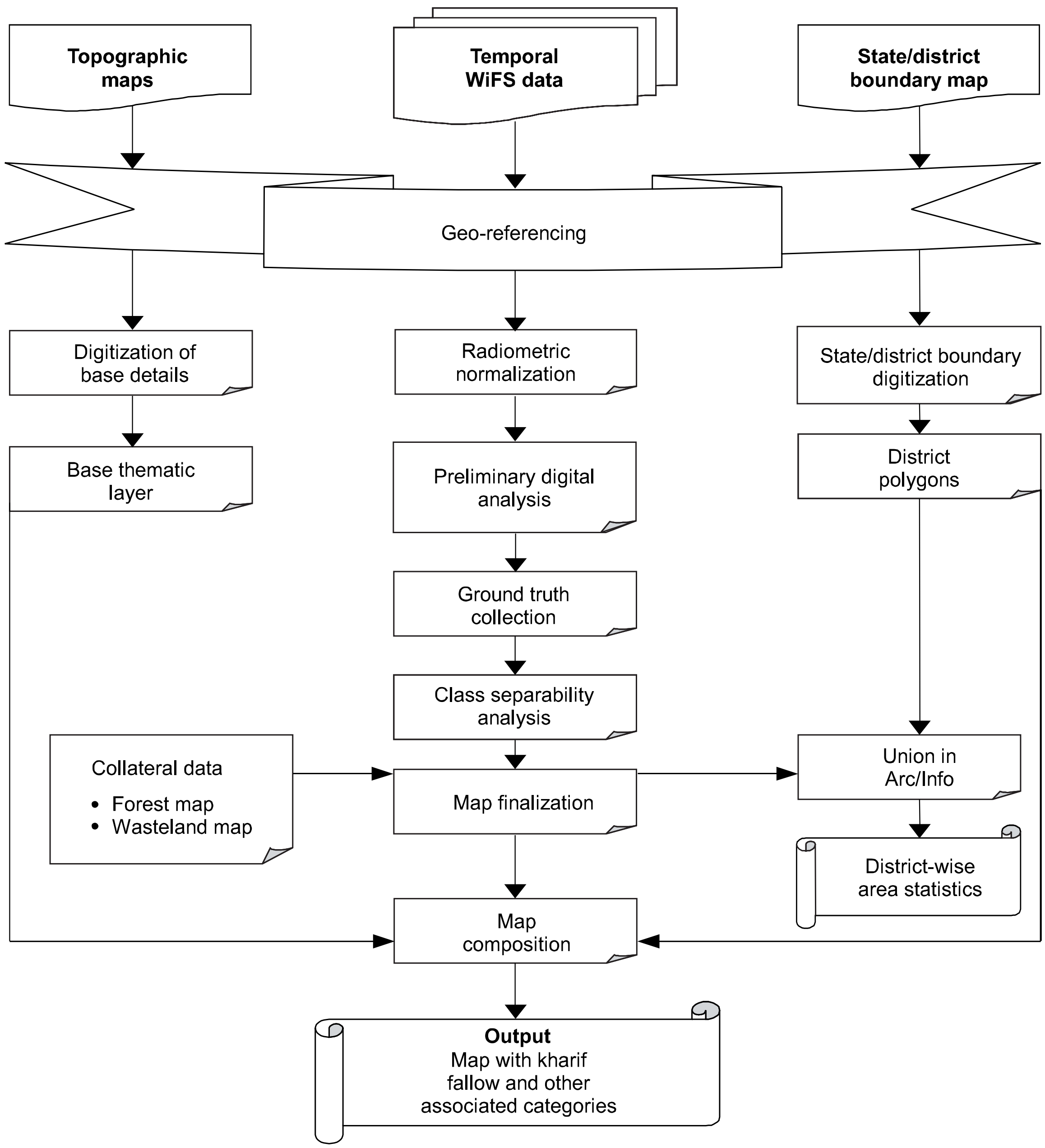
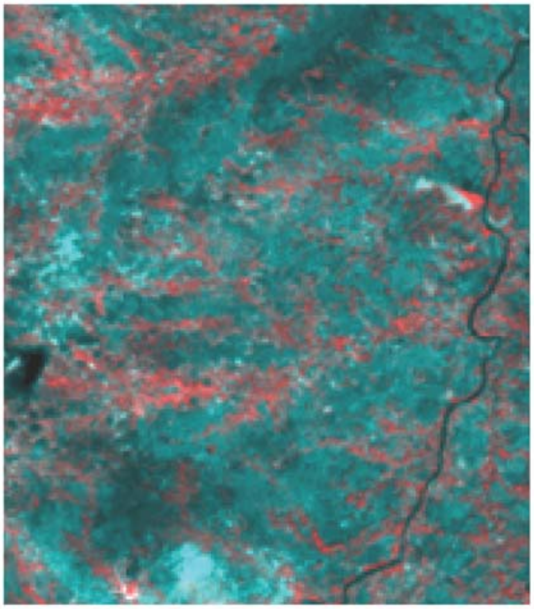
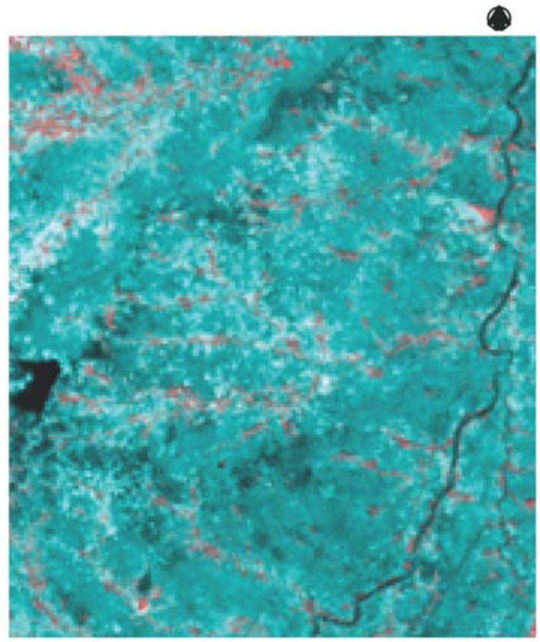


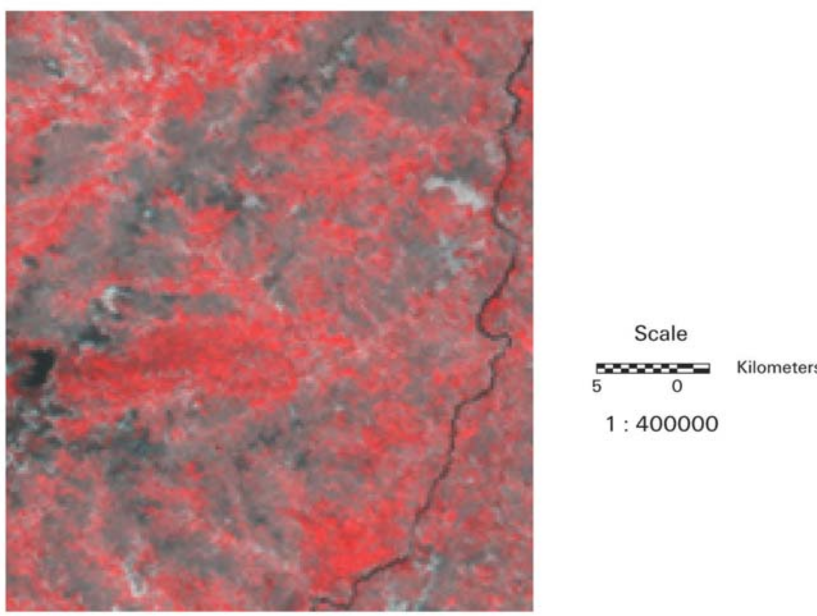
Figure 4. Schematic diagram of the approach.



Mid-kharif



Late kharif



Rabi

Figure 5. A close view of WiFS images of part of Vidisha district, Madhya Pradesh during three periods.

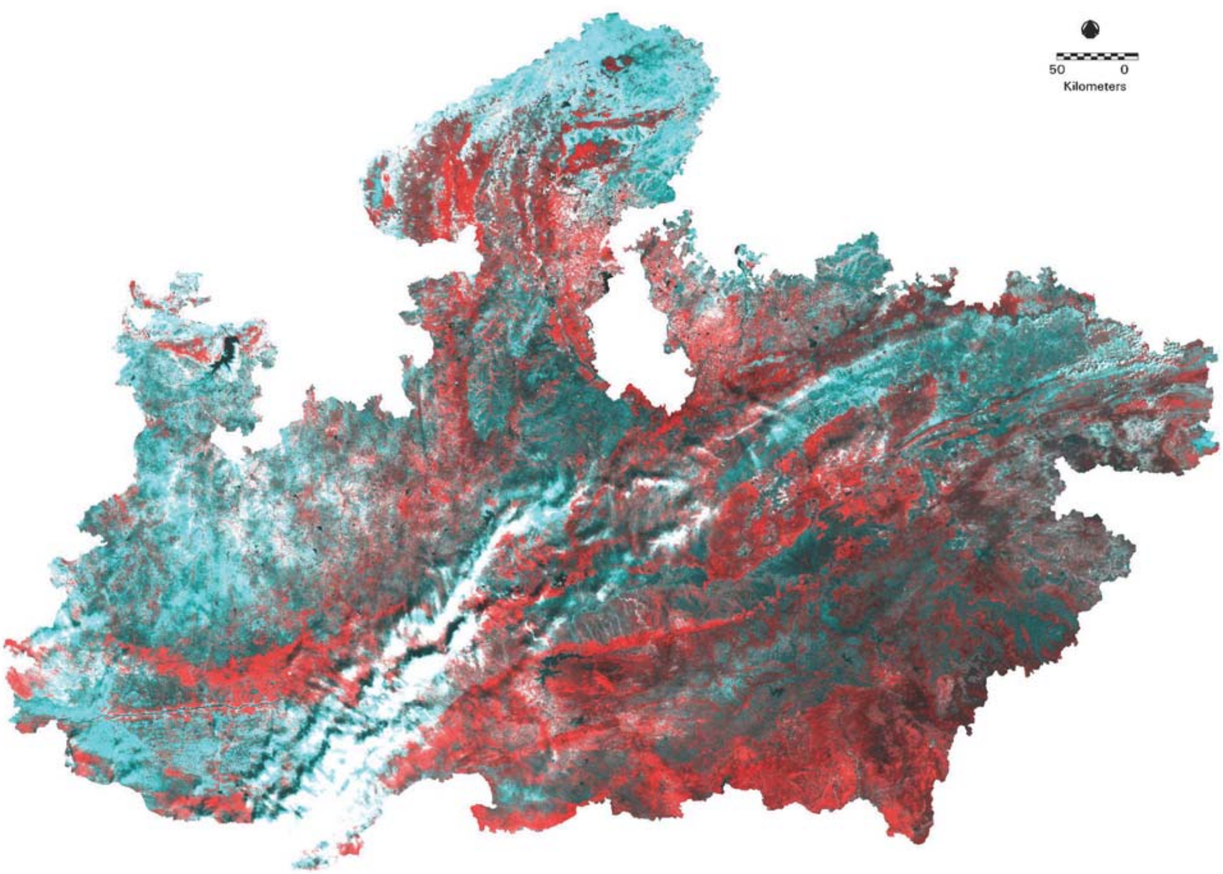


Figure 6. IRS-1D WiFS image of mid-kharif season 2001 in Madhya Pradesh.

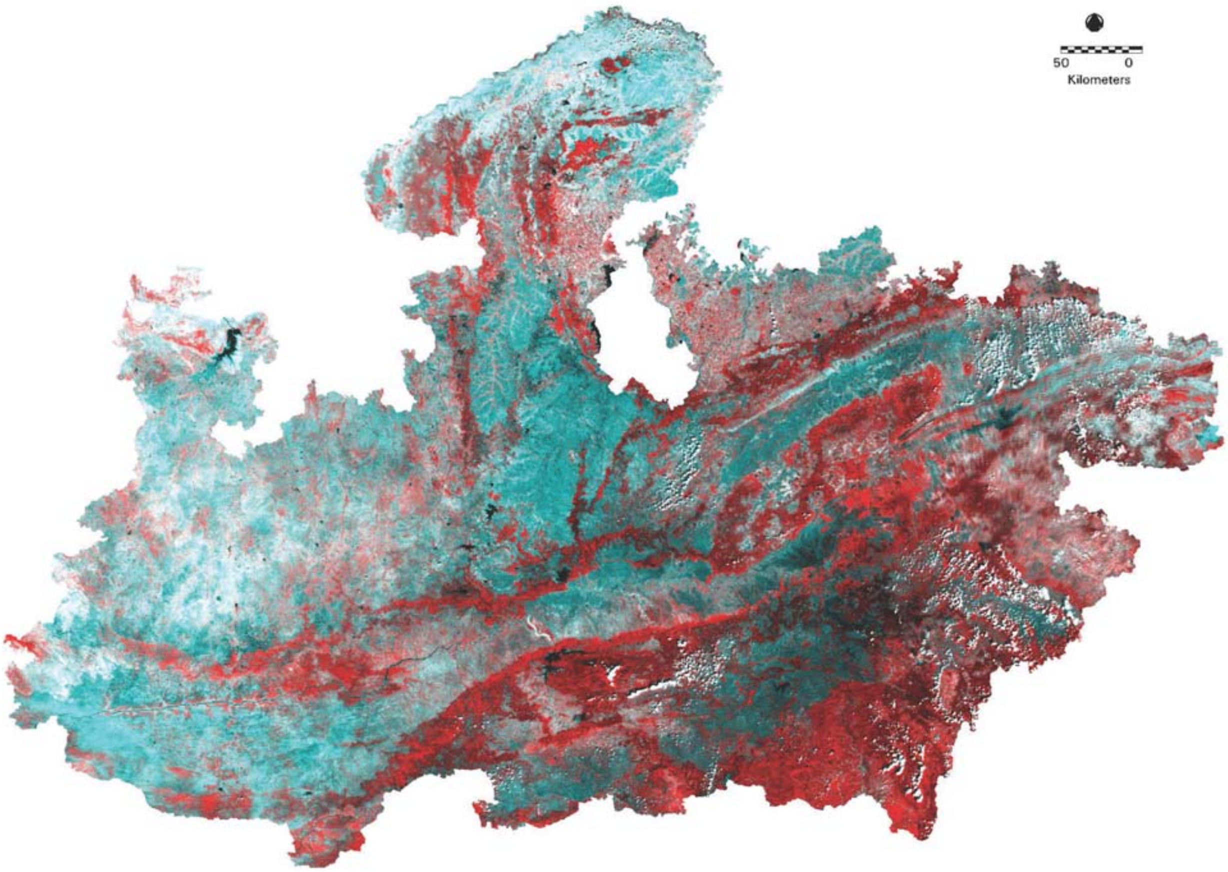


Figure 7. IRS-P3 WiFS image of late kharif season 2000 in Madhya Pradesh.

Figure 8. IRS-1C WiFS image of rabi season 1999–2000 in Madhya Pradesh.

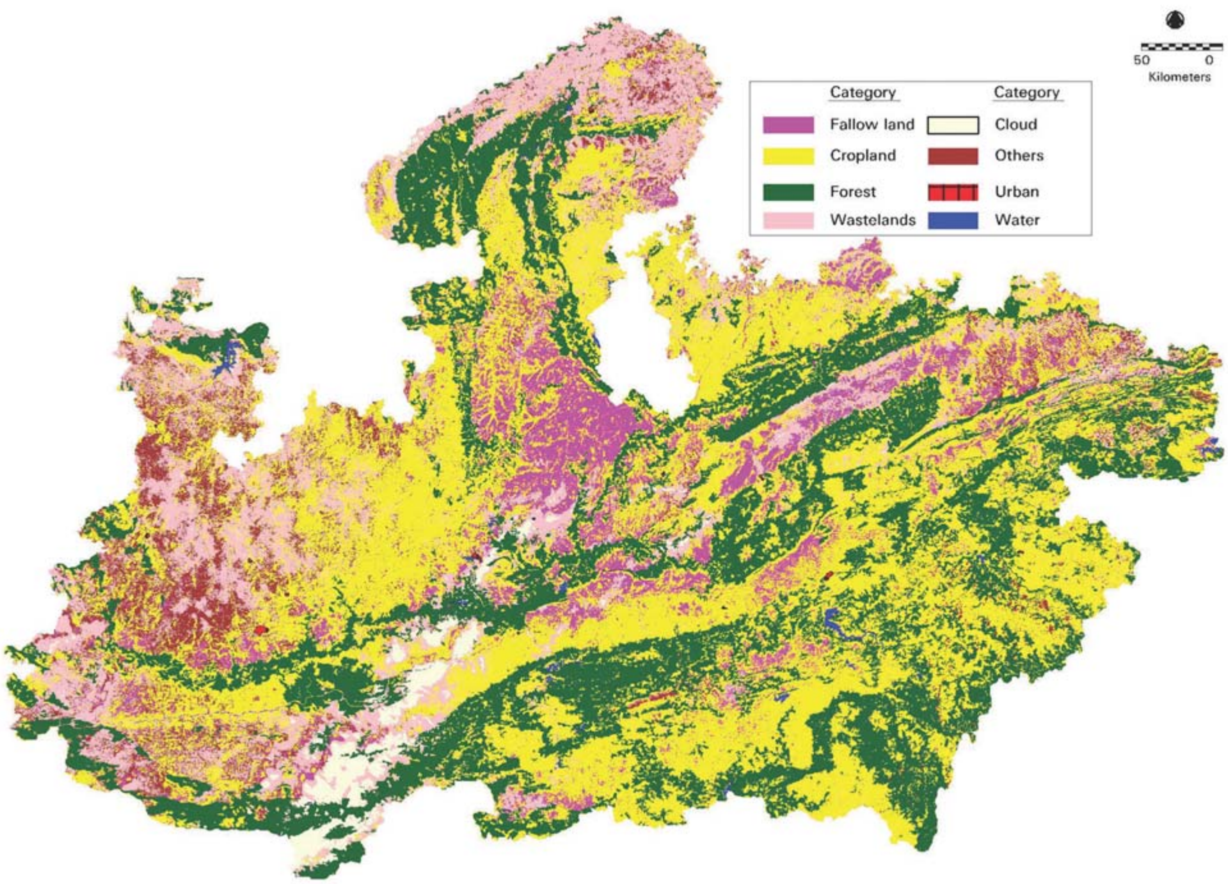


Figure 9. Spatial distribution of various land use/land cover categories in Madhya Pradesh.

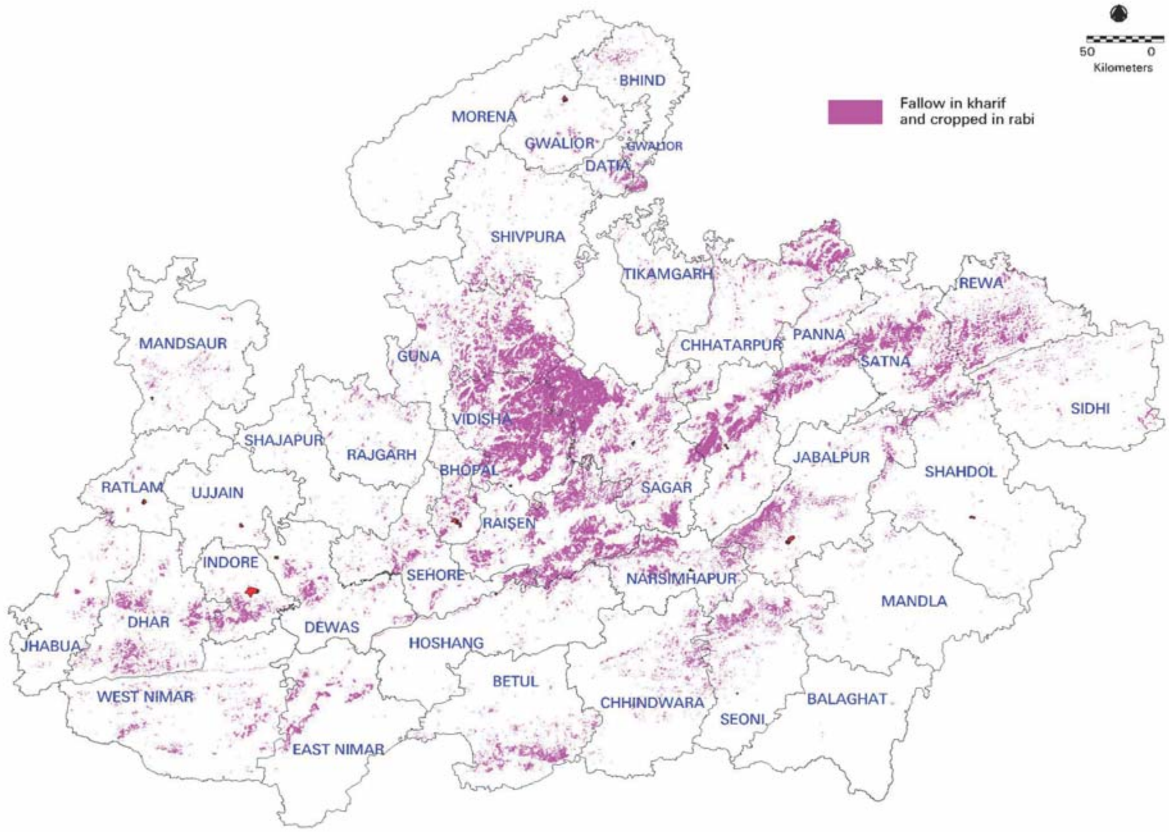


Figure 10. Spatial distribution of fallow lands in Madhya Pradesh.

About ICRISAT

The semi-arid tropics (SAT) encompass parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea and groundnut; these five crops are vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, CGIAR-supported Future Harvest Centers. The Consultative Group on International Agricultural Research (CGIAR) is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

National Remote Sensing Agency
Balanagar, Hyderabad 500 037
Andhra Pradesh, India

Asian Development Bank
0401 Metro Manila, 0980 Manila
The Philippines

BAIF Development Research Foundation
Arera Colony, Bhopal 462 016
Madhya Pradesh, India

502-2002