

**ESTIMATION AND MONITORING OF SOIL MOISTURE BY RADAR
REMOTE SENSING TECHNIQUE AND IDENTIFICATION OF SOIL
PRODUCTIVITY CONSTRAINTS IN BHANAPUR MICROWATERSHED**

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1. INTRODUCTION

Land and water are essential resources for the sustained quality of human life and form the foundation of agricultural development. Highly competing and conflicting demands on soil, vegetation, water and other natural resources from increasing population pressure have resulted in an over exploitation and deterioration of our valuable natural resources.

Availability of adequate moisture and nutrients during crop growth are the major constraints to successful farming in dry land areas. Very often, even available rainwater is not conserved properly. It is allowed to go as runoff, resulting in soil erosion and loss of soil productivity. Adoption of soil water conservation measures with balanced use of fertilizer and other package of practices can increase the crop production and stabilize the yields at reasonably higher level to make crop cultivation profitable in dry land farming areas.

Soil moisture is essential for seed germination and for the growth and development of agricultural crops. It is also important for partitioning rainfall and irrigation water into runoff, infiltration and redistribution, drainage and storage. Regional level estimation of soil moisture is essential for crop yield modeling, water balance computations and irrigation management.

Soil moisture is the temporary storage of precipitation or rainfall within a shallow layer of the earth. Soil moisture is highly variable as a result of heterogeneity of soil properties, topography, land cover and non-uniformity of input from rainfall. Typically average of point measurements are used to characterize the soil moisture of an area, but these averages seldom yield information that is representative of characterizing other hydrological process i.e., evapotranspiration, runoff, groundwater recharge etc., (Engman and Gurney, 1991).

Remotely sensed data especially RADAR (Radio detection and ranging) remote sensing have great potential for providing real estimates of soil moisture rather than point measurement. "RADAR is an active remote sensing system which bounces microwave energy (Wave length between 1mm to 1m) from the target and records the energy that returns to the sensors". It provides its own energy source and therefore, can operate both during day and night and also through cloud cover. This type of system is known as active remote sensing system. Remote sensing in the microwave band can be classified into active and passive remote sensing. Passive systems use the sun as their source of microwave energy and are known as radiometers, whereas active systems have their own source and are known as RADAR. Active microwave remote sensing offers several advantages over passive sensing such as its ability to penetrate cloud cover (making it an all weather sensor), moderate penetration of vegetation cover, independent energy source and is a strong function of dielectric constant.

In rainfed agriculture, information on soil moisture before sowing and upto establishing of crop cover is very essential. Active RADAR operating at microwave frequency is very sensitive to dielectric properties of target because of large difference between dielectric properties of wet soil (80) and that of dry soil (3-5). Ulbay *et al.* (1986) demonstrated the strong dielectric response to soil moisture. The scattering of microwave radiation at the soil depends on sensor parameters like microwave frequency, look angle and kind of polarization, surface roughness, soil texture and vegetation cover. RADAR also helps in studying spatio-temporal variability of soil moisture at regional level.

The need for estimation of soil moisture may differ from an agriculturist's, a meteorologist's, or a water reservoir manager's standpoint of view. Estimation of soil moisture in agricultural areas is important for improving yield forecasts, scheduling irrigations and other farm management activities (Idso *et al.*, 1975). Remote sensing can provide indirect estimates over large areas with frequent repeat coverage. The microwave region has been the most favorable spectral region for surface soil moisture studies (Schmugge, 1985; Engman and Chauhan, 1995).

Remote sensing techniques make it possible to obtain and distribute information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. A satellite, which orbits the earth is able to explore the whole surface in a few days and repeat the survey of the same area at regular intervals, whilst an aircraft can give a more detailed analysis of a smaller area, if a specific need occurs. The spectral bands used by these sensors cover the whole range between visible and microwaves.

Regional soil moisture estimation and mapping by remote sensing techniques has been seriously investigated for several years in view of its importance in agriculture. Active microwave sensing techniques are particularly suitable for soil moisture estimation. In addition, ability of these sensors to provide cloud free data during the monsoon period with highly spatial resolution makes them highly attractive for the purpose.

Assessment of major soil productivity limitations, both in terms of soil fertility and edaphic factors may help to make advisory services to the farmers in improving their soil productivity levels. Keeping these considerations in view, the present investigation was undertaken in the Bhanapur micro watershed area of Koppal district with the following objectives;

1. To estimate and monitor soil moisture of the micro watershed by RADAR remote sensing technique.
2. To relate soil moisture status with land use pattern of the microwatershed, and
3. To identify the soil productivity constraints of the microwatershed and mapping by GIS technique.

2. REVIEW OF LITERATURE

The carrying capacity of land is threatened by the ever increasing human and animal population. So, the present day agriculture demands the rational utilization, scientific management and conservation of existing soil resources. Hence, research information on these aspects is meager and scanty. An attempt has been made to review the literature pertaining to the various aspects of the investigations contemplated in the study and is presented in this chapter.

Although the soils of the arid and semi-arid regions are superficially similar in appearance, careful study reveals a great diversity. Studies carried out, both within and outside India, on red and black soils are exhaustive. Based on the available information, the literature is reviewed under the following headings.

- 2.1 Surface soil moisture estimation and mapping
- 2.2 Relating soil moisture and land use
- 2.3 Surface soil properties
- 2.4 Mapping fertility status of soils using GIS

2.1 Surface soil moisture estimation and mapping

Ulaby (1974) reported that the effect of soil moisture on the radar backscattering coefficient was investigated by measuring the 4-8 GHz spectral responses from two types of bare-soil fields: slightly rough and very rough. Used eight different look angles (0° - 70°) for all polarization combinations. A total of 17 sets of data were collected covering the range 4-36 percent soil moisture content by weight. The results indicated that the radar response to soil moisture content was highly dependent on the surface roughness, microwave frequency, and look angle. The response seems to be linear, however, over the range at 15-30 percent moisture content for all angles, frequencies, polarizations, and surface conditions.

Chang *et al.* (1980) assessed the performance of L-band for soil moisture determination, and to study the temporal variability of radar returns from a number of agricultural fields. The results of correlations between the relative return power and per cent of field capacity (%FC) demonstrated that the relative return power from this imaging radar system was responsive to the amount of soil moisture in bare fields. The signal returned from dry (15% FC) and wet (130% FC) fields where furrowing was parallel to the radar beam differed by about 15 dB.

Lin *et al.* (1994) made Soil moisture estimates from a distributed hydrological model and two microwave airborne sensors (Push Broom Microwave Radiometer and Synthetic Aperture Radar) were compared with ground measurements on two different scales, using data collected during a field experiment over a 7.4 km² heterogeneous watershed in Pennsylvania. Both microwave sensors and the hydrological model successfully reflected the temporal variation of soil moisture. Watershed-averaged soil moistures estimated by the microwave sensors were in good agreement with ground measurements.

Giacomelli *et al.* (1995) derived surface soil moisture information for two catchments under different climates in Europe based on active microwave remote sensing techniques and conceptual hydrological modeling. Based on ground-truth data collected during the flights, simple SAR-soil moisture relationships were established. This allows the estimation of the spatial variation of surface soil moisture at the field scale. Simulation results for soil moisture were then compared with SAR-based soil moisture estimates. The comparison between sampled, modeled and SAR-derived soil moisture at the transect scale is acceptable, but the spatial patterns of soil moisture predicted by the conceptual model and the SAR images were different owing to the influence of vegetation.

Verhoest *et al.* (1998) reported that the active microwave remote sensing offers the potential for frequent observation of soil moisture at basin and regional scales. The main difficulties for active sensors such as synthetic aperture radar (SAR) are the combined effects of soil moisture, surface roughness, and vegetation on the backscattered signal. It was shown that it was possible to separate soil moisture information from the other physical factors that

dominate the radar backscattering, such as topography and land cover, through a principal component analysis of a time series of eight European Remote Sensing SAR images.

Van Oevelen and Hoekman (1999) using a Semiempirical model and a numerical inversion of the Integral Equation Method (IEM) model, introduced as "INVIEM," were applied to retrieve soil moisture over bare soil surfaces from active microwave data. The two models were compared using data from the Jet Propulsion Laboratory (JPL) air synthetic aperture radar (Air SAR) taken during the EFEDA-Spain'91 experiment and ERS-1 data from the HAPEX-Sahel'92 experiment.

The comparison was performed within a general framework to estimate soil moisture from radar data, describing all necessary steps. The range of soil moisture values estimated by the INVIEM model, using the air SAR and ERS-1 data was in agreement with the soil moisture variation found in the field.

Moeremans and Dautrebande (2000) studying the feasibility of using multi-temporal space borne Synthetic Aperture Radar (SAR) imagery for the evaluation of soil moisture at a field and regional scale was evaluated using the European Remote Sensing Satellite (ERS-1 and ERS-2) images. The backscattering coefficient values and the mean coherence values were calculated for each field and compared with soil moisture and crop characteristics measurements. A linear relationship existed between the volumetric near-surface soil moisture and the backscattering coefficient for unsaturated soils, with a determination coefficient of 0.75. The innovative key point of the study showed an excellent correlation between the backscatter value of the image subset of the test site (80 km²), and the corresponding mean soil moisture measurements, with a determination coefficient of 0.98. The image subset comprises agricultural fields with some forests, meadows and urban areas. Moreover, the relation was as valid in the spring, before the growing season, as in the summer, when the vegetation cover was high. The study showed that coherence images are useful to identify bare soil fields.

Burker and Simmonds (2001) reported that a physically based soil water and energy balance model coupled with a microwave emission model, was used to investigate the relationship between near surface soil moisture (0-5 cm) and L-band microwave brightness temperature (BT) under a wide range of conditions. The effects of soil texture look angle and vegetation on this relationship were parameterised and combined into a simple summary model. It was tested using a variety of truck-based L-band data sets collected between 1980 and 1982. This paper emphasises the need to have an accurate estimate of the vegetation optical depth (a parameter that describes the degree of influence of the vegetation on the microwave emission from the soil surface) in order to retrieve correctly the soil water content.

Mazlan Hashim *et al.* (2001) developed three empirical and theoretical radar backscatter models and were examined in this study to characterise radar backscatter of TOPSAR data of Sadong Simunjan River Basin, Sarawak, Malaysia. The analysis of these models were examined using varying terrain-and-sensor related parameters namely surface roughness, dielectric constant, incidence angle, polarization and frequency, respectively. The results of this study indicate good relationship between moisture content and radar backscatter (RMSE < 5.0) in empirical model. However, this relationship was found rather restricted in the theoretical models due to its sensitivity to very moist to wet nature of the study area.

Western *et al.* (2001) assessed the potential for measuring spatial patterns of soil moisture using SAR at spatial resolutions down to 15 m. Highly detailed ground data on soil moisture and dielectric constant were collected in the 10.5 ha Tarrawarra experimental catchment in south-eastern Australia. C-band SAR measurements by ERS-1, ERS-2 and Air SAR provided no useful information on the spatial moisture pattern. Empirical comparisons suggest that L and P-band Air SAR data contain useful information on the soil moisture pattern, but this could not be extracted using a semi-empirical inversion algorithm. The spatial average moisture was successfully obtained from the L-band Air SAR data.

Wickel *et al.* (2001) monitored soil moisture using multi-temporal RADARSAT, synthetic aperture imagery over the one month experiment, a total of ten RADARSAT (C-band, 5.3 GHz: HH-polarized) acquisition were obtained. An angular correlation scheme applied to the data and the correct of backscattering value with volumetric soil moisture measurement determined a high positive correlation between the two was observed for pasture field, a change detection approach yielded a correlation of soil moisture changes to

backscattering changes for wheat stubble field, indicating the potential of this method for soil moisture monitoring.

Baghdadi *et al.* (2002) estimated surface roughness and soil moisture over bare fields using European Remote Sensing (ERS) and RADARSAT data. The neural networks were trained with a simulated data set generated from the integral equation model. Later the networks were applied to a field data set spanning a wide range of surface roughness and soil moisture, with backscattering coefficients for three radar configurations (VV 23°, HH 39°, and HH 47°). Approaches based on two and three radar image configurations were examined and tested. The three-image configuration produced slightly more accurate results; a two-image configuration gave results of comparable accuracy when a favourable combination of incidence angles was adopted. The Soil moisture and surface roughness errors were estimated at about 7.6% and 0.47 cm, respectively, using the root mean square error (RMSE).

Pauwels *et al.* (2002) developed an algorithm to estimate surface soil moisture values through active microwave remote sensing, by passing the need to collect in situ ground parameters. The algorithm to estimate soil moisture by use of radar data combines a physically based and an empirical backscatter model. This method estimates effective soil roughness parameters, and good estimates of surface soil moisture were provided for bare soils. These remotely sensed soil moisture values over bare soils were then assimilated into a hydrological model using the statistical correction method. The results suggest that it is possible to determine soil moisture values over bare soils from remote sensing observations without the need to collect ground truth data, and that there was potential to improve model-based discharge predictions through assimilation of these remotely sensed soil moisture values.

Laurent Prevot *et al.* (2003) using the “water-cloud” model for estimation of surface soil moisture from SAR (ERS-2 and RADARSAT) images. It was verified that the “water-cloud” model can adequately represent the back scattering coefficients over winter wheat field, during the entire growing season, as a function of canopy water content and surface soil moisture.

Kelly *et al.* (2003) reported that a series of soil moisture measurements were taken within a 15 ha bare field on the Essex (UK) coast at times to coincide with ERS-1 overpasses in the autumn and winter of 1995-96. Analysis of variograms of SAR backscatter showed that spatial variations in the ERS SAR data can be detected within the field and that spatial dependency increased when the soil was wet. Field measurements of soil moisture did not reflect these findings in quite the same way; during periods of low soil moisture content, the spatial variation of soil moisture autocorrelation was more evident in the variograms. Regression analysis of paired observations of measured soil moisture and ERS SAR backscatter demonstrated that no significant relationship could be obtained for each day. However, when paired data for different dates were combined, a significant relationship between SAR backscatter and soil moisture could be obtained. It is, therefore, suggested that soil moisture can be predicted at the field scale but not within field/pixel scale.

Haider *et al.* (2004) reported that spatial and temporal variation of soil moisture in a catchment is most important in hydrological, as well as many other studies. Point measurements from gravimetric and other methods for soil moisture determination are insufficient to understand the spatial behaviour of soil moisture in a region. Microwave remote sensing data have been used to map spatial distribution of soil moisture within the 0-10 cm top surface soils of northern part of India (catchment of the Solani River), therefore, spatial and temporal distribution of soil moisture in this region has a significant bearing on the hydrology of the region. The radar backscatter coefficient for each pixel of the image has been modeled from the digital numbers of the SAR image. Gravimetric measurements have been made simultaneously during the satellite pass to determine the concurrent value of volumetric soil moisture at a large number of sample points within the satellite sweep area. The backscatter coefficient was found to vary from -30 dB to -42 dB for a variation in soil moisture from 30 to 75%. Regression analyses between volumetric soil moisture and both the digital numbers and backscatter coefficients were performed. Strong correlations between volumetric soil moisture and digital number were observed with R^2 values of 0.84, 0.75 and 0.83 for bare soil, vegetative (vegetation constitutes short as well as tall agricultural plants) and combined surfaces, respectively. A similar trend was observed with the relationship

between backscatter and volumetric soil moisture with R^2 values of 0.60, 0.89 and 0.67 for bare soil, vegetative and combined surfaces, respectively. These results demonstrate the utilization of SAR data for estimation of spatial distribution of soil moisture in the region of the present study.

Robert Leconte *et al.* (2004) made an approach for mapping near-surface soil moisture at the watershed scale from seven RADARSAT-1 SAR images acquired over the northern portion of the Châteauguay River Basin in southwestern Quebec, Canada, dominated by agricultural and herbaceous fields. Field campaigns were conducted concurrent to SAR image acquisitions to measure soil moisture and surface roughness in 24 fields. Good agreement was observed between watershed-scale soil moisture values and measurements averaged for all sampled fields, with a correlation coefficient of 0.96 and an RMS error of 2.2%. However, considerable scatter was found between observed and SAR-derived soil moisture estimates at the field scale. Furrows and herbaceous and crop vegetation, which are known to affect the radar signal, appeared to have little influence on the ability to retrieve soil moisture at the watershed scale.

Walker *et al.* (2004) reported that SAR backscattering observations are highly dependent on topography, soil texture, surface roughness and soil moisture, meaning that soil moisture inversion from single frequency and polarization SAR observations is difficult. In this paper, the potential for measuring near-surface soil moisture with the ERS-2 satellite is explored by comparing model estimates of backscattering with ERS-2 SAR observations. Semi-empirical and empirical backscattering models, it was found that using measured soil moisture and roughness data there were root mean square (RMS) errors from 3.5 to 8.5 dB and r^2 values from 0.00 to 0.25, depending on the backscattering model and degree of filtering. Using model soil moisture in place of measured soil moisture reduced RMS errors slightly (0.5 to 2 dB) but did not improve r^2 values.

Loew *et al.* (2005) reported that the interaction of electromagnetic waves with the land surface can be dependant on the water content of the uppermost soil layer. Especially in the microwave domain of the electromagnetic spectrum, this is the case. New sensors as e.g. ENVISAT ASAR, allow for frequent, synoptically and homogeneous image acquisitions over larger areas. Parameter inversion models are therefore developed to derive bio and geophysical parameters from the image products. The paper presents a soil moisture inversion model for ENVISAT ASAR data for local and regional scale applications. The model is validated against in situ soil moisture measurements.

Andrew and Edwin (2006) reported that use of passive and active microwave techniques has provided theoretical and experimental evidence which shows that microwave sensing of soil water at a watershed scale with the synthetic aperture radar (SAR) system can be done from aircraft and space platforms. During a multi-sensor airborne campaign conducted on an agricultural watershed in central Pennsylvania, soil moisture changes were estimated from changes in remotely sensed SAR data and compared with the ground truth values. The approach used probability distribution functions (*PDFs*) and change detection, to minimize the impact of soil roughness, texture, and vegetation. Soil water content measurements were made using standard methods including time domain reflectometry, neutron thermalization, and inductive electrical conductivity. The *PDFs* of ground truth point values were similar to those for SAR data.

Mattia *et al.* (2006) reported that estimates spatial and temporal distribution of volumetric soil moisture content, using multitemporal ENVISAT Advanced Synthetic Aperture Radar (ASAR) alternating polarization images, acquired at low incidence angles (i.e., from 15/spl deg/ to 31/spl deg/). The developed retrieval algorithm was assessed on the Matera site (Italy) where multitemporal ground and ASAR data were simultaneously acquired in 2003. Simulated and experimental results indicate the possibility of attaining an accuracy of approximately 5% in the retrieved volumetric soil moisture content, provided that sufficiently accurate a prior information on surface parameters (i.e., within 20% of their whole variability range) is available. As an example, multitemporal soil moisture maps at watershed scale, characterized by a spatial resolution of approximately 150 m, were derived and illustrated.

2.2 Relating soil moisture and land use

Bush and Ulaby (1976) reported that radar backscatter coefficient of alfalfa was investigated as a function of both radar parameters and the physical characteristics of the alfalfa canopy. Measurements were acquired with an 8-18 GHz FM-CW mobile radar over an angular range of 0 deg - 70 deg measured from nadir. The experimental data indicate that the excursions of sigma_{adeg} at nadir cover a range of nearly 18 dB during one complete growing cycle. An empirical model for sigma_{adeg} was developed, which accounts for its variability in terms of soil moisture, plant moisture, and plant height.

Owe *et al.* (1992) using seven scanning multichannel microwave radiometer 6.6-GHz passive microwave data were studied in relation to large scale soil moisture estimates over a 3- year period in southeastern Botswana. It receives annual rainfall of the region it varies from 300 mm in the west to 500 mm in the east. An extensive database of weekly surface soil moisture measurements was used with meteorological data to estimate pixel average soil moisture on a daily basis. The influence of the vegetation canopy on the surface emissivity was studied by partitioning the data set in to classes on the basis of the normalized difference vegetation index.

Dubois *et al.* (1995) developed an empirical algorithm for the retrieval of soil moisture content and surface root mean square (RMS) height from remotely sensed radar data was developed using scatterometer data. The algorithm was optimized for bare surfaces and required two co-polarized channels at a frequency between 1.5 and 11 GHz. It omitting weaker HV-polarized returns makes the algorithm less sensitive to system cross-talk and system noise, simplifies the calibration process and adds robustness to the algorithm in the presence of vegetation. However, inversion results indicated that significant amounts of vegetation (NDVI>0.4) cause the algorithm to underestimate soil moisture and overestimate RMS height. The inversion accuracy was assessed on the original scatterometer data sets but also on several SAR data sets by comparing the derived soil moisture values with in-situ measurements collected over a variety of scenes between 1991 and 1994. Both spaceborne (SIR-C) and airborne (AIRSAR) data were used in the test. Over this large sample of conditions, the RMS error in the soil moisture estimate was found to be less than 4.2% soil moisture.

Griffiths and Wooding (1996) observed that Multi-temporal synthetic aperture radar (SAR) imagery from the European Remote Sensing Satellite (ERS-1) was evaluated for monitoring soil moisture at the Romney Marsh test site as part of the UK. A total of 18 C-band (5.3 GHz) ERS-1 SAR images were acquired during the three day orbit and co-registered. Accurate calibration of the backscatter measurements was achieved using calibration constants derived from an analysis of corner reflector target responses. Mean backscatter measurements were recorded for each field and compared with field data on soil moisture, surface roughness and rainfall patterns. A comparison of daily and hourly rainfall and soil moisture measurements with backscatter for different cover types showed that the observed trends in backscatter were dominated by moisture effects. A high positive correlation between volumetric soil moisture in the range 10-40% was observed for bare soil fields. A much weaker positive relationship between soil moisture and backscatter was observed for grassland fields.

Ulbay *et al.* (1996) studied the spatial distributions and temporal variations of soil moisture by using radar imaging and associated attributes. To place the soil moisture sensing task in proper perspective, the prerequisite step of classifying terrain into four basic types bare surfaces, short vegetation, tall vegetation, and urban. The radar can correctly classify terrain with accuracy greater than 90%. Over 8000 image pixels with known terrain identity were involved in the evaluation of the radar image classifier. For bare soil (with vegetation cover shorter than 15 cm), radar can estimate the volumetric moisture content of the top 5 cm soil layer with an RMS error of 3.5%. Based on theoretical model predictions as well as experimental observations, strong evidence exists in support of radar's potential for sensing soil moisture under vegetation cover.

Wang *et al.* (1997) developed an Integral equation method (IEM) for estimation of soil moisture and surface roughness parameter from synthetic aperture radar (SAR) measurements. This algorithm was applied to a series of measurements acquired at L-band (1.25 GHz) from both AIRSAR (Airborne Synthetic Aperture Radar) and SIR-C (Spaceborne Imaging Radar-C) over a well-managed watershed in southwest Oklahoma. Prior to its application for soil moisture inversion, a good agreement was found between the single-

scattering IEM simulations and the L-band measurements of SIR-C and AIRSAR over a wide range of soil moisture and surface roughness conditions. It was found that the two co-polarized backscattering coefficients and their combinations would provide the best input to the algorithm for estimation of soil moisture and roughness parameter. Application of the inversion algorithm to the co-polarized measurements of both AIRSAR and SIR-C resulted in estimated values of soil moisture and roughness parameter for bare and short-vegetated fields that compared favorably with those sampled on the ground. The root-mean-square (rms) errors of the comparison were found to be 3.4% and 1.9 dB for soil moisture and surface roughness parameter, respectively.

Njoku *et al.*, (1999) using the Passive/Active L-band (PALS) airborne microwave sensor were flown for the first time in southern Great Plains (SGP99) experiment. The objective was to acquire a dataset for studying combined radiometer-radar multifrequency, multipolarization approach to soil moisture sensing under varied terrain conditions. Six days of PALS flight data were acquired over the Little Washita and El Reno areas in Oklahoma, in conjunction with ground-based soil and vegetation in-situ sampling. The data illustrate the different sensitivities of the PALS channels to soil moisture, temperature, surface roughness, and vegetation cover, and will provide a basis for development of passive and active multichannel algorithms for soil moisture sensing.

Moran *et al.* (2000) designed an experiment to investigate the sensitivity of C-band SAR backscatter (σ_0) to surface soil moisture (θ_s) in a semiarid rangeland in Arizona, USA, and to test a data-fusion approach based on both optical (Landsat TM) and radar (ERS-2 SAR) measurements to improve regional estimates of surface soil moisture content. Three flat, uniformly vegetated sites of known surface roughness were monitored for variations in surface soil moisture, vegetation density and SAR signal over time, and eight optical/SAR image pairs were obtained throughout the dry and wet seasons. For these sparsely vegetated sites during this dry year (1997), the SAR signal was not significantly attenuated by sparse green vegetation cover (green leaf area index <0.35) and dense standing brown vegetation cover (brown leaf area index up to 1.5). Consequently, the approach could be implemented by simply taking the difference between the dry and wet season SAR σ_0 . For a dataset of eight dates at three study sites, the relation between ERS-2 C-band SAR σ_0 and θ_s was weak ($r^2=0.27$); yet for the same dataset, that the relation between $\sigma_0 - \sigma_{0dry}$ and θ_s was strong and significant ($r^2=0.93$). This study also raised two concerns: (1) the overall sensitivity of SAR σ_0 to θ_s was relatively low, and (2) the approach required a high level of accuracy in the estimate of green leaf area level that may not be obtainable with standard optical remote sensing algorithms. The results from this study should encourage the use of a multi-temporal SAR and optical/SAR fusion for monitoring semiarid range conditions, and improving management of scarce resources.

Lu and Meyer (2002) used the pair of repeat-pass ERS-1 synthetic aperture radar (SAR) images to study soil moisture changes over sparsely vegetated targets. The intensity of the SAR image acquired at one time was higher than that of an image acquired at an earlier time. A correlation image was computed from the SAR image pair to study the cause of the observed changes in SAR intensity. Because a reduction of correlation over areas with intensity changes was not observed, the intensity changes was interpreted as not being caused by changes in roughness/structure, but by a change in soil moisture owing to rainfall. An increase in soil moisture ranging from 5% to 20% is the most likely explanation for the increase of intensity. These analyses imply that both intensity and phase information should be used in SAR change detection applications.

Simonetta Paloscia (2002) reported that space borne imaging radar-C, L and X-band synthetic aperture radar (SIR-C/X-SAR) hydrological experiment, by using multi-frequency and multi-polarization synthetic aperture radar (SAR) data measured by JPL/AIRSAR, SIR-C, EMISAR, ERS-1, and JERS-1 sensors. The sensitivity of backscattering coefficients to some geophysical parameters that play a significant role in hydrological processes, such as vegetation biomass, soil moisture, and surface roughness, is discussed. Experimental results show that P band appears to be suitable for the monitoring of forest biomass, whereas L band is mainly sensitive to the biomass of wide-leaf crops and C band to narrow-leaf crops. Moreover, the L-band sensor gives the highest contribution in estimating soil moisture and surface roughness. The sensitivity of backscatter to soil moisture and surface roughness for

individual agricultural fields is rather low, since both parameters affect the radar signal. However, by observing data collected at different dates and averaged over a relatively wide agricultural area, the correlation with soil moisture becomes considerable, since the effects of spatial roughness variations are smoothed. Retrievals of both soil moisture and surface roughness were performed using a semi-empirical model.

Mattia *et al.* (2003) studied the relationship between C-band backscatter measurements and wheat biomass and the underlying soil moisture content. The study was based on a ground-based scatterometer experiment conducted on a wheat field at the Matera site in Italy during the 2001 growing season. From March to June 2001, eight C-band scatterometer acquisitions at HH and VV polarization, with incidence angles ranging from 23/spl deg/ to 60/spl deg/, were taken. At the same time, soil moisture, wheat biomass, and canopy structure were collected and investigated the radar sensitivity to biophysical parameters at different polarizations and incidence angles, and at different wheat phenological stages. Based on the experimental results, the retrieval of wheat biomass and soil moisture content using Advanced Synthetic Aperture Radar data was discussed.

Zribi *et al.* (2003) reported that surface soil moisture over low vegetated regions using the two active microwave instruments of ERS satellites. The developed algorithm takes advantage of the multi-angular configuration and high temporal resolution of the Wind Scatterometer (WSC) combined with the SAR high spatial resolution. As a result, a mixed target model was proposed. The WSC backscattered signal may be represented as a combination of the vegetation weighted by their representative fractional covers. The integral equation model was used to estimate the effect of surface roughness and to retrieve surface soil moisture from the WSC multi-angular measurements.

Notarnicola *et al.* (2006) assessed the possibility of obtaining soil moisture maps of vegetated fields using information derived from radar and optical images. The retrieval was obtained by using a Bayesian approach, where the key point was the evaluation of probability density functions (PDFS) based on the knowledge of soil parameter measurements and of the corresponding remotely sensing data. The correlation coefficients between measured and extracted soil moisture values were $R=0.68$ for C-band and $R=0.60$ for L-band. The PDFS parameters have been found to be correlated to the vegetation water content estimated from a Landsat image with correlation coefficients of $R=0.65$ and 0.91 for C- and L-bands, respectively. The results derived from the Bayesian approach have also been compared with a classical inversion method that was based on a linear relationship between soil moisture and the backscattering coefficients for horizontal and vertical polarizations.

Loew *et al.* (2006) reported that microwave remote sensing can provide spatially distributed patterns of surface soil moisture. In order to use remote-sensing-derived soil moisture information for practical applications as, for example, flood forecasting and water balance modeling in Mesoscale areas, frequent large-area coverage is a prerequisite. New sensor generations such as ENVISAT Advanced Synthetic Aperture Radar (ASAR) or RADARSAT allow for image acquisitions in different imaging modes and geometries. Imaging modes with the capability of large-area coverage, such as the Wide Swath Mode of ENVISAT ASAR, were of special interest for practical applications in this context. This paper presents a Semiempirical soil moisture inversion scheme for ENVISAT ASAR data. Different land cover types as well as mixed-image pixels are taken into account in the soil moisture retrieval process. The inversion results were validated against in situ measurements, and a sensitivity analysis of the model was conducted.

2.3 Surface soil properties

2.3.1 Physical properties of soil

2.3.1.1 Particle size distributions

While studying the physico-chemical properties of soils under different land use systems in central dry zone of Karnataka, Dhananjaya (2000) observed that soil texture was coarse at surface and finer at bottom this was attributed to illuviation of clay. Sahu and Mishra (1997) while studying the irrigated soils of Orissa reported that texture of soil ranging from loamy sand to loam in the surface and clay loam downwards. (74.4 to 44.4%), where as clay

content gradually increased with the depth (9.3 to 35.3%) indicating pedogenic soil development.

While studying comparative assessment of resource degradation under identified land use system in selected agro climatic zones of Karnataka, Sreerangappa (1998) reported that the texture of soils were sandy clay loam to sandy clay under agriculture, agro forestry and agri-horti systems. The clay content increased with soil depth, this was attributed to high rain fall resulting in vertical movement of clay down the soil profile, through the voids created by plant roots and decomposed organic matters.

2.3.1.2 Maximum water holding capacity

Water retention capacity of any given soil is dependent on adsorptive force of clay and pore size distribution (Rangaswamy and Murthy, 1978). The adsorptive capacity was more in expanding type of clay than non-expanding types. Misra *et al.* (1985) while studying the soils under grassland reported higher water holding capacity of the soil under silvipasture system compared to other land use systems. Mongia and Bandyopadhyay (1992) reported that moisture content was minimum under plantation and maximum under virgin forest. This was due to variation in vegetative covers and difference in their evaporative demands. The maximum water holding capacity increased with depth and was maximum under forest and pasture land compared to other land use system (Srinivasamurthy, 1989).

Hirekurubar *et al.* (1991) reported about some physical properties of vertisols derived from different parent materials of north Karnataka. Water holding capacity, available water capacity, plasticity index; specific area and total porosity were higher in soils derived from chlorite schist. Gaddi (1995) reported that Maximum water holding capacity in the black soil was higher (43.8% to 31.9%) in agro- climatic zone of Karnataka.

Sreerangappa (1998) and Dhananjaya (2000) observed that Maximum water holding capacity of soils increased in surface and sub surface soil of Horti-pasture as compared to agricultural system. This may be due to moderate amount of clay contents and improvement of soil structure.

2.3.1.3 Bulk density

Walia and Rao (1996) characterized and classified some red soils in Bundelkhand region of Uttar Pradesh and reported that low bulk density values of surface horizon (1.35 to 1.75 g/cc) are associated with relatively high organic matter content but its progressive increase with depth was probably related to increasing coarse fraction and or fragments of coarse sand or filling of pores by eluvial materials leading to compaction.

Jadhav (1990) conducted a field experiment to assess the change in soil fertility under wheat based cropping systems. Bulk density decreased significantly under groundnut-wheat-cropping than sorghum-wheat-cropping system. Water stable aggregates and moisture retention capacity of the soil increased due to inclusion of groundnut in the cropping sequence.

2.3.2 Soil chemical properties

2.3.2.1 Soil reaction (pH)

Sivasankaran *et al.* (1993) observed that the pH of red soils varied from 3.9 to 7.0 in western ghat of Karnataka and remarked that rainfall was the major factor contributed to the increase in acidity in these soils. Shivaprasad *et al.* (1998) while characterizing the soils of Karnataka observed that soils derived from granitic-gneiss materials were found to be slightly acidic to near neutral in reaction. Soils of Bangalore district were found to be acidic to near neutral and showed decreasing trend with the depth, as reported by Reddy *et al.* (1993).

In a study, on red soils of Bundelkhand region of Uttar Pradesh, Walia and Rao (1996) noticed that there was tendency of pH to increase with depth possible due to leaching of bases. Mahapatra *et al.* (2000) reported that soils of sub humid ecosystem of Kashmir region were generally slightly acidic to neutral in reaction, which was associated with high level of organic matter and leaching of bases due to sloping land scape and fluvial actions were as higher pH reported in some areas was due to calcareousness. Basavaraju *et al.* (2005) while characterizing and classification of soils of Chandragiri mandal of Chittoor district

in Andhra Pradesh observed that the pH of soil was generally slightly acidic to moderately alkaline in reaction.

2.3.2.2 Electrical conductivity

Working with red and black soils of Andhra Pradesh, Krishnamoorthy and Govindarajan (1977) observed that in red soils electrical conductivity values ranged from less than 0.15 to 0.25 dSm⁻¹ and did not show any trend with the depth of soil while electrical conductivity of black soil ranged from 0.15 to 0.80 dSm⁻¹ and showed increasing trend with depth. Gundlur (1991) concluded that the electrical conductivity was found to increase with depth in Vertisols in both the irrigated and unirrigated conditions.

Sivasankaran *et al.* (1993) while characterizing the soils of western ghat in Karnataka observed that the electrical conductivity values ranged from 0.1 to 0.4 dSm⁻¹ indicating no accumulation of salts in the soils, while characterizing the soils of the trans-yamuna plain, Walia and Rao (1997) reported that the electrical conductivity of these soils were very low ranging from 0.08 to 0.4 dSm⁻¹ did not show any specific relationship with the depth indicating the low amount of soluble salts in the soil.

2.3.2.3 Organic carbon (OC)

While, the organic matter content of arid and semiarid regions was low under virgin conditions, it commonly increased with the application of irrigation water and cultivation, especially when crop management is good and this organic matter, apart from being a source of nutrient to plants, also has a favorable effect on soil physical properties (USSL staff, 1954).

Krishnamurthy and Govinda Rajan (1977) working with black and red soils of Andhra Pradesh noticed higher organic matter in second horizon which later decreased in red soils while in black soils accumulation of organic matter was noticed in fourth horizon due to the down word movement of it along with clay.

Sivasankaran *et al.* (1993) while studying red and lateritic soils under plantation crops in southern India found that the organic carbon content of soils varied between 1 to 10 % and remarked that, it varied with altitude and cultural practices. Walia and Rao (1996) working with red soils of Bundelkhand region of Uttar Pradesh noticed that the organic carbon content of soils (0.5 to 1.5 %) increased with depth. The distribution was mainly associated with physiography and land use.

2.3.2.4 Free calcium carbonate

Desai (1942) reported that in general red soils were devoid of free CaCO₃ whereas associated black soils were rich in free CaCO₃ in some cases however; free CaCO₃ was present in small quantity in red soils due to the semi-arid climatic condition.

Maji *et al.* (2005) reported that the CaCO₃ and base saturation increases with the decreasing elevation and slope. The percent calcium carbonate in north Gujarat soils increased with depth and the values were 0, 1.8, 6.7 and 20.5 at 0-25, 25-50, 50-75 and 75-100 cm depth, respectively (Barde and Gowaikar, 1965). The adjoining soils of Uttar Pradesh have shown increase in calcium carbonate with depth and the values were 0.2 and 22.0 percent at surface and 1m depth, respectively (Sehgal *et al.*, 1968).

2.3.2.5 Free iron oxide

The dithionite extractable iron includes iron extracted from iron bearing secondary minerals and amorphous iron or stable allophanes (McKeague and Day, 1966).

Iron can move within the profile along with the movement of clay. Thus higher content of clay could be noticed in B₁ horizon (Krishnamurthy 1993 and Alur, 1994) of the alfisols of North Karnataka and in alfisols of Goa (Raghumohan and Bhonsle, 1993).

An increase in the dithionite extractable iron was noticed in the lower solum of lowland soils of North Karnataka (Patil and Dasog, 1997). They did not observe a definite trend in the distribution of dithionite extractable aluminium with in the pedons.

2.3.2.6 Available nutrient status

Ramamoorthy and Bajaj (1964) assessed the soil fertility status of Indian soils. They observed that soils of majority of the states were low in available nitrogen, medium in available phosphorus and medium to high in potassium status.

Dashratha singh *et al.* (1979) showed that soils under intensive cultivation had become poorer in available nitrogen and potassium. Soils under natural grasslands and cultivated pastures maintained their fertility status with respect to nitrogen and potassium while they become richer in phosphorus.

Divakar *et al.* (1989) assessed soil fertility status of five blocks of hilly region representing the horticultural area in Nainital region of Uttar Pradesh and found that all soils were slightly acidic to alkaline. Available nitrogen was high but available phosphorus and potassium was low in all the soils tested.

Vedavyasa (1989) reported that available plant nutrients such as nitrogen, phosphorus, potassium and sulphur increased significantly with the application of FYM or NPK fertilizers while the contents were highest under combination of both FYM and NPK fertilizers in agricultural system.

Chavan *et al.* (1995) observed that the available nitrogen, phosphorus and potassium increased very markedly in the surface layers. The changes of these nutrients were due to decomposition of organic matter added through the leaf litters.

Ashoka (1998) reported that forest tree species recorded higher available nutrients such as nitrogen, phosphorus, potassium and sulphur both at surface and subsurface soils respectively. Where as lower values were recorded in surface and subsurface soils for agricultural lands. Changes in nutrient status were due to decomposition of organic matter added through the leaf litter.

Sreerangappa (1998) and Dhananjaya (2000) found that available nutrients like nitrogen, phosphorus, potassium and sulphur contents were increased in both surface and subsurface soils of agriculture followed by agri-hort system.

Basavaraju *et al.* (2005) while characterizing and classification of soils of Chandragiri mandal of Chittoor district in Andhra Pradesh found that soils were low in available nitrogen, medium in available phosphorus, high in available potassium but deficient in sulphur, iron and zinc.

While studying morphological, physical and physico-chemical characteristics of soils in sivagiri micro-watershed of Chittoor district in Andhra Pradesh, Thangasamy *et al.* (2005) reported that soils were low to medium in available nitrogen, phosphorus and potassium and high in sulphur.

2.3.2.7 Available nitrogen

Mruthyunjaya and Kenchanagowda (1993) while studying some salt affected soils of Cauvery and Vanivilasagar command areas of Karnataka reported that the available nitrogen in the profiles ranged from 30.71 to 10.51 kg per hectare. Nitrogen content decreased with depth.

In Karnataka about 10.3 per cent of soils fall under low category, 35.8 per cent under medium and 53.9 per cent under high category of available nitrogen status (Shivaprasad *et al.*, 1998).

2.3.2.8 Available phosphorus

Gangappa (1989) reported that the available phosphorus content of salt affected soils of Chitradurga district (Karnataka), varied from 2.69 to 80.64 kg per ha. In profile samples, it ranged from 2.72 to 41.2 kg per ha. The available phosphorus increased with depth in profile samples.

While characterizing and classifying soils of an irrigated river flood plain in the eastern coastal region, Sahu and Mishra (1997) reported that available phosphorus content varied between 12.76 to 14.00 kg per ha and was in medium level.

The data on the available phosphorus status in the soils of Karnataka showed that about 83 per cent of the soils are low in phosphorus and 17 per cent area is under medium category (Shivaprasad *et al.*, 1998).

2.3.2.9 Available potassium

While Characterizing and classifying soils of an irrigated river flood plain in the eastern coastal region, Sahu and Mishra (1997) reported that the available potassium content varied from 171.0 to 211.66 kg per ha and was in medium level.

The available potassium content of surface soil ranged from 0.082 to 0.03, 0.015 to 0.026 and 0.031 to 0.033 percent in Peelamedu, Periyannayakkan palayam and Dasarpatty series, respectively and in general its content decreased with depth (Parasuraman and Jayaraj, 1982).

The available potassium was medium to high in most of the soils of the Karnataka state except in lateritic soils of coastal plain and Western Ghats and in shallow red and black soils where it is low (Shivaprasad *et al.*, 1998).

2.3.2.10 Available sulphur

Balanagoudar (1989) studied 15 soil bodies representing red, black and lateritic soils in north Karnataka for sulphur status and forms of sulphur. The available sulphur content in different soils in surface in decreasing order was red soils > black soils > lateritic soils.

Ashok (2001) examined 12 soil series representing black, Red and coastal soils from different agro-climatic zones of Karnataka and 12 surface soil samples from each series are analyzed for sulphur status and distribution of different forms of sulphur, relationship between sulphur and various soil properties. The CaCl_2 extracted sulphur content in black, red and coastal soils ranged between 5.08 to 59.95 ppm, 8.66 to 27.15 ppm and 7.26 to 20.32 ppm, respectively.

2.3.2.11 Exchangeable calcium and magnesium

Madhumitas *et al.* (1997) observed that higher content of calcium and magnesium in agricultural lands as compared to fallow land.

Sreerangappa (1998) found high values of exchangeable calcium and magnesium both surface and subsurface soils of horti-pasture whereas; a lower value was recorded in surface and subsurface soils of horticulture system. Changes of these nutrients were due to decomposition of organic matter added through the roots of grasses and the leaf litters.

Dhananjaya (2000) reported that the highest values of exchangeable calcium and magnesium were reported in surface and subsurface soils in silvi-pasture system whereas the lower values were recorded in natural system.

2.3.2.12 DTPA extractable micronutrients

Singh *et al.* (1993) found that the highest DTPA extractable Zn and Mn in forest and agricultural soils but did not show marked differences with waste lands. Rainfed agricultural lands were poorer in micronutrients than irrigated agricultural lands.

Venkatesh Bhardwaj *et al.* (1994) indicated that FYM when applied along with 100 per cent dosage of NPK increased the DTPA extractable micronutrients.

Ashoka (1998) reported that DTPA extractable iron, manganese, zinc and copper content of surface and subsurface soils were higher in the lands of forest trees as compared to agricultural lands.

Sreerangappa (1998) observed that DTPA extractable micronutrients like iron, manganese, zinc and copper were higher in surface and subsurface soils of Silvi-pasture system as compared to natural system.

Satyavathi and Suryanarayana Reddy (2004) studied fifty four soil samples from ten pedons of Telangana region. Andhra Pradesh for vertical distribution of DTPA- extractable Zn, Cu, Fe and Mn and their relationship with some soil properties. Soil pH, calcium carbonate, organic carbon and particle size fractions had strong influence on the distribution of these micronutrients. The content of micronutrient increased with the increase in organic carbon

and decreased with increase in pH and CaCO_3 . There was no definite trend for the distribution of these micronutrients with respect to depth. As per critical limit prescribed for Zn and Fe, 44 and 20 per cent of the soils could be rated as deficient in available zinc and iron respectively. Copper and manganese were found to be adequate.

Krishna Murthy and Srinivas Murthy (2005) studied fifty surface soil samples from black and red regions representing different agro climatic zones of Karnataka for the distribution of DTPA- extractable Zn, Cu, Fe, Mn and hot water soluble boron and for their relationship with some soil properties. The deficiency of Zn was noticed in large number of soil series studied compare to Cu and B deficiency. While, Fe and Mn were found to be adequate in all the soil series. In black soil region, available Mn and Zn correlated positively with organic carbon and but non-significantly with clay. In red soil region, available Fe, B and Zn showed significant and positive relationship with clay. Available Cu, Fe, Mn and B showed positive relationship with organic carbon except zinc.

2.4 Mapping fertility status of soils using GIS

The soil fertility status database created using GIS of Madhubani district at 1:50,000 scale and subsequent analysis of the selected soil samples. Soil fertility evaluation were done on 1 km grid point observation by Maji *et al.* (1997) revealed that 89 per cent area of the district was low to medium in organic carbon and low in available nitrogen, while in phosphorous 82 per cent area of the district was low.

Srinivas and Ramesh (1997) generated the fertility map of Goa using GIS. They reported that available P and K fall in three categories viz., low, medium and high. Majority of the samples showed low P and K was medium.

Soil fertility status of Karnataka as assessed by Shivaprasad *et al.* (1998) by collecting the grid soil samples (1906 grids) all over the state. The soils were analysed for pH, EC, organic carbon, available phosphorus and potassium. The data has been used to prepare nutrient status maps for individual nutrients using GIS. The Western Ghats area, coastal plain and Malnad areas were high in available nitrogen while the area under irrigation and the hilly areas were medium in nitrogen and rest of the area was low in nitrogen. With respect to available P, 86 per cent of the area was low and 17 per cent high. The available potassium content was high in majority of the soils except coastal plains and Western Ghats were it was low.

Binitha (2002) made an attempt to assess and mapping the soil fertility status of a portion of GLBC command area. The mapping of available nitrogen content ranged from 211-321.6 kg/ha with in 19540 ha as low and 26490 ha as medium status. The available phosphorus content ranged from 12 to 38 kg/ha with 11354 ha area recording medium and 34677 ha area as high in P status. The available potassium was high in 40612 ha and medium in 5418 ha area ranging from 201 to 689 kg/ha.

Ravikumar (2004) characterized and classified the soil resources of 48A Distributary of Malaprabha Right Bank Command for sustainable land use planning and assessed the productivity of the soils. The mapping of available nutrient status by GIS technique indicated that majority of the area was low to medium with respect to available N, P and S. The entire study area was high in K. Among the micronutrients, the majority area was deficient in iron and zinc, whereas manganese and copper status was low to sufficient. The crop cutting experiment revealed that the yields of the crops were in general low as soils were deficient in N, P, S, Zn and F.

Minakshi *et al.* (2005) assessed the micronutrient status of soils using Arc-info GIS. The 690 surface soil samples were analyzed for soil physico-chemical properties and DTPA-extractable micronutrients. About 11% (39,369 ha) of TGA of the Patiala district was deficient in Zn. Only 4 and 5% of the area was deficient in Mn and Fe, respectively. Deficiency of two or three micronutrients in combination was sparsely distributed. Individually, Zn followed by Mn, Fe and Cu was found deficient in the Patiala district.

3. MATERIAL AND METHODS

The particulars relating to the general description of the area, geographical setting of the study area viz., relief, drainage, climate, geology, collection and preparation of soil samples and the analytical methods adopted in the investigation are briefly presented in this chapter.

3.1 General description of the area

The selected area, the Bhanapur microwatershed lies 13 km away from Koppal district headquarter. Black and red soils occur adjacently in this area, which is also feature of the sub-watershed. The study area belongs to Northern Dry Zone, receiving lowest rainfall among all the dry zones of Karnataka. The availability of the moisture is limiting factor for crop production. Soil moisture also depends on soil types. Hence, characterization of the area is crucial for better agricultural production.

3.2 Location of the study area

The selected Bhanapur microwatershed belongs to Yelaburga taluk of Koppal district (Fig. 1). The Bhanapur microwatershed is located between 15°24'10" and 15°22'40" N latitude and 76°0'55" and 76°21'25" E longitude.

3.3 Relief and drainage

The average elevation of the study area is 671 m above mean sea level. The relief is nearly level to very gently slopping. The general slope of the area is towards north east and west. The drainage pattern is dendritic.

3.4 Geology

The peninsular gneiss covers the Bhanapur microwatershed area. The predominant minerals noticed in the peninsular gneiss are oligoclase and orthoclase feldspar besides some dark coloured minerals.

3.5 Climate

The climate of the area is semi-arid type with mean annual average rainfall of 572 mm. The summer season starts from third week of February and continues up to the middle of June, winter commences from first or second week of November and continues upto the middle of February or sometimes up to the end of February. The monsoon starts from end of June and continues up to end of October.

3.6 Natural vegetation and land use

Accasia spp. (*Accasia auruculiformis*) and Neem (*Azadiractia indica*) are the predominant trees found in the study area. The economy of the area revolves around agriculture. The crop selection is based on the soil type. In general, sunflower, cotton, maize, chilli, jowar are grown on black soils and groundnut, bajra, sunflower are grown on red soils.

3.7 Estimation of soil moisture by RADAR remote sensing

3.7.1 Soil sampling (Ground Truth locations)

An extensive real time ground truth (GT) on the 6 days of ENVISAT-1 pass during 2005 (24th June, 13th July, 29th July, 17th August, 2nd September and 21st September) had been collected at 0-5 cm and 5-10 cm depth of soil. Fifty well distributed locations in the micro watershed were selected for assessment of soil moisture (10 soil samples from black soils and 40 samples from, red soils). Latitude and longitude of sampling sites were recorded with the help of GPS.

3.7.2 Gravimetric soil moisture sampling with the scoop tool

Surface soil samples from 0-5cm and 5-10 cm were collected in triplicate using the special sampling tool. The sample (approximately 100-150 grams) was put in previously

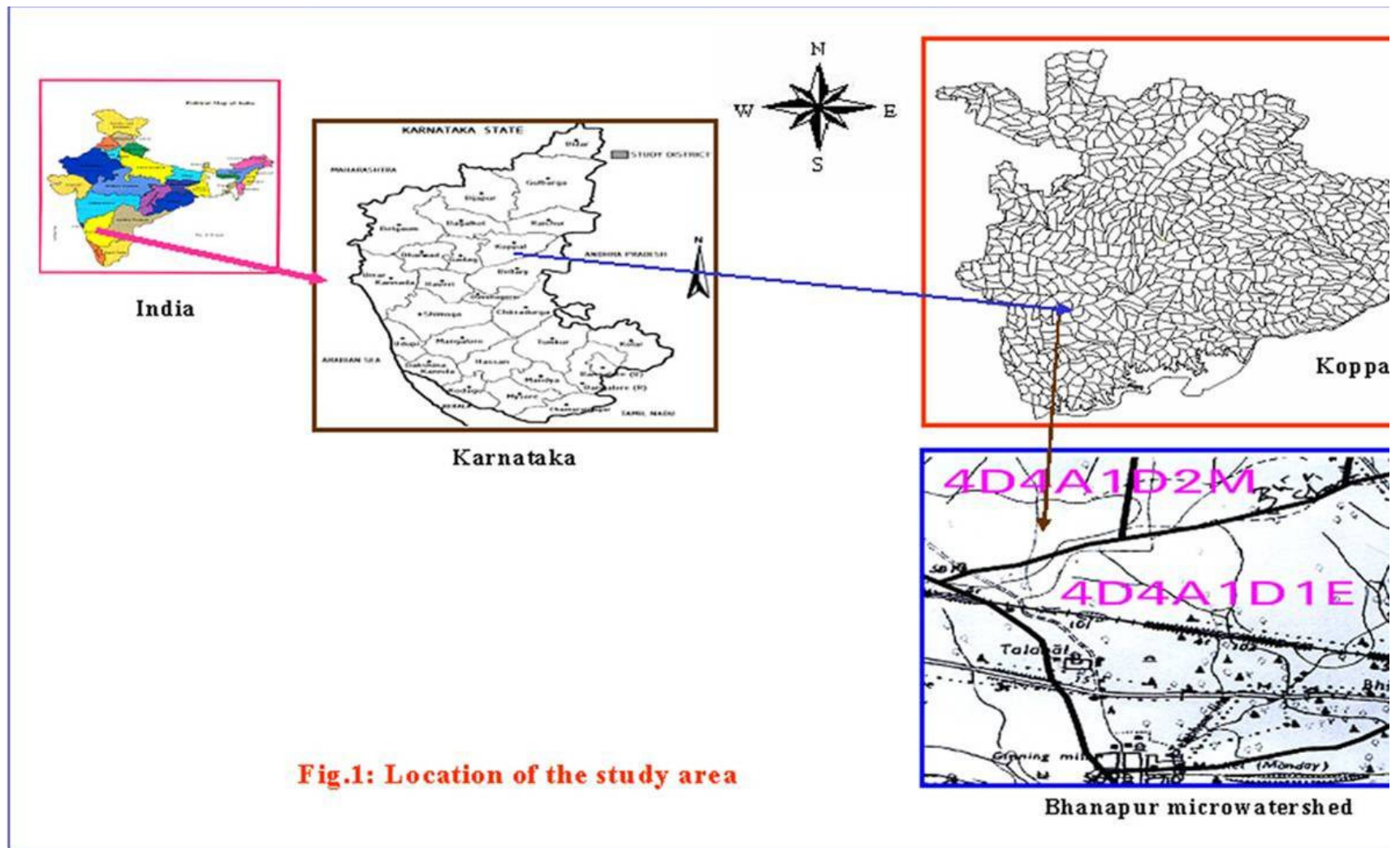


Fig 1. Location of the study area

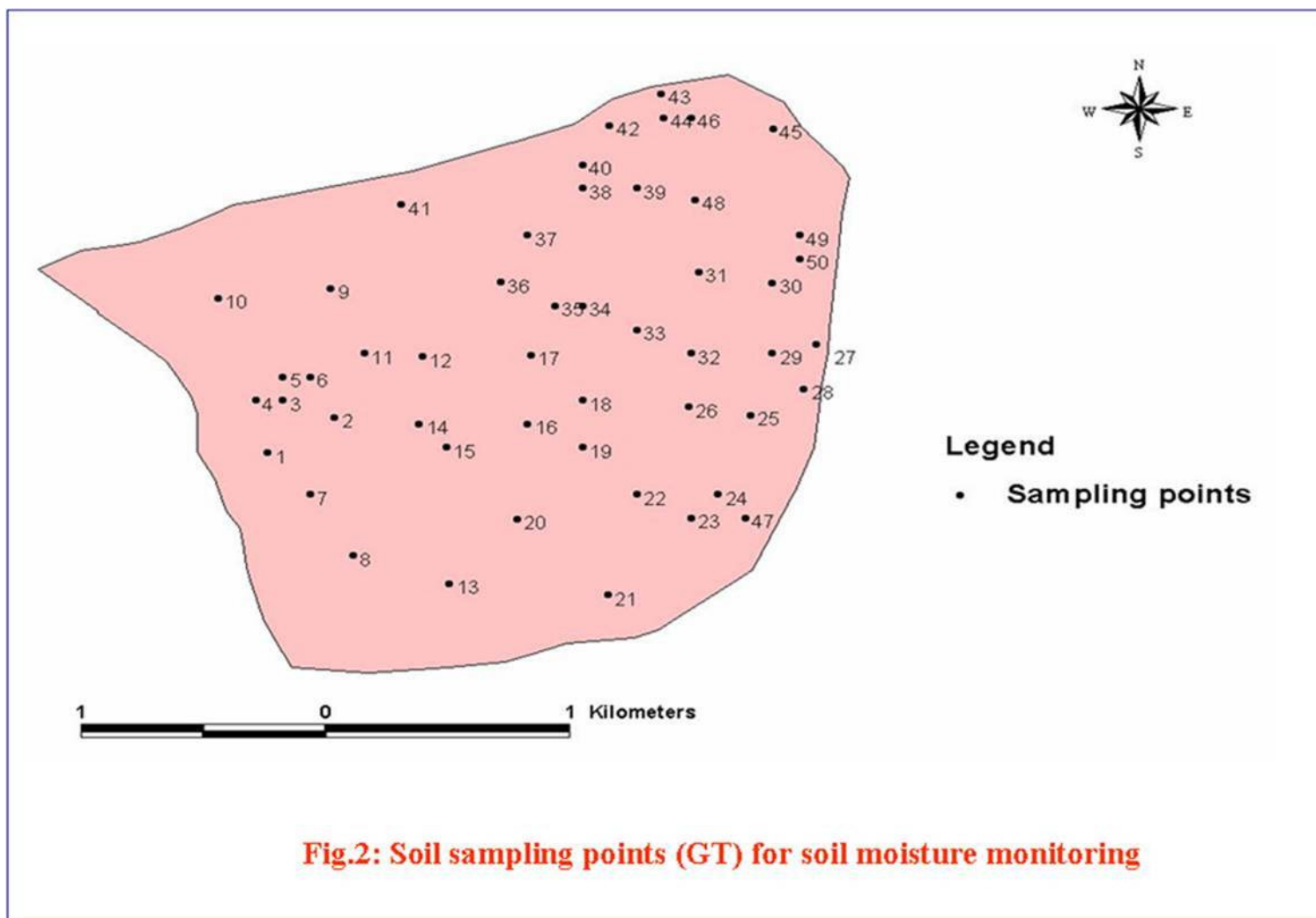


Fig 2. Soil sampling points (GT) for soil moisture monitoring

weighed aluminium cans and sealed with cellopane tape. Each sample can was identified by the sample site ID code. Fresh/ wet weight of the sealed boxes was recorded immediately. Then the cans were placed in oven at 105⁰ C for drying. The weight of oven dried samples was recorded and finally the soil moisture content was calculated and expressed on oven dry weight basis as well as volume basis.

3.7.3 ENVISAT advanced synthetic aperture radar (ASAR)

The ENVISAT satellite was launched by the European Space Agency in March 2002. It is designed to provide earth observations using a suite of remote sensing instruments. Advanced Synthetic Aperture Radar that will provide both continuity to the ERS-1 and ERS-2 mission SARs and next generation capabilities. ENVISAT also has a visible and near infrared imaging system ENVISAT has a sun synchronous polar orbit. The exact repeat cycle for a specific scene and sensor configuration is 35 days.

ENVISAT'S ASAR system operates in the C band (frequency is 5.3 GHz). In the image mode, ASAR generates four-look high resolution (30 m) images and operates in one of seven predetermined swath configurations (IS1- IS7), with swath width ranging from 58 to 109 km and look angle ranging from 15° to 45°. ASAR data in alternating polarization precision image (API) mode HH (send signal horizontally and receive horizontally) / HV (send signal horizontally and receive vertically) was acquired for the test site in descending mode from the month of May to September 2005 in IS-1, IS-2 swath mode (out of the available 7 swath modes) with the incidence angles ranging from 15° to 24° because of their low incidence angle when compared to other swath mode available. Each dataset cover an area of 100 Km² (approx.). These products are geocoded with un- signed 16-bit radiometric resolution of 30 x 30 m, pixel size of 12.5 x 12.5 m and swath coverage of 100 sq.km approx.

3.7.4.1 Processing of ASAR data (Fig. 3a, 3b and 4)

3.7.4.1 Speckle filtration

Acquired ASAR data was processed by following the principles explained by Henderson and Lewis (1998), using ERDAS 8.7 image processing software. Parameters required for calculation of sigma nought (σ^0) were read from header file in the data CD. To reduce speckle noise inherent in the radar data, lee-sigma speckle filter with window size of 5 x 5 was applied. Speckle filtration was continued till the CV of about 0.15. This filter reduces the speckle to minimum and retained sharpness and edges of the features. The filtered ASAR data was registered with the available IRS-P6 LISS-III data for better identification of ground sample points. The backscatter coefficient (σ^0) is the portion of the microwave energy scattered by the terrain surface directly back toward the antenna. Creation of backscatter image is the basic step for calculating the soil moisture. In order to calculate the backscattered image, various information like incidence angle, azimuth angles etc. are recorded from the header file of the radar image.

3.7.4.2 Calculation and extraction of backscatter coefficient (σ^0) from ENVISAT-1 ASAR data and relating to volumetric soil moisture

Backscatter coefficient for each speckle separated image was calculated by building model with the help of ERDAS 8.7 image processing software, using the equation;

$$\sigma^0 = 10 \cdot \log_{10} (DN^2/K) \cdot \sin(i)$$

Where

σ^0 = backscatter in dB (decibel)

DN = pixel value of the image

K = absolute calibration constant (obtained from raw image header)

i = incidence angle of the image (23⁰).

The backscatter coefficient calculated image was named as σ^0 images. On the same viewer of σ^0 image, vector layer of GT points was over laid. Individual GT points were zoomed to see pixels. A polygon was drawn around each GT point using AOI tools to include near-by pixels. With the help of classifier on ERDAS main tool, statistics (minimum,

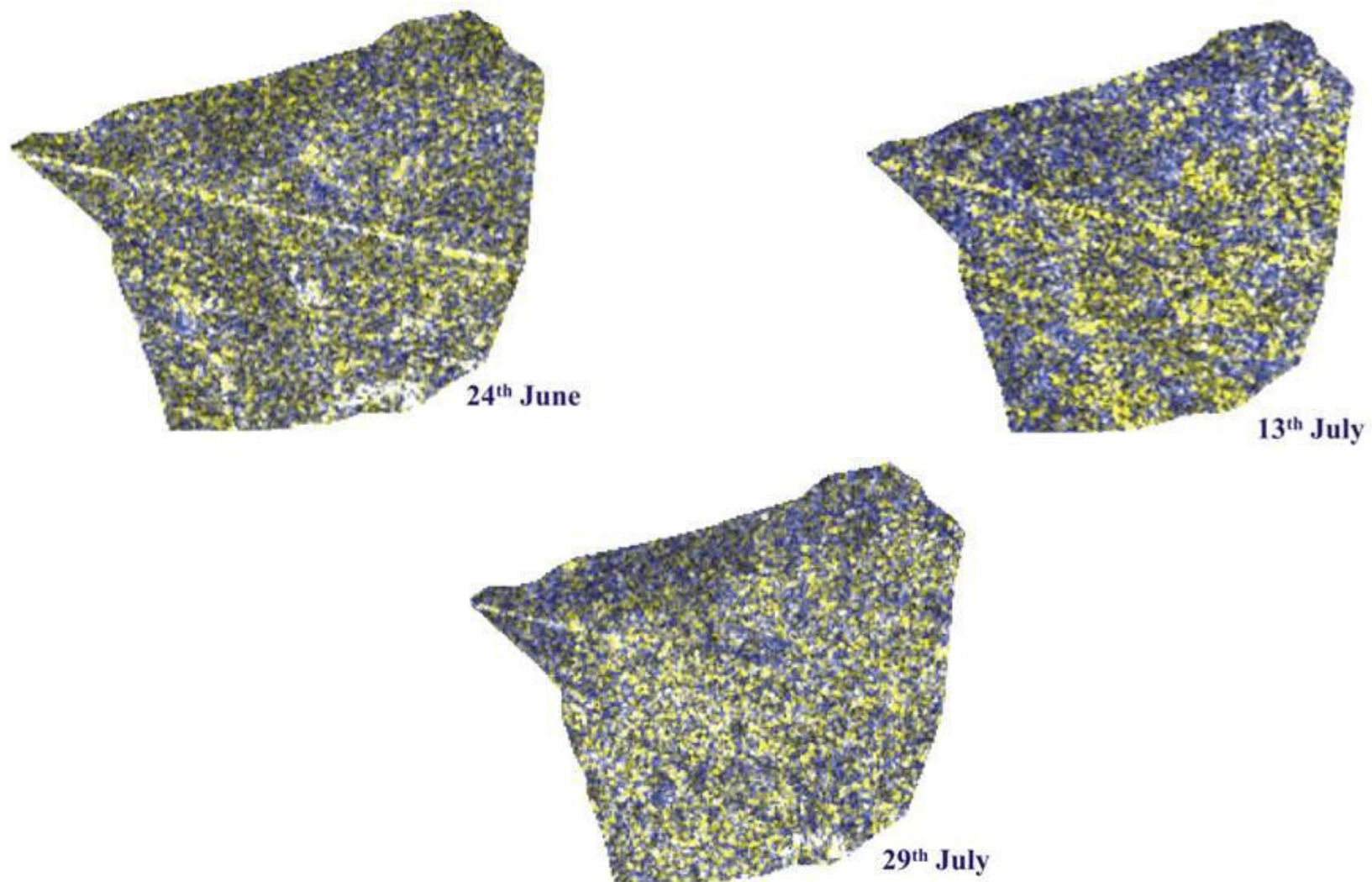
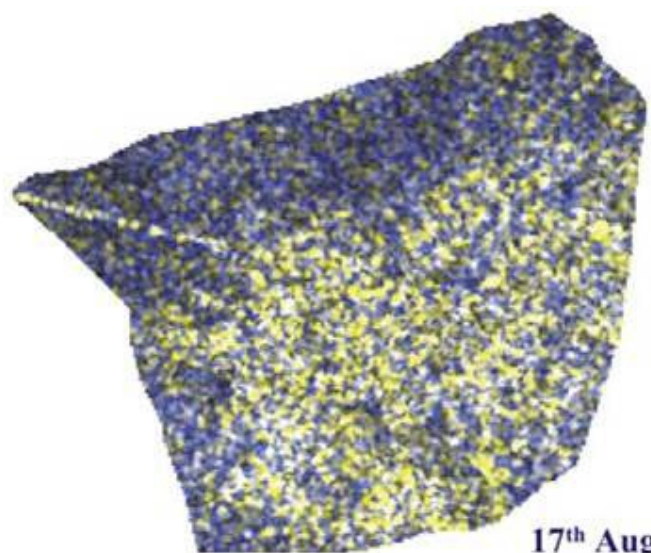
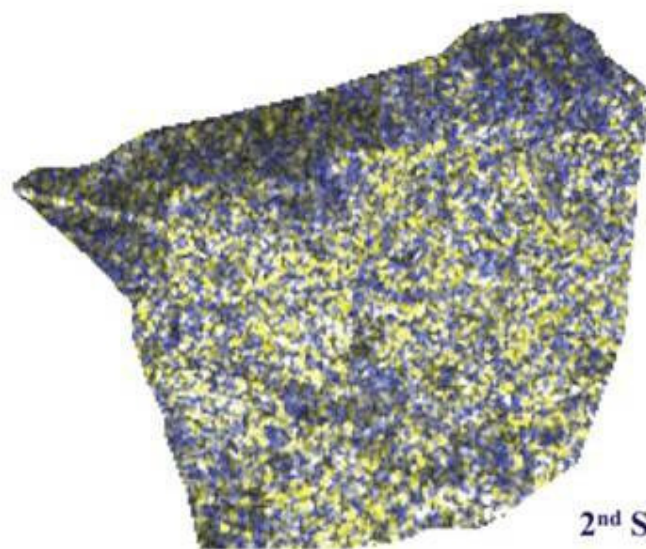


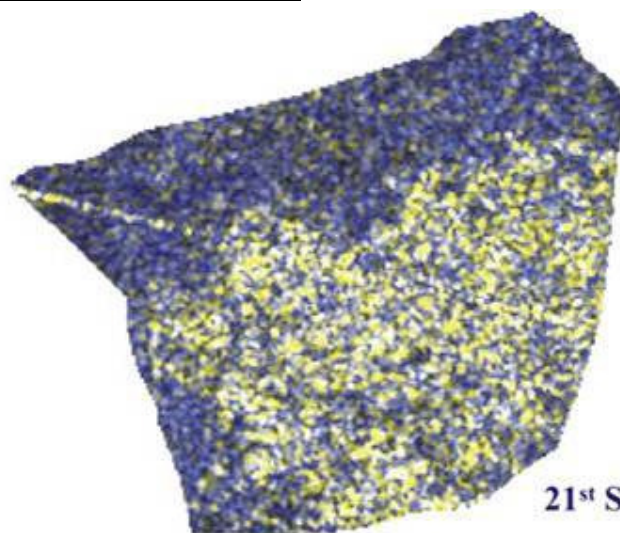
Fig 3a. ENVISAT-1 ASAR images on 24th June, 13th July and 29th July, 2005



17th August



2nd September



21st September

Fig 3b. ENVISAT-1 ASAR images on 17th August, 2nd September and 21st September, 2005

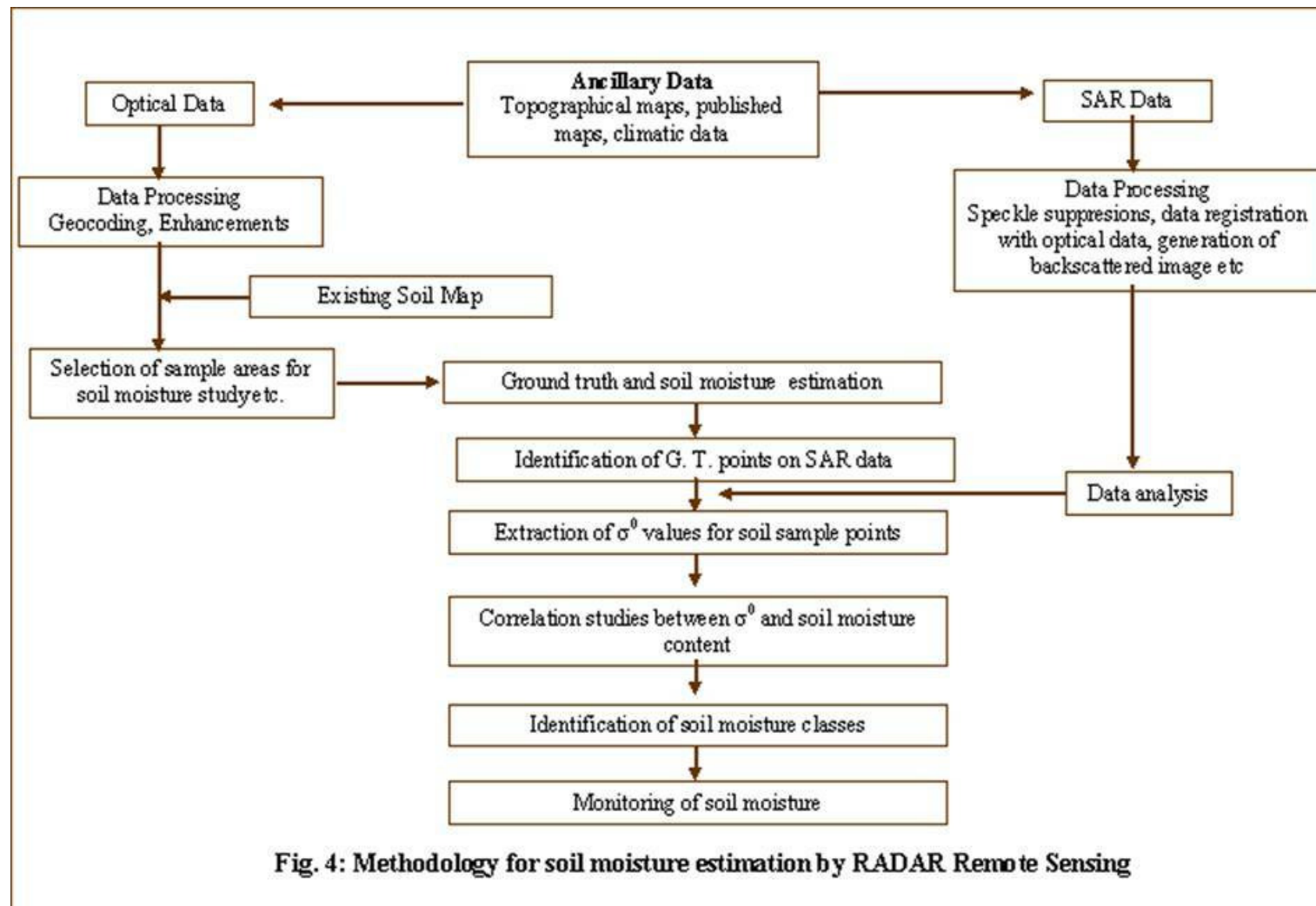


Fig 4. Methodology for soil moisture estimation by RADAR Remote Sensing

maximum, mean and SD) for σ^0 of HH and HV layers was extracted. The σ^0 values for HH and HV layers were correlated with volumetric soil moisture, separately for red and black soils.

3.8 Assessment of soil productivity

The yield of various crops being grown in the microwatershed was estimated by crop cutting experiment method and expressed as kg ha^{-1} .

3.9 Assessment of soil productivity constraints

Soil physical and chemical properties and nutrient status of micro watershed were estimated to assess soil productivity constraints.

3.9.1 Collection of samples

Soil samples (0-30 cm) at random (25 from black soils and 75 from red soils) were collected during March 2006. The exact sample location was recorded using a GPS (Appendix II).

3.9.2 Preparation and storing of the soil samples

The collected soil samples were air dried in shade. The air dried samples were ground with wooden pestle and mortar and passed through 2 mm sieve to separate the coarse fragments (>2 mm). The sieved soil samples were stored in separate clean and dry containers and used for various physical and chemical analyses including available nutrients for identification of soil productivity constraints.

3.10 Methods of soil analysis

3.10.1 Physical properties

3.10.1.1 Particle size analysis

Particle size analysis of soil samples was carried out by hydrometer method as explained by Piper (1966).

3.10.1.2 Bulk density

Bulk density of soil samples was determined by core samples method as described by Black (1965).

3.10.1.3 Maximum water holding capacity

Maximum water holding capacity of soil samples was determined by using Keen's cup as described by Piper (1966). Fifty percent of maximum water holding capacity was assumed as moisture content at field capacity.

3.10.1.4 Soil depth

Depth of soil in microwatershed was determined by digging pit at random and thickness of soil solum was measured.

3.10.2 Chemical Properties

3.10.2.1 Soil reaction

The pH of soil samples was determined in 1:2.5 soil-water suspension with glass electrode using pH meter (Jackson, 1967).

3.10.2.2 Electrical conductivity

Electrical conductivity of 1:2.5 soil water extract was determined by using Conductivity Bridge and expressed as dS m^{-1} (Jackson, 1967).

3.10.2.3 Organic carbon

Organic carbon was estimated by Walkley and Black wet oxidation method where organic matter in finely ground soil samples was oxidized by chromic acid by making use of heat of dilution of sulphuric acid for reaction (Jackson, 1967).

3.10.2.4 Free calcium carbonate

The free calcium carbonate of soil samples was determined by rapid titration method using standard HCl (Piper, 1966).

3.10.2.5 Free iron oxide

The free iron oxides in soil samples were extracted by citrate bicarbonate-dithionite procedure as described by Mehra and Jackson (1958). Iron in the extract was determined colorimetrically by orthophenanthroline method (Jackson, 1979).

3.10.2.6 Available nitrogen

Available nitrogen of soil samples was estimated by modified alkaline permanganate method where the organic matter in soil was oxidized with hot alkaline KMnO_4 solution. The ammonia (NH_3) evolved during oxidation was distilled and trapped in boric acid mixed with indicator solution. After cooling the contents of distillation flask, nitrate nitrogen reduced to NH_3 using Devarda's alloy and distilled. The total amount of NH_3 was estimated by titrating with standard acid (Sharawat and Burford, 1982).

3.10.2.7 Available phosphorus

Available phosphorus in soil samples was extracted by Bray's and Kurtz method for red soils ($0.03 \text{ N NH}_4\text{F} + 0.025 \text{ N HCl}$) and Olsen's method for black soil (0.5 N NaHCO_3) as described by Jackson (1967). Phosphorus in the extract was reduced by ascorbic acid in presence of H_2SO_4 and estimated using spectrophotometer at 660 nm against P standards.

3.10.2.8 Available potassium

Available potassium in soil samples was extracted using neutral normal ammonium acetate (pH 7.0) and K in the extract was estimated with the help of flame photometer (Jackson, 1967).

3.10.2.9 Available sulphur

Available sulphur in soil samples was extracted with 0.15% CaCl_2 extractant and sulphur in solution was estimated by turbidometry as outlined by Jackson, (1973) using spectrophotometer at 420 nm.

3.10.2.10 Available Ca and Mg

Calcium and magnesium in the ammonium acetate extract was estimated by versenate titration method (Jackson, 1967).

3.10.2.11 DTPA extractable micronutrients (Zn, Fe, Mn, Cu)

Available Zinc, Iron, Manganese and Copper were determined by following Lindsay and Norvell's method (1978). A 20 gram of soil sample with 40 ml of DTPA extractant ($0.005 \text{ M DTPA} + 0.01 \text{ M CaCl}_2$ and $0.1 \text{ M triethanolamine}$ adjusted to pH 7.3) was shaken for two hours and filtered through Whatman No.42 filter paper. The concentration of Zn, Fe, Mn, and Cu in the filtrate was read using atomic absorption spectrophotometer (model aa630-1 of shimadzu).

3.11 Preparation of thematic maps by GIS techniques

A dbf file consisting of data for X and Y coordinates in respect of sampling site location was created. A shape file (Vector data) showing the outline of Bhanapur microwatershed area was created in Arc view 3.2a.

The dbf file was opened in the project window and in X-field, X-coordinates were selected and in Y-field, Y-coordinates were selected. The Z field was used for different parameter. The Bhanapur microwatershed file was also opened and from the 'surface menu' of Arc view spatial analyst "Interpolate grid option" was selected.

On the output "grid specification dialogue", output grid extent chosen was same as Bhanapur microwatershed and the interpolation method employed was spline. Then map was reclassified based on ratings of respective parameter.

4. EXPERIMENTAL RESULTS

Results of the investigation carried out to assess the soil moisture status and analysis physical and chemical characteristics and nutrients status of surface samples representing red and black soils are presented under the different headings as follows.

4.1 Soil moisture estimation by RADAR remote sensing and monitoring of soil moisture

4.2 Physical properties

4.3 Chemical properties

4.4 Fertility status

4.5 Soil moisture and nutrients mapping

4.1 Soil moisture estimation by RADAR remote sensing and monitoring of soil moisture

4.1.1 Extraction of backscattered (σ^0) values from ENVISAT-1, ASAR images in different dates of pass (cf. Table 1)

4.1.1.1 Backscattered values for 24th June 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -19.57 to -25.65 dB with mean and standard deviation of -21.45 and 1.88 dB respectively. Where as, backscattered values in HH polarization varied from -10.12 to -19.07 dB with mean and standard deviation of -13.97 and 2.71 dB, respectively.

Backscattered values of red soils at HV polarization ranged from -16.20 to -25.87 dB with mean and standard deviation of -21.60 and 2.11 dB respectively, Where as backscattered values in HH polarization varied from -10.37 to -20.03 dB with mean and standard deviation of -14.58 and 2.09 dB, respectively.

4.1.1.2 Backscattered values for 13th July 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -16.57 to -26.12 dB with mean and standard deviation of -20.05 and 2.78 dB respectively. Whereas, backscattered values in HH polarization varied from -3.12 to -12.17 dB with mean and standard deviation of -6.93 and 3.33 dB, respectively.

Backscattered values of red soils at HV polarization ranged from -15.46 to -22.88 dB with mean and standard deviation of -19.66 and 1.94 dB respectively. Where as, backscattered values in HH polarization varied from -1.48 to -10.80 dB with mean and standard deviation of -7.93 and 2.26 dB, respectively.

4.1.1.3 Backscattered values for 29th July 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -11.97 to -23.21 dB with mean and standard deviation of -18.69 and 2.90 dB respectively. Where as, backscattered values in HH polarization varied from -3.12 to -14.26 dB with mean and standard deviation of -9.96 and 3.94 dB, respectively.

Backscattered values of red soils at HV polarization ranged from -14.43 to -22.62 dB with mean and standard deviation of -18.40 and 1.95 dB respectively. Where as, backscattered values in HH polarization varied from -7.22 to -13.91 dB with mean and standard deviation of -11.52 and 1.19 dB, respectively.

4.1.1.4 Backscattered values for 17th August 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -14.21 to -20.11 dB with mean and standard deviation of -17.37 and 1.83 dB respectively. Where as, backscattered values in HH polarization varied from -5.12 to -11.56 dB with mean and standard deviation of -8.87 and 1.61 dB, respectively.

Backscattered values of red soils at HV polarization ranged from -13.58 to -25.48 dB with mean and standard deviation of -18.15 and 2.79 dB respectively. Where as,

Table 1: Backscattered (σ^0) values (dB) for ENVISAT-1 ASAR images on different dates during 2005

Sample No.	Backscattered values (dB) on different dates during 2005 at HV and HH polarization											
	24 th June		13 th July		29 th July		17 th August		2 nd September		21 st September	
	HV	HH	HV	HH	HV	HH	HV	HH	HV	HH	HV	HH
	1	2	3	4	5	6	7	8	9	10	11	12
	Black soils											
1	-21.38	-12.76	-16.57	-12.13	-11.97	-9.08	-17.47	-9.46	-14.40	-8.65	-11.68	-11.67
2	-19.83	-15.44	-19.25	-12.17	-17.97	-10.41	-15.24	-8.54	-13.21	-6.24	-14.19	-8.03
3	-25.65	-12.20	-21.30	-6.12	-19.21	-13.12	-17.13	-9.15	-21.82	-10.85	-23.18	-9.94
4	-22.06	-19.07	-20.00	-3.19	-18.66	-13.21	-14.21	-5.12	-18.72	-16.25	-22.67	-11.73
5	-20.36	-14.70	-19.92	-4.31	-23.21	-14.26	-18.59	-8.69	-17.80	-11.54	-18.40	-7.73
6	-19.57	-13.64	-17.54	-5.21	-17.37	-12.04	-15.75	-11.56	-13.67	-10.04	-15.53	-4.29
7	-19.99	-12.25	-17.28	-7.73	-18.13	-3.46	-17.86	-9.34	-17.68	-8.42	-16.00	-8.12
8	-22.06	-12.14	-20.45	-6.12	-19.59	-3.12	-20.11	-9.56	-23.66	-16.25	-25.66	-12.52
9	-20.43	-10.12	-26.12	-9.21	-20.91	-8.76	-19.12	-8.13	-20.03	-13.71	-22.25	-13.24
10	-23.14	-17.40	-22.09	-3.12	-19.91	-12.12	-18.21	-9.16	-21.35	-10.00	-21.29	-14.47
Mean	-21.45	-13.97	-20.05	-6.93	-18.69	-9.96	-17.37	-8.87	-18.23	-11.19	-19.08	-10.17
SD	1.88	2.71	2.78	3.33	2.90	3.94	1.83	1.61	3.60	3.32	4.58	3.12
Range	-19.57 - -25.65	-10.12 - -19.07	-16.57 - -26.12	-3.12 - -12.17	-11.97 - -23.21	-3.12 - -14.26	-14.21 - -20.11	-5.12 - -11.56	-13.21 - -23.66	-6.24 - -16.25	-11.68 - -25.66	-4.29 - -14.47
	Red soils											
1	-19.61	-13.69	-19.22	-5.48	-17.08	-7.22	-13.59	-9.89	-14.60	-11.82	-18.14	-13.16
2	-22.70	-17.58	-20.06	-10.80	-20.50	-12.00	-18.50	-8.51	-16.61	-6.28	-12.74	-10.61
3	-21.74	-13.25	-18.26	-7.85	-17.68	-11.53	-15.41	-4.06	-16.15	-11.36	-18.27	-6.98
4	-23.94	-17.24	-17.73	-8.24	-17.37	-11.97	-15.78	-6.66	-14.46	-10.87	-14.39	-11.34
5	-23.41	-16.28	-22.71	-6.01	-17.23	-11.41	-14.02	-8.54	-14.15	-11.25	-15.89	-7.48
6	-20.06	-13.61	-18.55	-9.09	-18.80	-11.24	-17.68	-9.13	-19.05	-9.27	-14.49	-11.79

Contd.....

7	-24.13	-17.27	-22.17	-8.75	-21.16	-10.76	-25.48	-11.13	-24.67	-11.88	-19.82	-8.86
8	-20.32	-14.46	-21.84	-9.96	-17.10	-10.73	-17.97	-6.79	-15.56	-9.80	-14.21	-11.55
9	-20.35	-13.22	-21.84	-6.85	-17.10	-10.73	-17.97	-6.79	-15.56	-9.80	-14.21	-11.55
10	-21.86	-13.74	-19.17	-9.96	-19.04	-13.56	-21.34	-12.92	-18.26	-9.92	-17.89	-11.47
11	-21.96	-13.85	-19.93	-6.86	-21.06	-10.25	-17.99	-11.81	-18.52	-9.15	-17.07	-9.26
12	-22.92	-12.31	-16.52	-10.24	-20.32	-10.90	-17.58	-7.73	-17.94	-9.41	-19.83	-11.67
	1	2	3	4	5	6	7	8	9	10	11	12
13	-24.56	-12.93	-19.98	-8.03	-14.43	-12.58	-21.86	-10.82	-16.49	-7.86	-17.89	-9.24
14	-16.20	-11.72	-19.77	-7.68	-17.58	-12.35	-22.74	-11.26	-14.52	-8.27	-21.47	-14.12
15	-20.36	-16.31	-21.52	-6.75	-18.63	-11.68	-18.86	-9.78	-19.75	-10.93	-20.56	-9.65
16	-22.08	-15.36	-20.54	-5.10	-16.51	-10.98	-15.30	-8.73	-15.88	-12.74	-16.36	-6.19
17	-22.91	-15.85	-22.23	-8.82	-15.98	-10.94	-20.20	-11.68	-15.97	-11.25	-17.72	-10.72
18	-21.79	-15.56	-18.09	-6.81	-18.26	-13.36	-16.68	-13.23	-16.39	-8.84	-14.20	-10.33
19	-20.16	-13.06	-20.08	-10.14	-21.53	-11.36	-19.86	-8.00	-17.72	-8.81	-19.89	-13.01
20	-20.58	-11.76	-19.36	-8.43	-19.99	-10.12	-13.58	-9.30	-16.05	-10.89	-23.24	-10.18
21	-23.30	-12.32	-18.56	-10.80	-17.27	-12.14	-14.65	-11.03	-16.89	-11.33	-17.11	-11.05
22	-23.25	-17.46	-18.94	-10.77	-16.34	-13.25	-16.47	-6.50	-15.21	-12.84	-13.59	-11.16
23	-22.28	-14.35	-22.88	-10.24	-18.66	-11.25	-18.29	-11.80	-14.88	-6.28	-14.69	-14.65
24	-22.76	-14.54	-18.87	-7.36	-18.52	-13.49	-16.36	-8.16	-16.84	-8.46	-14.52	-11.37
25	-25.87	-17.06	-19.66	-7.76	-16.22	-12.27	-17.42	-8.47	-15.05	-8.01	-14.03	-9.89
26	-21.11	-14.42	-17.67	-10.14	-18.88	-12.51	-18.14	-6.70	-15.42	-10.30	-13.47	-11.27
27	-23.25	-17.25	-15.56	-10.18	-20.06	-11.63	-14.50	-8.06	-17.27	-10.01	-15.31	-11.02
28	-22.76	-14.66	-22.51	-1.71	-16.00	-13.91	-18.42	-8.78	-13.79	-13.90	-16.84	-10.20
29	-16.53	-12.66	-22.72	-8.25	-16.44	-11.25	-18.83	-8.96	-18.30	-12.01	-22.69	-9.60
30	-19.62	-12.95	-17.65	-10.72	-17.79	-12.29	-21.20	-9.00	-13.68	-10.99	-22.34	-11.09
31	-21.69	-16.36	-15.46	-5.72	-21.31	-11.79	-23.19	-12.00	-20.39	-9.52	-22.54	-8.20
32	-21.82	-17.24	-21.24	-1.48	-20.95	-12.99	-22.40	-10.57	-20.98	-12.04	-20.86	-10.92
33	-23.13	-12.52	-22.53	-9.65	-22.62	-11.97	-21.29	-12.74	-19.89	-10.60	-22.09	-10.41
34	-23.04	-11.75	-18.69	-8.56	-17.01	-11.70	-18.61	-11.20	-17.43	-8.99	-19.68	-11.03
35	-19.80	-15.26	-18.78	-6.47	-18.57	-13.05	-15.20	-8.31	-19.28	-12.49	-18.72	-9.21
36	-22.16	-15.21	-18.69	-8.56	-22.06	-12.97	-17.29	-10.36	-16.97	-8.55	-22.07	-9.52
37	-17.63	-10.37	-18.55	-6.03	-18.12	-12.20	-17.10	-10.38	-16.98	-10.57	-14.76	-6.44

38	-17.55	-13.70	-20.10	-9.54	-16.17	-11.25	-18.53	-15.71	-15.96	-9.02	-16.28	-10.40
39	-21.99	-20.03	-17.83	-6.21	-17.05	-12.16	-19.69	-8.56	-16.90	-7.15	-11.38	-11.64
40	-23.00	-13.93	-20.02	-5.21	-18.49	-11.89	-15.87	-13.01	-14.67	-9.26	-13.58	-12.59
Mean	-21.60	-14.58	-19.66	-7.93	-18.40	-11.52	-18.15	-9.68	-16.88	-10.07	-17.37	-10.52
SD	2.11	2.09	1.94	2.26	1.95	1.19	2.79	2.31	2.24	1.77	3.27	1.84
Range	-16.20 - -25.87	-10.37 - -20.03	-15.46 - -22.88	-1.48 - -10.80	-14.43 - -22.62	-7.22 - -13.91	-13.58 - -25.48	-4.06 - -15.71	-13.68 - -24.67	-6.28 - -13.90	-11.38 - -23.24	-6.19 - -14.65

Table 2: Correlation coefficient for σ^0 versus volumetric soil moisture

Date of sampling	Correlation value (r)					
	0-5 cm		5-10 cm		0-10 cm	
	HV	HH	HV	HH	HV	HH
Black soils						
24 th June	-0.409	0.228	0.205	0.342	-0.127	0.330
13 th July	0.153	0.307	-0.138	0.364	0.011	0.369
29 th July	-0.108	0.254	-0.317	0.388	-0.208	0.329
17 th August	0.078	0.269	-0.171	0.317	-0.072	0.332
2 nd September	-0.069	0.322	0.064	0.346	-0.003	0.335
21 st September	-0.136	0.146	-0.132	0.269	-0.137	0.227
Red soils						
24 th June	0.061	0.435**	0.079	0.448**	0.086	0.518**
13 th July	-0.031	0.498**	0.120	0.516**	0.053	0.534**
29 th July	-0.076	0.439**	-0.215	0.493**	-0.180	0.550**
17 th August	0.252	0.435**	0.201	0.457**	0.234	0.472**
2 nd September	0.010	0.390*	0.102	0.451**	0.059	0.449**
21 st September	0.022	0.347*	-0.063	0.348*	-0.034	0.409**

** Correlation is significant at the 1% level

* Correlation is significant at the 5% level

backscattered values in HH polarization varied from -4.06 to -15.71 dB with mean and standard deviation of -9.68 and 2.31 dB, respectively.

4.1.1.5 Backscattered values for 2nd September 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -13.21 to -23.66 dB with mean and standard deviation of -18.23 and 3.60 dB respectively. Where as, backscattered values in HH polarization varied from -6.24 to -16.25 dB with mean and standard deviation of -11.19 and 3.32 dB, respectively.

Table 3: Models for estimation of volumetric soil moisture using σ^0 (dB) for HH and HV polarization

Date of sampling	Linear regression equation					
	0-5 cm		5-10 cm		0-10 cm	
	HV	HH	HV	HH	HV	HH
Black soils						
24 th June	$Y = -0.175x - 19.12$	$Y = 0.171x - 16.24$	$Y = 0.097x - 23.83$	$Y = 0.234x - 19.74$	$Y = -0.264x + 13.28$	$Y = 0.474x + 25.57$
13 th July	$Y = 0.074x - 21.49$	$Y = -0.068x - 18.03$	$Y = 0.177x - 10.39$	$Y = 0.216x - 13.27$	$Y = 0.020x + 24.99$	$Y = 0.572x + 28.55$
29 th July	$Y = -0.044x - 17.45$	$Y = -0.181x - 12.64$	$Y = 0.142x - 13.94$	$Y = 0.300x - 19.97$	$Y = -0.410x + 23.10$	$Y = 0.478x + 35.52$
17 th August	$Y = 0.052x - 18.64$	$Y = -0.085x - 15.06$	$Y = 0.157x - 12.70$	$Y = 0.138x - 12.62$	$Y = -0.114x + 23.82$	$Y = 0.595x + 31.07$
2 nd September	$Y = -0.039x - 17.02$	$Y = 0.037x - 19.52$	$Y = 0.167x - 16.36$	$Y = 0.182x - 17.59$	$Y = -0.03x + 32.55$	$Y = 0.640x + 40.24$
21 st September	$Y = -0.13x - 15.62$	$Y = -0.083x - 16.19$	$Y = 0.097x - 12.70$	$Y = 0.115x - 14.18$	$Y = -0.175x + 27.17$	$Y = 0.425x + 34.84$
Red soils						
24 th June	$Y = 0.075x - 22.18$	$Y = 0.526x - 18.67$	$Y = 0.044x - 22.29$	$Y = 0.245x - 18.42$	$Y = 0.097x + 13.84$	$Y = 0.591x + 20.35$
13 th July	$Y = -0.011x - 19.47$	$Y = 0.204x - 11.40$	$Y = 0.036x - 20.45$	$Y = 0.182x - 11.87$	$Y = 0.154x + 22.38$	$Y = 1.340x + 29.98$
29 th July	$Y = -0.059x - 17.67$	$Y = 0.209x - 14.37$	$Y = -0.106x - 16.72$	$Y = 0.154x - 14.25$	$Y = -0.249x + 9.54$	$Y = 1.251x + 28.88$
17 th August	$Y = 0.204x - 20.53$	$Y = 0.292x - 13.08$	$Y = 0.112x - 19.79$	$Y = 0.209x - 12.76$	$Y = 0.338x + 19.35$	$Y = 0.823x + 21.17$
2 nd September	$Y = 0.006x - 16.95$	$Y = 0.164x - 12.12$	$Y = 0.0559x - 17.76$	$Y = 0.195x - 13.15$	$Y = 0.102x + 15.90$	$Y = 0.984x + 24.07$
21 st September	$Y = 0.025x - 17.57$	$Y = 0.221x - 12.27$	$Y = -0.050x - 16.65$	$Y = 0.155x - 12.76$	$Y = -0.031x + 10.67$	$Y = 0.649x + 18.03$

Table 4: Regression analysis for σ^0 versus volumetric soil moisture

Date of sampling	R ² value					
	0-5 cm		5-10 cm		0-10 cm	
	HV	HH	HV	HH	HV	HH
Black soils						
24 th June	0.168	0.077	0.042	0.117	0.016	0.109
13 th July	0.024	0.094	0.019	0.133	0.000	0.136
29 th July	0.012	0.065	0.101	0.150	0.043	0.108
17 th August	0.006	0.072	0.029	0.101	0.005	0.11
2 nd September	0.005	0.104	0.004	0.120	0.000	0.112
21 st September	0.019	0.021	0.017	0.072	0.019	0.051
Red soils						
24 th June	0.004	0.189	0.006	0.201	0.007	0.269
13 th July	0.001	0.248	0.015	0.267	0.003	0.289
29 th July	0.06	0.193	0.042	0.244	0.032	0.303
17 th August	0.064	0.189	0.041	0.208	0.055	0.223
2 nd September	0.000	0.152	0.010	0.203	0.004	0.202
21 st September	0.000	0.114	0.004	0.121	0.001	0.167

Backscattered values of red soils at HV polarization ranged from -13.68 to -24.67 dB with mean and standard deviation of -16.88 and 2.24 dB respectively. Where as, backscattered values in HH polarization varied from -6.28 to -13.90 dB with mean and standard deviation of -10.07 and 1.77 dB, respectively.

4.1.1.6 Backscattered values for 21st September 2005, ENVISAT-1 ASAR image

Backscattered values of black soils at HV polarization ranged from -11.68 to -25.66 dB with mean and standard deviation of -19.08 and 4.58 dB respectively. Where as, backscattered values in HH polarization varied from -4.29 to -14.47 dB with mean and standard deviation of -19.08 and 4.58 dB, respectively.

Table 5: Gravimetric and volumetric soil moisture content on 24th June 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	7.39	27.55	17.52	65.31	9.02	33.62	21.37	79.66
2	11.37	46.48	24.12	98.60	14.21	58.09	30.15	123.25
3	14.74	49.39	20.28	67.96	16.21	54.32	22.31	74.76
4	6.26	22.03	17.17	60.42	6.95	24.46	19.06	67.07
5	11.99	48.26	21.90	88.14	12.11	48.74	22.12	89.03
Mean	10.35	38.74	20.20	76.09	11.70	43.85	23.00	86.75
Maize								
6	7.23	28.62	17.92	70.95	9.69	38.36	24.01	95.06
7	7.49	26.10	16.63	57.94	10.04	34.98	22.28	77.62
Mean	7.36	27.36	17.28	64.44	9.87	36.67	23.15	86.34
Groundnut								
8	17.40	65.72	25.76	97.29	20.35	76.86	30.14	113.83
9	14.81	52.74	27.46	97.79	15.69	55.88	29.10	103.63
Mean	16.11	59.23	26.61	97.54	18.02	66.37	29.62	108.73
Groundnut + Red gram								
10	14.70	44.71	20.64	62.78	18.38	55.91	25.80	78.48
Mean	11.34	41.16	20.94	76.72	13.27	48.12	24.63	90.24
SD	4.02	14.27	3.81	16.76	4.40	15.36	3.96	18.37
Range	6.26-17.40	22.03-65.72	16.63-27.46	57.94-98.60	6.95-20.35	24.46-76.86	19.06-30.15	67.07-123.25
Red soils								
Bare								
1	5.34	22.32	9.94	41.54	8.70	36.36	16.21	67.74
2	3.72	18.55	7.92	39.49	5.09	25.38	10.85	54.10
Mean	4.53	20.43	8.93	40.51	6.90	30.87	13.53	60.92
Maize								
3	4.44	19.25	10.60	45.95	7.01	30.39	16.74	72.57
4	3.62	16.02	8.48	37.52	5.62	24.87	13.15	58.19
Mean	4.03	17.63	9.54	41.74	6.32	27.63	14.95	65.38
Bajra + Red gram								
5	7.15	36.77	15.38	79.09	9.94	51.12	21.37	109.89
6	3.68	17.24	10.42	48.83	5.74	26.90	16.25	76.15
7	3.17	14.17	6.10	27.26	5.24	23.42	10.06	44.96
Mean	4.67	22.73	10.63	51.73	6.97	33.81	15.89	77.00
Groundnut								
8	5.73	25.72	12.05	54.09	9.52	42.73	20.01	89.82

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	5.97	32.53	12.13	66.09	8.24	44.89	16.75	91.26
10	6.69	33.76	10.82	54.61	10.04	50.67	16.23	81.91
11	6.36	29.99	13.36	63.01	10.25	48.34	21.51	101.44
12	7.21	35.15	12.98	63.28	11.47	55.92	20.64	100.63
13	6.36	30.62	12.13	58.39	10.50	50.55	20.01	96.32
14	4.07	21.01	14.01	72.32	6.27	32.36	21.58	111.39
15	6.14	31.69	6.55	33.81	9.45	48.78	10.09	52.08
16	4.25	20.53	11.84	57.19	7.19	34.73	20.01	96.65
17	5.62	31.35	8.13	45.36	8.38	46.75	12.12	67.62
18	3.58	17.64	5.92	29.17	6.04	29.76	10.01	49.32
19	4.24	21.21	9.85	49.27	7.08	35.42	16.45	82.29
20	5.84	32.66	10.83	60.57	8.76	48.99	16.25	90.88
21	4.19	23.59	13.43	75.62	6.24	35.13	20.01	112.66
22	4.26	26.61	13.71	85.65	6.21	38.80	20.01	125.01
23	4.90	26.09	10.53	56.06	7.85	41.79	16.84	89.65
24	5.60	28.12	9.42	47.29	9.63	48.35	16.21	81.39
25	4.25	26.22	7.75	47.80	5.95	36.70	10.85	66.93
26	5.47	29.42	7.65	41.14	8.81	47.38	12.32	66.25
27	4.47	26.05	6.58	38.34	6.79	39.57	10.00	58.27
28	5.40	32.24	12.55	74.94	8.05	48.07	18.70	111.66
29	5.68	32.01	10.56	59.51	9.03	50.89	16.78	94.57
30	4.57	25.92	12.68	71.91	7.22	40.95	20.03	113.60
31	4.31	23.47	10.73	58.43	7.11	38.72	17.70	96.38
32	3.10	17.19	6.32	35.05	5.02	27.84	10.24	56.79
33	6.50	38.48	11.48	67.96	9.94	58.85	17.56	103.96
34	5.30	31.85	10.32	62.01	8.32	49.99	16.21	97.40
35	3.65	23.90	9.63	63.05	5.41	35.42	14.25	93.30
36	5.81	35.07	7.65	46.18	9.36	56.50	12.31	74.30
Mean	5.16	27.93	10.40	56.49	8.07	43.61	16.26	88.06
Groundnut + Red gram								
37	5.00	29.06	5.48	31.85	8.39	48.77	9.21	53.54
38	6.06	42.70	10.91	76.87	8.42	59.33	15.16	106.82
39	4.38	28.50	7.38	48.02	6.66	43.34	11.21	72.95
40	3.46	19.96	9.57	55.21	5.98	34.50	16.55	95.47
Mean	4.73	30.06	8.34	52.99	7.36	46.48	13.03	82.19
Mean	4.99	26.87	10.09	54.24	7.77	41.73	15.71	84.15
SD	1.12	6.76	2.53	14.77	1.73	9.78	3.83	21.12
Range	3.10 - 7.21	14.17- 42.70	5.48- 15.38	27.26- 85.65	5.02- 11.47	23.42- 59.33	9.21- 21.58	44.96- 125.01

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Backscattered values of red soils at HV polarization ranged from -11.38 to -23.24 dB with mean and standard deviation of -17.37 and 3.27 dB respectively. Where as, backscattered values in HH polarization varied from -6.19 to -14.65 dB with mean and standard deviation of -10.52 and 1.84 dB, respectively.

In general, backscattered values were lower for HV polarization than HH polarization irrespective of soil type and date of satellite pass.

4.1.2 Soil moisture status during – 2005 (cf. Table 5, 6, 7, 8, 9 and 10)

The volumetric soil moisture content for two soil depths, surface (0-5 cm) and subsurface soils (5-10 cm) in kharif 2005 and 2006 was monitored in the micro watershed for both red and black soils.

This thesis is limited to the estimation of soil moisture contained in the depth range of 0 to 10 cm because of the penetration limit of radar. The moisture in this depth is generally referred to as surface soil moisture. Soil moisture is a constituent in the interface between atmosphere and land surface.

4.1.2.1 Soil moisture status on 24th June 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 6.95 to 20.35 per cent with mean and standard deviation of 13.27 and 4.40 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 19.06 to 30.15 per cent with mean and standard deviation of 24.63 and 3.96 per cent, respectively. The mean surface and subsurface soil moisture was at 48.12 and 90.24 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 5.02 to 11.47 per cent with mean and standard deviation of 7.77 and 1.73 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 9.21 to 21.58 per cent with mean and standard deviation of 15.71 and 3.83 per cent, respectively. The mean surface and subsurface soil moisture was at 41.73 and 84.15 per cent of FC respectively.

4.1.2.2 Soil moisture status on 13th July 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 12.13 to 30.42 per cent with mean and standard deviation of 21.35 and 7.50 per cent respectively. Soil moisture content in subsurface soils (5-10 cm) varied from 22.10 to 41.16 per cent with mean and standard deviation of 29.27 and 6.42 per cent, respectively. The mean surface and subsurface soil moisture was at 77.95 and 106.30 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 8.46 to 30.01 per cent with mean and standard deviation of 17.01 and 5.52 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 10.01 to 40.95 per cent with mean and standard deviation of 21.70 and 6.43 per cent, respectively. The mean surface and subsurface soil moisture was at 90.36 and 116.57 per cent of FC respectively.

4.1.2.3 Soil moisture status on 29th July 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 19.25 to 40.16 per cent with mean and standard deviation of 28.05 and 7.05 per cent, respectively. Soil moisture content in subsurface of black soils (5-10 cm) varied from 24.80 to 41.56 per cent with mean and standard deviation of 33.47 and 5.09 per cent, respectively. The mean surface and subsurface soil moisture was at 101.52 and 121.70 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 8.02 to 17.27 per cent with mean and standard deviation of 12.33 and 2.50 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 9.90 to 25.31 per cent with mean and standard deviation of 15.93 and 3.80 per cent, respectively. The mean surface and subsurface soil moisture was at 65.86 and 85.33 per cent of FC respectively.

Table 6: Gravimetric and volumetric soil moisture content on 13th July 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	12.05	44.92	18.15	67.65	14.70	54.79	22.14	82.53
2	17.72	72.44	25.70	105.06	22.15	90.55	32.12	131.30
3	11.03	36.96	29.20	97.85	12.13	40.65	32.12	107.63
4	13.78	48.49	26.24	92.34	15.29	53.81	29.13	102.51
5	20.09	80.86	21.88	88.06	20.29	81.66	22.10	88.95
Mean	14.93	56.73	24.23	90.19	16.91	64.29	27.52	102.58
Maize								
6	22.48	89.00	21.12	83.61	30.12	119.24	35.50	140.54
7	23.29	81.14	22.01	76.68	31.21	108.74	22.09	76.96
Mean	22.89	85.07	21.57	80.15	30.67	113.99	28.80	108.75
Groundnut								
8	20.83	78.67	26.68	100.77	24.37	92.04	31.21	117.88
9	12.05	42.91	23.70	84.40	12.78	45.51	25.12	89.46
Mean	16.44	60.79	25.19	92.58	18.58	68.78	28.17	103.67
Groundnut + Red gram								
10	24.33	74.01	32.93	100.17	30.42	92.53	41.16	125.20
Mean	17.77	64.94	24.76	89.66	21.35	77.95	29.27	106.30
SD	5.13	19.33	4.31	11.85	7.50	27.49	6.42	21.90
Range	11.03 - 24.33	36.96-89.00	18.15 - 32.93	67.65-105.06	12.13 - 30.42	40.65-119.24	22.10 - 41.16	76.96-140.54
Red soils								
Bare								
1	12.25	51.19	14.60	61.02	19.96	83.42	23.8	99.46
2	7.59	37.84	7.31	36.45	10.39	51.80	10.01	49.91
Mean	9.92	44.52	10.96	48.73	15.18	67.61	16.91	74.69
Maize								
3	11.54	50.03	13.30	57.66	18.24	79.07	21.01	91.08
4	11.77	52.08	13.21	58.45	18.25	80.76	20.47	90.58
Mean	11.66	51.05	13.26	58.05	18.25	79.91	20.74	90.83
Bajra + Red gram								
5	11.68	60.06	12.46	64.07	16.24	83.51	17.31	89.02
6	6.56	30.74	9.13	42.78	10.24	47.98	14.25	66.77
7	11.48	51.31	12.46	55.69	18.94	84.65	20.55	91.85
Mean	9.91	47.37	11.35	54.18	15.14	72.05	17.37	82.55
Groundnut								
8	12.14	54.50	12.68	56.92	20.15	90.45	21.05	94.49

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	14.59	79.49	21.75	118.50	20.14	109.73	30.02	163.56
10	13.33	67.27	13.41	67.68	20.00	100.93	20.12	101.54
11	12.42	58.57	13.76	64.89	19.99	94.28	22.16	104.51
12	13.36	65.14	18.94	92.34	21.25	103.60	30.12	146.85
13	10.37	49.92	13.66	65.76	17.11	82.36	22.54	108.50
14	13.08	67.52	17.05	88.01	20.14	103.96	26.25	135.50
15	12.97	66.95	13.63	70.35	19.97	103.08	20.99	108.35
16	11.03	53.28	11.47	55.40	18.64	90.04	19.38	93.61
17	8.29	46.25	13.43	74.92	12.35	68.90	20.01	111.63
18	11.91	58.68	18.17	89.52	20.12	99.13	30.71	151.30
19	12.18	60.93	12.96	64.83	20.34	101.75	21.64	108.25
20	20.01	111.91	27.30	152.68	30.01	167.84	40.95	229.03
21	8.03	45.21	13.43	75.62	11.96	67.34	20.01	112.66
22	6.81	42.54	7.27	45.42	9.94	62.10	10.61	66.28
23	6.33	33.70	7.88	41.95	10.13	53.93	12.61	67.13
24	11.19	56.18	14.69	73.75	19.24	96.60	25.26	126.82
25	6.75	41.64	14.29	88.14	9.46	58.35	20.01	123.43
26	6.36	34.20	12.43	66.84	10.24	55.07	20.01	107.61
27	13.30	77.50	13.39	78.03	20.22	117.83	20.36	118.64
28	14.26	85.15	17.61	105.15	21.24	126.82	26.24	156.68
29	12.59	70.95	13.63	76.81	20.01	112.77	21.67	122.12
30	6.48	36.75	7.13	40.44	10.25	58.13	11.26	63.86
31	12.26	66.76	14.70	80.05	20.23	110.16	24.25	132.05
32	16.20	89.85	19.90	110.37	26.25	145.59	32.24	178.81
33	7.27	43.04	8.07	47.78	11.12	65.83	12.34	73.06
34	7.87	47.29	12.82	77.03	12.36	74.27	20.12	120.90
35	6.75	44.19	13.43	87.93	9.99	65.41	19.87	130.09
36	7.74	46.72	12.50	75.45	12.46	75.21	20.12	121.45
Mean	10.89	58.69	14.19	76.99	17.08	91.77	22.17	119.96
Groundnut + Red gram								
37	11.91	69.23	13.30	77.31	20.01	116.32	22.34	129.86
38	6.08	42.84	10.54	74.27	8.46	59.61	14.65	103.23
39	9.38	61.04	20.08	130.67	14.25	92.73	30.52	198.60
40	17.35	100.09	17.41	100.43	30.01	173.12	30.12	173.76
Mean	11.18	68.30	15.33	95.67	18.18	110.44	24.41	151.36
Mean	10.84	57.71	13.88	74.78	17.01	90.36	21.70	116.57
SD	3.34	18.06	4.10	24.67	5.52	29.36	6.43	37.58
Range	6.08 - 20.01	30.74- 111.91	7.13 - 27.30	36.45- 152.68	8.46 - 30.01	47.98- 173.12	10.01 - 40.95	49.91- 229.03

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 7: Gravimetric and volumetric soil moisture content on 29th July 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	16.51	61.54	20.33	75.78	20.14	75.07	24.80	92.44
2	20.10	82.17	27.33	111.72	25.12	102.69	34.16	139.64
3	22.84	76.53	27.38	91.75	25.12	84.17	30.12	100.93
4	28.14	99.03	28.04	98.68	31.23	109.90	31.12	109.52
5	20.93	84.24	27.21	109.51	21.14	85.08	27.48	110.60
Mean	21.70	80.70	26.06	97.49	24.55	91.38	29.54	110.63
Maize								
6	22.48	89.00	26.46	104.75	30.12	119.24	35.45	140.35
7	23.96	83.48	27.46	95.67	32.11	111.87	36.80	128.21
Mean	23.22	86.24	26.96	100.21	31.12	115.56	36.13	134.28
Groundnut								
8	30.87	116.59	32.59	123.09	36.12	136.42	38.13	144.01
9	18.16	64.67	33.08	117.81	19.25	68.56	35.06	124.86
Mean	24.52	90.63	32.84	120.45	27.69	102.49	36.60	134.44
Groundnut + Red gram								
10	32.13	97.73	33.25	101.14	40.16	122.16	41.56	126.42
Mean	23.61	85.50	28.31	102.99	28.05	101.52	33.47	121.70
SD	5.24	16.39	3.89	13.69	7.05	22.35	5.09	17.64
Range	16.51 - 32.13	61.54-116.59	20.33 - 33.25	75.78-123.09	19.25 - 40.16	68.56-136.42	24.80 - 41.56	29.44-144.01
Red soils								
Bare								
1	8.67	36.23	15.53	64.90	14.13	59.05	25.31	105.77
2	8.20	40.88	11.59	57.79	11.24	56.04	15.88	79.18
Mean	8.44	38.56	13.56	61.34	12.69	57.55	20.60	92.47
Maize								
3	8.62	37.37	12.73	55.18	13.62	59.04	20.11	87.18
4	7.52	33.28	9.20	40.71	11.65	51.55	14.25	63.06
Mean	8.07	35.32	10.97	47.95	12.64	55.30	17.18	75.12
Bajra + Red gram								
5	11.69	60.11	12.38	63.66	16.25	83.56	17.22	88.55
6	10.42	48.83	10.94	51.26	16.25	76.15	17.07	79.99
7	9.35	41.79	6.67	29.81	15.42	68.92	11.01	49.21
Mean	10.49	50.24	10.00	48.25	15.97	76.21	15.10	72.58
Groundnut								
8	8.87	39.82	9.31	41.79	14.73	66.12	15.46	69.40

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	7.50	40.86	9.67	52.69	10.35	56.39	13.34	72.68
10	7.76	39.16	8.17	41.23	11.64	58.74	12.26	61.87
11	7.67	36.17	10.86	51.22	12.35	58.24	17.49	82.49
12	10.05	49.00	10.22	49.83	15.98	77.91	16.25	79.23
13	5.88	28.31	7.85	37.79	9.70	46.69	12.96	62.39
14	8.38	43.26	9.70	50.07	12.90	66.59	14.94	77.12
15	8.61	44.44	8.61	44.44	13.25	68.39	13.25	68.39
16	10.22	49.37	13.30	64.24	17.27	83.42	22.48	108.59
17	8.66	48.31	12.47	69.57	12.91	72.02	18.58	103.66
18	5.92	29.17	7.69	37.89	10.01	49.32	13.00	64.05
19	8.56	42.82	10.31	51.58	14.30	71.54	17.21	86.09
20	9.50	53.13	12.16	68.01	14.25	79.70	18.24	102.01
21	6.36	35.81	13.74	77.36	9.48	53.38	20.48	115.31
22	6.86	42.86	7.12	44.48	10.01	62.53	10.39	64.91
23	8.91	47.43	11.21	59.68	14.26	75.92	17.94	95.51
24	6.87	34.49	9.44	47.40	11.82	59.34	16.24	81.54
25	5.73	35.34	7.07	43.61	8.02	49.47	9.90	61.07
26	4.99	26.83	6.28	33.77	8.03	43.18	10.11	54.37
27	6.51	37.94	8.15	47.49	9.90	57.69	12.39	72.20
28	7.28	43.47	7.64	45.62	10.84	64.73	11.39	68.01
29	5.20	29.31	6.85	38.60	8.26	46.55	10.89	61.37
30	7.07	40.10	10.48	59.43	11.18	63.40	16.56	93.92
31	7.50	40.84	12.52	68.18	12.38	67.41	20.65	112.45
32	5.02	27.84	7.62	42.26	8.13	45.09	12.35	68.49
33	5.69	33.69	15.49	91.70	8.70	51.51	23.70	140.31
34	9.07	54.50	10.14	60.93	14.24	85.57	15.92	95.66
35	8.11	53.10	8.27	54.15	12.01	78.63	12.24	80.14
36	8.62	52.03	12.43	75.03	13.88	83.78	20.01	120.78
Mean	7.50	40.67	9.82	53.45	11.75	63.56	15.40	83.59
Groundnut + Red gram								
37	9.05	52.61	9.94	57.78	15.21	88.41	16.70	97.07
38	9.50	66.94	11.69	82.37	13.20	93.01	16.25	114.50
39	7.98	51.93	11.72	76.27	12.13	78.93	17.81	115.90
40	7.66	44.19	10.92	63.00	13.25	76.44	18.89	108.97
Mean	8.55	53.92	11.07	69.85	13.45	84.20	17.41	109.11
Mean	7.90	42.34	10.20	54.82	12.33	65.86	15.93	85.33
SD	1.57	9.13	2.37	14.09	2.50	13.36	3.80	21.37
Range	4.99 - 11.69	26.83- 66.94	6.28 - 15.53	29.81- 91.70	8.02 - 17.27	43.18- 93.01	9.90 - 25.31	49.21- 140.31

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

4.1.2.4 Soil moisture status on 17th August 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 20.90 to 28.87 per cent with mean and standard deviation of 24.43 and 2.75 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 23.12 to 33.84 per cent with mean and standard deviation of 27.15 and 3.69 per cent, respectively. The mean surface and subsurface soil moisture was at 88.62 and 98.51 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 3.90 to 20.05 per cent with mean and standard deviation of 11.65 and 3.44 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 4.21 to 30.27 per cent with mean and standard deviation of 14.77 and 5.05 per cent, respectively. The mean surface and subsurface soil moisture was at 18.31 and 27.47 per cent of FC respectively.

4.1.2.5 Soil moisture status on 2nd September 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 20.18 to 39.24 per cent with mean and standard deviation of 30.99 and 6.40 per cent respectively. Where as, moisture content in subsurface of soils (5-10 cm) varied from 24.15 to 41.70 per cent with mean and standard deviation of 35.17 and 6.32 per cent, respectively. The mean surface and subsurface soil moisture was at 113.00 and 128.54 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 6.21 to 22.96 per cent with mean and standard deviation of 12.53 and 4.20 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 8.69 to 23.12 per cent with mean and standard deviation of 15.80 and 4.08 per cent, respectively. The mean surface and subsurface soil moisture was at 67.38 and 84.92 per cent of FC respectively.

4.1.2.6 Soil moisture status on 21st September 2005

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 19.90 to 35.01 per cent with mean and standard deviation of 28.01 and 5.52 per cent, respectively. Soil moisture content in subsurface of soils (5-10 cm) varied from 24.81 to 48.71 per cent with mean and standard deviation of 32.14 and 7.30 per cent, respectively. The mean surface and subsurface soil moisture was at 102.22 and 135.66 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 3.24 to 20.31 per cent with mean and standard deviation of 7.94 and 2.81 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 9.19 to 22.86 per cent with mean and standard deviation of 14.47 and 4.14 per cent respectively. The mean surface and subsurface soil moisture was at 43.10 and 77.26 per cent of FC respectively.

In general, red soils were low in soil moisture status (7.77 to 17.01 per cent at 0-5 cm and 14.77 to 21.70 per cent at 5-10 cm respectively) than black soils (13.27 to 30.99 at 0-5 cm and 24.63 to 35.17 per cent at 5-10 cm respectively) during monitoring period of June to September 2005. Except on 24th June 2005, the soil moisture status in black soils was around FC and higher. Such value for red soils was only on 13th July. However the quantity of soil moisture held in red soils was very low compared to black soils.

4.1.3 Soil moisture status during 2006 (cf. Table 11, 12, 13, 14, 15 and 16)

4.1.3.1 Soil moisture status on 28th June 2006

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 3.63 to 13.85 per cent with mean and standard deviation of 8.51 and 3.32 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 4.99 to 23.32 per cent with mean and standard deviation of 14.64 and 5.72 per cent, respectively.

Table 8. Gravimetric and volumetric soil moisture content on 17th August 2005Table 8: Gravimetric and volumetric soil moisture content on 17th August 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	17.13	63.85	18.96	70.67	20.90	77.90	23.13	86.22
2	18.16	74.24	21.31	87.11	22.70	92.80	26.63	108.86
3	25.43	85.21	26.04	87.26	27.97	93.72	28.65	96.00
4	23.44	82.49	26.68	93.89	26.01	91.53	29.61	104.20
5	21.91	88.18	23.91	96.23	22.13	89.07	24.15	97.20
Mean	21.21	78.79	23.38	87.03	23.94	89.00	26.43	98.50
Maize								
6	17.65	69.88	17.25	68.29	23.65	93.63	23.12	91.53
7	17.44	60.76	18.28	63.69	23.38	81.46	24.49	85.32
Mean	17.55	65.32	17.77	65.99	23.52	87.54	23.81	88.43
Groundnut								
8	18.81	71.04	27.03	102.09	22.01	83.13	31.62	119.42
9	25.19	89.71	24.76	88.18	26.71	95.12	26.24	93.45
Mean	22.00	80.38	25.90	95.13	24.36	89.13	28.93	106.44
Groundnut + Red gram								
10	23.09	70.24	27.07	82.34	28.87	87.82	33.84	102.94
Mean	20.83	75.56	23.13	83.98	24.43	88.62	27.15	98.51
SD	3.33	10.22	3.86	12.70	2.75	5.93	3.69	10.56
Range	17.13 - 25.43	60.76 - 89.71	17.25 - 27.07	63.69 - 102.09	20.90 - 28.87	77.90 - 95.12	23.12 - 33.84	85.32 - 119.42
Red soils								
Bare								
1	6.89	28.79	8.75	36.57	11.23	46.93	14.26	59.59
2	13.50	67.31	21.99	109.64	18.49	92.19	30.12	150.17
Mean	10.20	48.05	15.37	73.10	14.86	69.56	22.19	104.88
Maize								
3	7.00	30.35	9.88	42.83	11.06	47.95	15.61	67.67
4	10.34	45.75	10.71	47.39	16.02	70.89	16.61	73.50
Mean	8.67	38.05	10.30	45.11	13.54	59.42	16.11	70.58
Bajra + Red gram								
5	11.69	60.11	13.67	70.30	16.25	83.56	19.00	97.71
6	9.13	42.78	11.44	53.61	14.25	66.77	17.84	83.60
7	7.22	32.27	7.49	33.48	11.92	53.28	12.36	55.24
Mean	9.35	45.06	10.87	52.46	14.14	67.87	16.40	78.85
Groundnut								
8	5.55	24.91	9.88	44.35	9.21	41.34	16.40	73.62

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	7.41	40.37	12.08	65.82	10.23	55.74	16.66	90.77
10	5.21	26.29	7.35	37.09	7.82	39.47	11.02	55.61
11	7.67	36.17	8.85	41.74	12.35	58.24	14.25	67.21
12	10.22	49.83	13.38	65.23	16.25	79.23	21.28	103.75
13	6.92	33.31	8.65	41.64	11.41	54.93	14.27	68.69
14	3.51	18.12	5.20	26.84	5.41	27.93	8.01	41.35
15	4.69	24.21	6.20	32.00	7.23	37.32	9.55	49.29
16	4.93	23.81	5.90	28.50	8.33	40.24	9.97	48.16
17	3.46	19.30	6.97	38.88	5.16	28.79	10.39	57.96
18	7.81	38.48	8.69	42.81	13.19	64.99	14.68	72.33
19	8.50	42.52	10.45	52.28	14.20	71.04	17.45	87.29
20	9.18	51.34	10.63	59.45	13.76	76.96	15.95	89.21
21	7.33	41.27	8.28	46.62	10.92	61.48	12.34	69.48
22	11.13	69.53	12.50	78.09	16.25	101.52	18.25	114.01
23	7.07	37.64	8.76	46.64	11.31	60.21	14.02	74.64
24	11.66	58.54	12.65	63.51	20.05	100.66	21.76	109.25
25	7.98	49.22	9.76	60.20	11.17	68.90	13.66	84.26
26	6.22	33.45	8.50	45.71	10.01	53.83	13.68	73.57
27	8.72	50.81	10.69	62.29	13.25	77.21	16.25	94.69
28	9.07	54.16	20.32	121.33	13.51	80.67	30.27	180.74
29	8.22	46.32	8.96	50.49	13.06	73.60	14.25	80.31
30	7.71	43.73	10.28	58.30	12.18	69.08	16.25	92.16
31	8.27	45.03	8.82	48.03	13.65	74.33	14.56	79.28
32	7.14	39.60	7.81	43.32	11.56	64.11	12.65	70.16
33	6.61	39.13	7.35	43.51	10.12	59.91	11.25	66.60
34	7.71	46.33	8.44	50.72	12.1	72.71	13.25	79.62
35	7.71	50.48	8.55	55.98	11.41	74.70	12.65	82.82
36	6.86	41.41	7.47	45.09	11.04	66.64	12.02	72.55
Mean	7.40	40.53	9.43	51.60	11.59	63.30	14.72	80.32
Groundnut + Red gram								
37	4.09	23.77	4.51	26.22	6.87	39.93	7.58	44.06
38	2.81	19.80	3.03	21.35	3.90	27.48	4.21	29.66
39	6.51	42.36	6.54	42.56	9.90	64.42	9.95	64.75
40	5.83	33.63	9.29	53.59	10.08	58.15	16.07	92.70
Mean	4.81	29.89	5.84	35.93	7.69	47.50	9.45	57.79
Mean	7.49	40.06	9.52	50.85	11.65	62.18	14.77	78.70
SD	2.31	12.62	3.56	19.55	3.44	18.31	5.05	27.47
Range	2.81 - 13.50	18.12- 69.53	3.03 - 7.49	21.35- 121.33	3.90 - 20.05	27.48- 101.52	4.21 - 30.27	29.66- 180.74

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 9: Gravimetric and volumetric soil moisture content on 2nd September 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	22.25	82.94	26.95	100.46	27.15	101.20	32.88	122.56
2	28.08	114.79	31.72	129.67	35.10	143.48	39.65	162.08
3	23.11	77.44	25.10	84.11	25.43	85.21	27.61	92.52
4	18.18	63.98	21.76	76.58	20.18	71.02	24.15	84.99
5	23.91	96.23	28.85	116.12	24.15	97.20	29.14	117.28
Mean	23.11	87.07	26.88	101.38	26.40	99.62	30.69	115.89
Maize								
6	25.46	100.80	29.63	117.30	34.12	135.08	39.71	157.21
7	26.96	93.93	29.63	103.23	36.12	125.84	39.71	138.35
Mean	26.21	97.36	29.63	110.27	35.12	130.46	39.71	147.78
Groundnut								
8	31.78	120.03	35.05	132.38	37.18	140.42	41.01	154.89
9	29.44	104.85	34.08	121.37	31.21	111.15	36.12	128.64
Mean	30.61	112.44	34.57	126.87	34.20	125.79	38.57	141.76
Groundnut + Red gram								
10	31.39	95.48	33.36	101.48	39.24	119.36	41.70	126.84
Mean	26.06	95.05	29.61	108.27	30.99	113.00	35.17	128.54
SD	4.32	16.89	4.19	18.48	6.40	24.27	6.32	26.03
Range	18.18 - 31.78	63.98-120.03	21.76 - 35.05	76.58-132.38	20.18 - 39.24	71.02-143.48	24.15 - 41.70	84.99-162.08
Red soils								
Bare								
1	6.18	25.83	7.20	30.09	10.07	42.08	11.74	49.06
2	8.34	41.58	10.22	50.96	11.42	56.94	14.00	69.80
Mean	7.26	33.70	8.71	40.52	10.75	49.51	12.87	59.43
Maize								
3	6.48	28.09	9.02	39.10	10.24	44.39	14.25	61.77
4	7.60	33.63	9.19	40.67	11.77	52.08	14.25	63.06
Mean	7.04	30.86	9.11	39.88	11.01	48.24	14.25	62.41
Bajra + Red gram								
5	8.09	41.60	10.25	52.71	11.25	57.85	14.25	73.28
6	14.72	68.98	13.10	61.38	22.96	107.59	20.43	95.73
7	5.91	26.41	7.48	33.43	9.76	43.62	12.34	55.15
Mean	9.57	45.66	10.28	49.18	14.66	69.69	15.67	74.72
Groundnut								
8	5.96	26.75	9.78	43.90	9.9	44.44	16.24	72.90

Contd....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	9.59	52.25	11.77	64.13	13.24	72.14	16.25	88.54
10	5.49	27.71	7.50	37.85	8.24	41.58	11.25	56.78
11	8.85	41.74	11.73	55.32	14.25	67.21	18.88	89.04
12	12.67	61.77	13.41	65.38	20.14	98.19	21.32	103.94
13	6.21	29.89	8.05	38.75	10.24	49.29	13.29	63.98
14	4.17	21.52	13.59	70.15	6.42	33.14	20.92	107.98
15	4.04	20.85	5.64	29.11	6.21	32.05	8.69	44.86
16	10.97	52.99	12.46	60.19	18.54	89.55	21.06	101.73
17	6.85	38.22	8.20	45.75	10.20	56.90	12.22	68.17
18	12.67	62.42	13.10	64.54	21.42	105.53	22.15	109.13
19	12.66	63.33	13.84	69.23	21.14	105.75	23.12	115.66
20	6.60	36.91	7.53	42.11	9.90	55.37	11.30	63.20
21	6.87	38.68	7.55	42.51	10.24	57.66	11.25	63.34
22	7.29	45.54	8.91	55.66	10.64	66.47	13.01	81.28
23	10.80	57.50	11.93	63.51	17.28	91.99	19.10	101.68
24	8.29	41.62	11.19	56.18	14.26	71.59	19.24	96.60
25	11.60	71.55	13.32	82.16	16.25	100.23	18.64	114.98
26	6.81	36.62	10.09	54.26	10.96	58.94	16.25	87.39
27	8.12	47.32	11.61	67.65	12.34	71.91	17.64	102.79
28	5.02	29.97	6.17	36.84	7.49	44.72	9.19	54.87
29	6.31	35.56	12.6	71.01	10.04	56.58	20.04	112.94
30	5.03	28.53	6.39	36.24	7.95	45.09	10.10	57.28
31	5.64	30.71	7.46	40.62	9.31	50.70	12.31	67.03
32	7.17	39.77	7.46	41.37	11.62	64.45	12.08	67.00
33	7.35	43.51	9.43	55.83	11.25	66.60	14.43	85.43
34	6.66	40.02	9.71	58.35	10.46	62.85	15.24	91.58
35	6.77	44.32	7.80	51.07	10.02	65.60	11.55	75.62
36	6.79	40.99	8.64	52.15	10.94	66.04	13.91	83.96
Mean	7.70	41.68	9.89	53.51	12.10	65.26	15.54	83.78
Groundnut + Red gram								
37	7.35	42.72	13.61	79.11	12.34	71.73	22.86	132.88
38	11.97	84.34	12.98	91.46	16.64	117.25	18.04	127.11
39	11.35	73.86	12.66	82.38	17.25	112.25	19.25	125.27
40	9.7	55.96	11.42	65.88	16.78	96.80	19.75	113.93
Mean	10.09	64.22	12.67	79.71	15.75	99.51	19.98	124.80
Mean	8.02	43.29	10.10	54.48	12.53	67.38	15.80	84.92
SD	2.61	15.29	2.46	15.37	4.20	23.25	4.08	23.77
Range	4.04 - 14.72	20.85- 84.34	5.64 - 13.84	29.11- 91.46	6.21 - 22.96	32.05- 117.25	8.69 - 23.12	44.86- 132.88

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

The mean surface and subsurface soil moisture was at 30.72 and 53.26 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 0.99 to 12.81 per cent with mean and standard deviation of 4.43 and 3.12 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 4.71 to 27.02 per cent with mean and standard deviation of 9.27 and 4.63 per cent, respectively. The mean surface and subsurface soil moisture was at 23.64 and 50.42 per cent of FC respectively.

4.1.3.2 Soil moisture status on 14th July 2006

The volumetric soil moisture content of surface black soils (0-5 cm) ranged from 1.31 to 7.95 per cent with mean and standard deviation of 5.59 and 2.36 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 2.98 to 15.26 per cent with mean and standard deviation of 10.67 and 3.45 per cent respectively. The mean surface and subsurface soil moisture was at 19.97 and 38.40 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 1.06 to 10.63 per cent with mean and standard deviation of 2.64 and 1.92 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 1.92 to 15.96 per cent with mean and standard deviation of 7.43 and 2.60 per cent, respectively. The mean surface and subsurface soil moisture was at 13.93 and 40.12 per cent of FC respectively.

4.1.3.3 Soil moisture status on 2nd August 2006

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 2.83 to 20.47 percent with mean and standard deviation of 10.95 and 5.16 per cent respectively. Soil moisture content in subsurface of black soils (5-10 cm) varied from 6.71 to 33.87 per cent with mean and standard deviation of 21.75 and 8.10 per cent, respectively. The mean surface and subsurface soil moisture was at 39.01 and 77.35 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 2.44 to 14.18 per cent with mean and standard deviation of 4.78 and 2.43 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 5.41 to 26.20 per cent with mean and standard deviation of 10.66 and 4.72 per cent, respectively. The mean surface and subsurface soil moisture was at 25.92 and 57.65 per cent of FC respectively.

4.1.3.4 Soil moisture status on 18th August 2006

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 0.93 to 11.73 per cent with mean and standard deviation of 6.18 and 3.79 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 4.54 to 18.35 per cent with mean and standard deviation of 12.71 and 5.58 per cent, respectively. The mean surface and subsurface soil moisture was at 22.26 and 45.67 per cent of FC respectively.

The volumetric soil moisture content of surface red soils (0-5 cm) ranged from 0.28 to 6.89 per cent with mean and standard deviation of 1.69 and 1.48 per cent respectively. Soil moisture content in subsurface red soils (5-10 cm) varied from 1.22 to 18.94 per cent with mean and standard deviation of 4.89 and 3.77 per cent, respectively. The mean surface and subsurface soil moisture was at 8.94 and 25.66 per cent of FC respectively.

4.1.3.5 Soil moisture status on 6th September 2006

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 1.13 to 8.10 per cent with mean and standard deviation of 4.70 and 2.44 per cent respectively. Where as, moisture content in subsurface soils (5-10 cm) varied from 1.95 to 11.49 per cent with mean and standard deviation of 6.89 and 3.12 per cent, respectively. The mean surface and subsurface soil moisture was at 16.78 and 24.43 per cent of FC respectively.

Table 10: Gravimetric and volumetric soil moisture content on 21st September 2005

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	16.31	60.80	20.34	75.82	19.90	74.18	24.81	92.48
2	23.82	97.37	33.14	135.47	35.01	143.12	48.71	199.12
3	26.10	87.46	30.76	103.07	28.72	96.24	33.84	113.39
4	22.57	79.43	30.95	108.92	25.05	88.15	34.36	120.92
5	19.86	79.93	29.46	118.57	20.06	80.74	29.75	119.74
Mean	21.73	81.00	28.93	108.37	25.75	96.48	34.29	129.13
Maize								
6	27.53	108.99	32.39	128.23	32.21	127.52	37.90	150.05
7	22.33	77.80	32.40	112.88	23.67	82.47	34.35	119.67
Mean	24.93	93.39	32.40	120.56	27.94	104.99	36.13	134.86
Groundnut								
8	23.62	89.21	31.14	117.61	32.36	122.22	42.67	161.16
9	22.26	79.28	30.98	110.33	29.83	106.23	41.51	147.83
Mean	22.94	84.24	31.06	113.97	31.10	114.23	42.09	154.49
Groundnut + Red gram								
10	26.64	81.03	34.78	105.79	33.31	101.32	43.47	132.23
Mean	23.10	84.13	30.63	111.67	28.01	102.22	37.14	135.66
SD	3.34	12.86	3.91	16.08	5.52	22.61	7.13	30.06
Range	16.31 - 25.66	60.80-108.99	16.49 - 34.78	75.82-135.47	19.90 – 35.01	74.18-143.12	24.81 – 48.71	92.48-199.12
Red soils								
Bare								
1	3.31	13.83	6.14	25.66	5.39	22.53	10.02	41.87
2	4.95	24.68	9.93	49.51	6.79	33.85	13.60	67.81
Mean	4.13	19.26	8.04	37.58	6.09	28.19	11.81	54.84
Maize								
3	5.22	22.63	10.28	44.56	8.25	35.76	16.25	70.44
4	3.39	15.00	6.96	30.80	5.26	23.28	10.79	47.75
Mean	4.31	18.81	8.62	37.68	6.76	29.52	13.52	59.09
Bajra + Red gram								
5	7.43	38.21	14.00	71.99	10.33	53.12	19.46	100.07
6	3.37	15.79	13.10	61.38	5.26	24.65	20.43	95.73
7	3.74	16.72	6.92	30.93	6.18	27.62	11.42	51.04
Mean	4.85	23.57	11.34	54.77	7.26	35.13	17.10	82.28
Groundnut								
8	6.05	27.16	8.58	38.51	10.04	45.07	14.25	63.97

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	7.29	39.72	9.00	49.04	10.06	54.81	12.43	67.72
10	4.17	21.04	6.76	34.12	6.25	31.54	10.14	51.17
11	5.49	25.89	10.16	47.92	8.83	41.64	16.35	77.11
12	2.04	9.95	12.67	61.77	3.24	15.80	20.14	98.19
13	5.01	24.12	11.66	56.13	8.26	39.76	19.24	92.62
14	6.57	33.91	13.59	70.15	10.12	52.24	20.92	107.98
15	5.26	27.15	8.81	45.48	8.10	41.81	13.56	69.99
16	3.61	17.44	13.23	63.91	6.10	29.47	22.36	108.01
17	4.17	23.26	8.28	46.19	6.21	34.64	12.34	68.84
18	6.04	29.76	11.83	58.28	10.20	50.25	20.00	98.54
19	6.73	33.67	12.01	60.08	11.24	56.23	20.06	100.35
20	5.68	31.77	10.83	60.57	8.51	47.60	16.25	90.88
21	4.97	27.98	6.88	38.74	7.41	41.72	10.25	57.71
22	5.65	35.30	7.01	43.79	8.26	51.60	10.24	63.97
23	5.64	30.03	6.26	33.33	9.02	48.02	10.01	53.29
24	3.11	15.61	5.96	29.92	5.35	26.86	10.25	51.46
25	5.80	35.78	11.61	71.61	8.12	50.09	16.26	100.30
26	4.20	22.59	10.09	54.26	6.76	36.35	16.25	87.39
27	3.17	18.47	8.54	49.76	4.82	28.09	12.99	75.70
28	5.35	31.94	6.17	36.84	7.97	47.59	9.19	54.87
29	5.38	30.32	13.42	75.63	8.56	48.24	21.34	120.26
30	3.57	20.25	6.39	36.24	5.64	31.99	10.10	57.28
31	6.00	32.67	7.46	40.62	9.90	53.91	12.31	67.03
32	3.29	18.25	7.46	41.37	5.34	29.62	12.08	67.00
33	6.53	38.66	8.07	47.78	9.99	59.14	12.35	73.11
34	4.01	24.10	6.45	38.76	6.30	37.86	10.12	60.81
35	6.84	44.78	8.95	58.60	10.12	66.26	13.25	86.75
36	4.88	29.46	8.64	52.15	7.85	47.38	13.91	83.96
Mean	5.05	27.62	9.20	49.71	7.88	42.95	14.45	77.80
Groundnut + Red gram								
37	12.09	70.28	13.61	79.11	20.31	118.06	22.86	132.88
38	5.90	41.57	8.10	57.07	8.20	57.78	11.26	79.34
39	5.78	37.61	8.32	54.14	8.79	57.20	12.64	82.25
40	2.48	14.31	6.51	37.55	4.28	24.69	11.26	64.96
Mean	6.56	40.94	9.14	56.97	10.40	64.43	14.51	89.86
Mean	5.10	27.79	9.27	49.61	7.94	43.10	14.47	77.26
SD	1.76	11.09	2.55	13.62	2.81	17.26	4.14	21.31
Range	2.04 - 12.09	9.95- 70.28	5.96 - 14.00	25.66- 79.11	3.24 - 20.31	15.80- 118.06	9.19 - 22.86	41.87- 132.88

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 11: Gravimetric and volumetric soil moisture content on 28th June 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	2.98	11.11	7.27	27.10	3.63	13.53	8.87	33.06
2	5.09	20.81	9.33	38.14	6.36	26.01	11.66	47.68
3	8.31	27.85	4.71	15.78	8.81	29.52	4.99	16.72
4	12.14	42.72	21.01	73.94	13.47	47.40	23.32	82.07
5	10.02	40.33	18.20	73.25	10.12	40.73	18.38	73.98
Mean	7.71	28.56	12.10	45.64	8.48	31.44	13.44	50.70
Maize								
6	6.99	27.67	12.69	50.24	9.37	37.08	17.00	67.32
7	4.14	14.42	9.07	31.60	5.92	20.63	12.98	45.22
Mean	5.57	21.05	10.88	40.92	7.64	28.85	14.99	56.27
Groundnut								
8	6.99	26.40	12.69	47.93	7.69	29.04	13.95	52.69
9	4.14	14.74	9.07	32.30	5.92	21.08	12.98	46.23
Mean	5.57	20.57	10.88	40.11	6.81	25.06	13.47	49.46
Groundnut + Red gram								
10	11.36	34.56	18.24	55.48	13.85	42.13	22.25	67.68
Mean	7.22	26.06	12.23	44.58	8.51	30.72	14.64	53.26
SD	3.20	10.92	5.36	19.27	3.32	10.88	5.72	19.87
Range	2.98 – 12.14	11.11- 42.72	4.71 – 21.01	15.78- 73.94	3.63 – 13.85	13.53- 47.40	4.99 – 23.32	16.72- 82.07
Red soils								
Bare								
1	1.04	4.35	4.82	20.14	1.46	6.10	6.75	28.21
2	1.04	5.19	3.78	18.85	1.58	7.88	5.75	28.67
Mean	1.04	4.77	4.30	19.49	1.52	6.99	6.25	28.44
Maize								
3	4.03	17.47	4.47	19.38	6.40	27.74	7.10	30.78
4	4.60	20.35	4.21	18.63	7.60	33.63	7.10	31.42
Mean	4.32	18.91	4.34	19.00	7.00	30.69	7.10	31.10
Bajra + Red gram								
5	1.75	9.00	6.57	33.79	2.19	11.26	8.21	42.22
6	3.11	14.57	6.12	28.68	4.27	20.01	8.38	39.27
7	2.55	11.40	6.09	27.22	3.72	16.63	8.90	39.78
Mean	2.47	11.66	6.26	29.89	3.39	15.97	8.50	40.42
Groundnut								
8	4.10	18.40	6.69	30.03	6.80	30.52	11.1	49.83

Contd....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	5.72	31.16	6.56	35.74	7.90	43.04	9.00	49.04
10	4.56	23.01	6.48	32.70	6.80	34.32	9.70	48.95
11	2.80	13.21	4.91	23.16	4.50	21.22	7.90	37.26
12	4.03	19.65	4.47	21.79	6.40	31.20	7.10	34.62
13	4.60	22.14	4.21	20.27	7.60	36.59	7.10	34.18
14	2.34	12.08	3.06	15.80	3.60	18.58	4.71	24.31
15	1.04	5.37	4.82	24.88	1.46	7.54	6.75	34.84
16	1.39	6.71	5.43	26.23	2.22	10.72	8.63	41.69
17	3.49	19.47	5.65	31.52	4.85	27.06	7.85	43.79
18	2.58	12.71	5.75	28.33	4.18	20.59	9.32	45.92
19	2.34	11.71	3.06	15.31	3.60	18.01	4.71	23.56
20	0.89	4.98	4.20	23.49	1.24	6.94	5.89	32.94
21	8.43	47.46	6.60	37.16	12.81	72.13	10.03	56.47
22	1.60	10.00	7.53	47.04	2.64	16.49	12.42	77.59
23	2.43	12.94	7.07	37.64	3.62	19.28	10.53	56.08
24	3.13	15.71	17.21	86.41	4.92	24.70	27.02	135.66
25	1.70	10.49	5.39	33.25	2.73	16.84	8.68	53.54
26	1.04	5.59	3.78	20.33	1.58	8.50	5.75	30.92
27	2.28	13.29	8.70	50.70	3.46	20.16	13.22	77.04
28	1.88	11.23	6.42	38.33	3.07	18.33	10.50	62.70
29	0.67	3.78	4.08	22.99	1.06	5.97	6.45	36.35
30	2.26	12.82	5.21	29.55	3.44	19.51	7.92	44.92
31	3.11	16.93	4.61	25.10	4.63	25.23	6.87	37.40
32	2.32	12.87	4.02	22.30	3.25	18.02	5.62	31.17
33	0.65	3.85	4.89	28.95	0.99	5.86	7.49	44.34
34	1.39	8.35	5.43	32.63	2.22	13.34	8.63	51.86
35	0.68	4.45	3.84	25.14	1.13	7.40	6.33	41.44
36	8.48	51.19	7.24	43.70	13.15	79.38	11.23	67.79
Mean	2.83	15.23	5.77	31.39	4.34	23.36	8.91	48.49
Groundnut + Red gram								
37	8.43	49.00	6.60	38.36	12.81	74.46	10.03	58.30
38	1.60	11.27	7.53	53.06	2.64	18.60	12.42	87.51
39	2.43	15.81	7.07	46.01	3.62	23.56	10.53	68.52
40	3.13	18.06	17.21	99.28	4.92	28.38	27.02	155.87
Mean	3.90	23.54	9.60	59.18	6.00	36.25	15.00	92.55
Mean	2.89	15.45	6.04	32.85	4.43	23.64	9.27	50.42
SD	2.03	11.46	2.92	16.88	3.12	17.52	4.63	26.89
Range	0.65 - 8.43	3.78- 51.18	3.06 – 17.21	15.30- 99.28	0.99 – 12.81	5.86- 79.38	4.71 – 27.02	23.56- 155.87

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 12: Gravimetric and volumetric soil moisture content on 14th July 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	5.36	19.98	8.64	32.21	6.54	24.38	10.54	39.29
2	1.05	4.29	2.38	9.73	1.31	5.37	2.98	12.16
3	7.22	24.19	12.89	43.19	7.95	26.64	14.18	47.52
4	7.11	25.02	11.18	39.34	7.89	27.77	12.40	43.64
5	4.76	19.16	10.31	41.50	4.81	19.36	10.41	41.90
Mean	5.10	18.53	9.08	33.19	5.70	20.70	10.10	36.90
Maize								
6	1.75	6.93	5.87	23.24	2.35	9.28	7.87	31.14
7	3.10	10.80	8.96	31.22	4.16	14.49	12.00	41.81
Mean	2.43	8.86	7.42	27.23	3.25	11.89	9.93	36.47
Groundnut								
8	5.58	21.07	13.05	49.29	6.53	24.66	15.26	57.63
9	7.33	26.10	9.04	32.19	7.77	27.67	9.58	34.12
Mean	6.46	23.59	11.05	40.74	7.15	26.17	12.42	45.88
Groundnut + Red gram								
10	5.29	16.09	9.16	27.86	6.61	20.11	11.45	34.83
Mean	4.86	17.36	9.15	32.98	5.59	19.97	10.67	38.40
SD	2.24	7.67	3.19	11.30	2.36	7.92	3.45	11.91
Range	1.05 – 7.33	4.25-26.10	1.54 – 7.95	9.73-49.29	1.31 – 7.95	5.37-27.77	2.98 – 15.26	12.16-57.63
Red soils								
Bare								
1	1.35	5.64	4.87	20.35	2.20	9.19	7.94	33.18
2	1.08	5.38	4.56	22.74	1.48	7.38	6.25	31.16
Mean	1.22	5.51	4.72	21.54	1.84	8.29	7.10	32.17
Maize								
3	1.30	5.64	4.80	20.81	2.06	8.93	7.58	32.86
4	3.74	16.55	7.95	35.18	5.80	25.66	12.32	54.52
Mean	2.52	11.09	6.38	27.99	3.93	17.30	9.95	43.69
Bajra + Red gram								
5	1.25	6.43	6.83	35.12	1.73	8.90	9.50	48.85
6	1.72	8.06	5.28	24.74	2.68	12.56	8.24	38.61
7	6.44	28.78	1.16	5.18	10.63	47.51	1.92	8.58
Mean	3.14	14.42	4.42	21.68	5.01	22.99	6.55	32.02
Groundnut								
8	1.07	4.80	3.44	15.44	1.78	7.99	5.71	25.63

Contd...

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	1.17	6.37	4.59	25.01	1.62	8.83	6.33	34.49
10	0.81	4.09	2.83	14.28	1.21	6.11	4.25	21.45
11	0.80	3.77	4.18	19.71	1.29	6.08	6.72	31.69
12	1.39	6.78	5.43	26.47	2.22	10.82	8.63	42.07
13	0.68	3.27	3.84	18.49	1.13	5.44	6.33	30.47
14	1.41	7.28	4.01	20.70	2.17	11.20	6.17	31.85
15	1.88	9.70	5.44	28.08	2.90	14.97	8.37	43.20
16	1.39	6.71	4.95	23.91	2.34	11.30	8.37	40.43
17	1.12	6.25	4.98	27.78	1.67	9.32	7.43	41.45
18	0.72	3.55	3.65	17.98	1.21	5.96	6.17	30.40
19	1.34	6.70	3.34	16.71	2.23	11.16	5.59	27.96
20	2.87	16.05	7.68	42.95	4.31	24.11	11.52	64.43
21	0.87	4.90	3.87	21.79	1.09	6.14	4.84	27.25
22	2.53	15.81	6.37	39.79	3.7	23.11	9.30	58.10
23	1.63	8.68	5.51	29.33	2.43	12.93	8.21	43.71
24	3.82	19.18	4.01	20.13	6.58	33.04	6.89	34.59
25	0.89	5.49	4.20	25.91	1.24	7.65	5.89	36.33
26	1.70	9.14	5.39	28.99	2.73	14.68	8.68	46.68
27	1.04	6.06	3.78	22.03	1.58	9.21	5.75	33.51
28	1.07	6.39	4.03	24.06	1.33	7.94	4.99	29.80
29	1.05	5.92	1.46	8.23	1.67	9.41	2.32	13.07
30	0.67	3.80	4.08	23.14	1.06	6.01	6.45	36.58
31	1.47	8.00	4.56	24.83	2.19	11.93	6.79	37.00
32	1.53	8.49	5.51	30.56	2.48	13.75	8.93	49.53
33	4.04	23.92	10.43	61.75	6.18	36.59	15.96	94.49
34	0.82	4.93	4.86	29.20	1.29	7.75	7.64	45.91
35	0.95	6.22	5.21	34.11	1.40	9.17	7.71	50.48
36	1.79	10.80	6.77	40.86	2.88	17.38	10.91	65.85
Mean	1.47	8.04	4.77	26.28	2.27	12.41	7.34	40.29
Groundnut + Red gram								
37	1.47	8.54	6.33	36.80	2.47	14.36	10.63	61.79
38	0.94	6.62	2.97	20.93	1.30	9.16	4.13	29.10
39	2.26	14.71	5.21	33.90	3.44	22.39	7.92	51.54
40	3.11	17.94	4.61	26.59	5.39	31.09	7.98	46.04
Mean	1.95	11.95	4.78	29.56	3.15	19.25	7.67	47.12
Mean	1.68	8.93	4.82	26.11	2.64	13.93	7.43	40.12
SD	1.16	5.79	1.67	10.00	1.92	9.52	2.60	15.38
Range	0.67 – 6.44	3.27- 28.78	1.06 – 10.63	5.18- 61.75	1.16 – 10.63	5.44- 47.51	1.92 – 15.96	8.58- 94.49

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 13: Gravimetric and volumetric soil moisture content on 2nd August 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	13.05	48.64	20.02	74.62	15.92	59.34	24.43	91.06
2	2.26	9.24	5.37	21.95	2.83	11.55	6.71	27.44
3	18.61	62.36	25.65	85.95	20.47	68.59	28.21	94.53
4	8.63	30.37	21.70	76.37	9.58	33.71	24.09	84.78
5	4.01	16.14	9.97	40.13	4.05	16.30	10.07	40.53
Mean	9.31	33.35	16.54	59.80	10.57	37.90	18.70	67.67
Maize								
6	7.52	29.77	14.09	55.78	10.08	39.89	18.88	74.75
7	9.45	32.92	16.24	56.58	12.66	44.11	21.76	75.81
Mean	8.49	31.35	15.17	56.18	11.37	42.00	20.32	75.28
Groundnut								
8	9.88	37.32	21.00	79.31	11.56	43.66	24.57	92.80
9	9.15	32.59	23.51	83.73	9.70	34.54	24.92	88.75
Mean	9.52	34.95	22.26	81.52	10.63	39.10	24.75	90.77
Groundnut + Red gram								
10	10.1	30.72	27.09	82.40	12.63	38.42	33.87	103.03
Mean	9.27	33.01	18.46	65.68	10.95	39.01	21.75	77.35
SD	4.51	14.90	6.98	21.45	5.16	17.18	8.10	24.54
Range	2.26 – 18.61	9.24-62.36	3.32 – 15.92	21.95-85.95	2.83 – 20.47	11.55-68.59	6.71 – 33.87	27.44-103.03
Red soils								
Bare								
1	2.04	8.53	4.00	16.72	3.33	13.92	6.52	27.25
2	2.67	13.31	10.01	49.91	3.66	18.25	13.72	68.41
Mean	2.36	10.92	7.01	33.31	3.50	16.08	10.12	47.83
Maize								
3	4.21	18.25	7.46	32.34	6.65	28.83	11.79	51.11
4	2.45	10.84	5.79	25.62	3.79	16.77	8.97	39.69
Mean	3.33	14.55	6.63	28.98	5.22	22.80	10.38	45.40
Bajra + Red gram								
5	2.96	15.22	7.28	37.44	4.11	21.14	10.13	52.09
6	3.34	15.65	7.85	36.78	5.21	24.41	12.25	57.40
7	3.30	14.75	9.70	43.35	5.44	24.31	16.00	71.51
Mean	3.20	15.21	8.28	39.19	4.92	23.29	12.79	60.34
Groundnut								
8	2.69	12.08	6.48	29.09	4.46	20.02	10.76	48.30

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	3.39	18.47	5.38	29.31	4.68	25.50	7.43	40.48
10	2.43	12.26	4.90	24.73	3.65	18.42	7.35	37.09
11	1.90	8.96	4.07	19.19	3.07	14.48	6.55	30.89
12	2.38	11.60	4.53	22.09	3.79	18.48	7.20	35.10
13	3.24	15.60	5.32	25.61	5.34	25.71	8.77	42.22
14	5.33	27.51	9.12	47.08	8.22	42.43	14.05	72.52
15	3.25	16.78	4.07	21.01	5.01	25.86	6.27	32.36
16	2.34	11.30	4.60	22.22	3.95	19.08	7.78	37.58
17	2.33	13.00	5.16	28.79	3.47	19.36	7.68	42.85
18	2.86	14.09	5.11	25.18	4.83	23.80	8.64	42.57
19	2.02	10.11	5.74	28.71	3.37	16.86	9.59	47.97
20	4.34	24.27	9.77	54.64	6.52	36.47	14.66	81.99
21	2.06	11.60	7.62	42.90	2.58	14.53	9.52	53.60
22	2.80	17.49	6.06	37.86	4.09	25.55	8.85	55.29
23	3.17	16.88	7.01	37.32	4.72	25.15	10.44	55.61
24	1.93	9.69	5.59	28.07	3.31	16.62	9.61	48.25
25	2.32	14.31	5.96	36.76	3.25	20.05	8.34	51.44
26	5.35	28.77	13.77	74.05	8.61	46.30	22.17	119.22
27	1.61	9.38	4.09	23.83	2.44	14.22	6.22	36.25
28	1.84	10.99	4.37	26.09	2.29	13.67	5.41	32.30
29	2.27	12.79	5.26	29.64	3.61	20.34	8.36	47.11
30	1.55	8.79	5.71	32.38	2.45	13.89	9.02	51.15
31	2.10	11.44	4.31	23.47	3.13	17.04	6.42	34.97
32	4.99	27.68	14.92	82.75	8.08	44.81	24.17	134.05
33	9.27	54.88	17.13	101.41	14.18	83.95	26.20	155.11
34	2.57	15.44	7.67	46.09	4.03	24.22	12.05	72.41
35	1.70	11.13	7.95	52.05	2.52	16.50	11.76	77.00
36	2.45	14.79	5.45	32.90	3.95	23.84	8.77	52.94
Mean	2.98	16.28	6.80	37.42	4.61	25.07	10.48	57.54
Groundnut + Red gram								
37	2.21	12.85	6.50	37.78	3.71	21.57	10.93	63.53
38	4.61	32.48	5.46	38.47	6.41	45.17	7.59	53.48
39	7.33	47.70	10.16	66.11	11.14	72.49	15.44	100.47
40	2.30	13.27	5.24	30.23	3.99	23.02	9.07	52.32
Mean	4.11	26.57	6.84	43.15	6.31	40.56	10.76	67.45
Mean	3.10	16.87	6.91	37.50	4.78	25.92	10.66	57.65
SD	1.57	9.86	2.99	17.81	2.43	14.98	4.72	27.67
Range	1.55 – 9.27	8.53-54.88	2.44 – 14.18	16.72-101.41	2.29 – 14.18	13.67-83.95	5.41 – 26.20	27.25-155.11

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 0.33 to 2.51 per cent with mean and standard deviation of 1.25 and 0.56 per cent respectively. Soil moisture content in subsurface of red soils (5-10 cm) varied from 0.51 to 10.25 per cent with mean and standard deviation of 2.43 and 2.06 per cent, respectively. The mean surface and subsurface soil moisture was at 6.69 and 12.99 per cent of FC respectively.

4.1.3.6 Soil moisture status on 22nd September 2006

The volumetric soil moisture content of black soils at the surface (0-5 cm) ranged from 1.29 to 11.34 per cent with mean and standard deviation of 6.04 and 2.91 per cent respectively. Soil moisture content in subsurface of black soils (5-10 cm) varied from 4.15 to 25.18 per cent with mean and standard deviation of 13.90 and 7.09 per cent, respectively. The mean surface and subsurface soil moisture was at 21.67 and 49.89 per cent of FC respectively.

The volumetric soil moisture content of red soils at the surface (0-5 cm) ranged from 0.66 to 5.72 per cent with mean and standard deviation of 1.67 and 0.93 per cent respectively, where as moisture content in subsurface soils (5-10 cm) varied from 1.17 to 14.25 per cent with mean and standard deviation of 4.29 and 2.76 per cent, respectively. The mean surface and subsurface soil moisture was at 8.93 and 22.73 per cent of FC respectively.

In general, volumetric soil moisture status was very low during 2006. Black soils had comparatively higher soil moisture (4.70 to 10.95 per cent at 0-5 cm and 6.89 to 21.75 per cent at 5-10 cm) than red soils (1.25 to 4.78 per cent at 0-5 cm and 2.43 to 10.66 per cent at 5-10 cm) during monitoring period of June to September 2006. Compared to 2005 soil moisture status during 2006, was very low. Mean surface soil moisture was <50 per cent FC in black soils and < 25 per cent FC in red soils during monitoring period of 2006.

4.2 Physical properties

4.2.1 Particle size distribution (cf. Table 17)

The gravel content of black soil ranged from 3.46 to 9.81 per cent with mean and standard deviation of 6.35 and 2.36 per cent, respectively. The gravel content in red soils varied from 20.09 to 41.58 per cent with mean and standard deviation of 27.84 and 5.41 per cent, respectively.

The coarse and fine sand content in black soils ranged from 15.36 to 26.20 and 20.37 to 30.87 per cent with mean and standard deviation of 19.03, 2.99 and 24.22, 2.94 per cent, respectively. Among red soils, coarse and fine sand content varied from 50.01 to 61.94 and 18.50 to 27.76 per cent with mean and standard deviation of 54.83, 3.18 and 21.83, 2.37 per cent respectively.

The clay content was higher in black soils than in red soils and varied from 31.73 to 39.40 per cent with mean and standard deviation of 36.86 and 2.29 per cent, respectively. In red soils clay content ranged from 7.82 to 14.32 per cent with mean and standard deviation of 10.78 and 1.84 per cent, respectively.

The silt content in black soils ranged from 16.45 to 22.51 per cent with mean and standard deviation of 19.89 and 1.75 per cent. Silt content of red soils varied from 7.78 to 18.06 per cent with mean and standard deviation of 12.56 and 2.47 per cent, respectively.

Red soils showed a higher amount of total sand (70.26 to 82.68 per cent but in black soils total sand content varied from 40.12 to 50.21 per cent) than black soils. Decrease in fine sand with simultaneous increase in coarse sand was observed in all the samples. The highest silt and clay content was observed in black soils than in red soils.

Table 14: Gravimetric and volumetric soil moisture content on 18th August 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	6.73	25.09	14.63	54.53	8.21	30.60	17.84	66.50
2	0.74	3.03	5.15	21.05	0.93	3.78	6.44	26.32
3	9.80	32.84	16.68	55.89	10.77	36.09	18.35	61.49
4	7.48	26.32	16.45	57.89	8.30	29.21	18.25	64.22
5	11.61	46.73	14.89	59.93	11.73	47.21	15.04	60.53
Mean	7.27	26.80	13.56	49.86	7.99	29.38	15.18	55.81
Maize								
6	2.00	7.92	6.30	24.94	2.68	10.61	8.44	33.42
7	1.36	4.74	3.39	11.81	1.82	6.34	4.54	15.82
Mean	1.68	6.33	4.85	18.38	2.25	8.48	6.49	24.62
Groundnut								
8	2.91	10.99	5.70	21.53	3.40	12.84	6.67	25.19
9	6.03	21.47	13.21	47.05	6.39	22.76	14.00	49.86
Mean	4.47	16.23	9.46	34.29	4.90	17.80	10.34	37.53
Groundnut + Red gram								
10	6.10	18.56	14.03	42.68	7.62	23.18	17.54	53.35
Mean	5.48	19.77	11.04	39.73	6.18	22.26	12.71	45.67
SD	3.66	13.73	5.23	18.13	3.79	13.95	5.58	18.74
Range	0.74 – 11.61	3.03- 46.7	1.08 – 11.73	11.81- 59.93	0.93 – 11.73	3.78- 47.21	4.54 – 18.35	15.82- 66.50
Red soils								
Bare								
1	0.6	2.51	5.86	24.49	0.98	4.10	9.55	39.91
2	0.49	2.44	4.57	22.79	0.68	3.39	6.26	31.21
Mean	0.55	2.48	5.22	23.64	0.83	3.74	7.91	35.56
Maize								
3	0.87	3.77	4.86	21.07	1.38	5.98	7.68	33.29
4	4.45	19.69	9.96	44.07	6.89	30.49	15.44	68.32
Mean	2.66	11.73	7.41	32.57	4.14	18.24	11.56	50.81
Bajra + Red gram								
5	3.51	18.05	4.97	25.56	4.88	25.10	6.91	35.53
6	1.05	4.92	4.24	19.87	1.63	7.64	6.62	31.02
7	0.29	1.30	1.18	5.27	0.48	2.15	1.95	8.72
Mean	1.62	8.09	3.46	16.90	2.33	11.63	5.16	25.09
Groundnut								
8	1.71	7.68	6.04	27.11	2.84	12.75	10.02	44.98

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	0.75	4.09	5.27	28.71	1.03	5.61	7.28	39.66
10	0.75	3.79	2.63	13.27	1.12	5.65	3.95	19.93
11	0.42	1.98	1.42	6.70	0.68	3.21	2.29	10.80
12	0.18	0.88	1.57	7.65	0.28	1.37	2.50	12.19
13	0.59	2.84	1.78	8.57	0.98	4.72	2.94	14.15
14	0.30	1.55	2.21	11.41	0.46	2.37	3.40	17.55
15	1.41	7.28	2.50	12.90	2.16	11.15	3.84	19.82
16	0.59	2.85	1.59	7.68	0.99	4.78	2.68	12.95
17	1.55	8.65	5.37	29.96	2.31	12.89	7.99	44.58
18	3.50	17.24	1.13	5.57	5.91	29.12	1.92	9.46
19	0.50	2.50	0.73	3.65	0.84	4.20	1.22	6.10
20	2.04	11.41	12.63	70.64	3.06	17.11	18.94	105.93
21	0.89	5.01	1.81	10.19	1.12	6.31	2.26	12.72
22	1.80	11.24	3.33	20.80	2.63	16.43	4.86	30.36
23	0.86	4.58	2.16	11.50	1.28	6.82	3.22	17.13
24	1.44	7.23	4.65	23.35	2.48	12.45	8.01	40.22
25	1.48	9.13	3.31	20.42	2.08	12.83	4.63	28.56
26	0.79	4.25	2.44	13.12	1.28	6.88	3.92	21.08
27	0.71	4.14	2.13	12.41	1.08	6.29	3.23	18.82
28	1.10	6.57	7.27	43.41	1.37	8.18	9.02	53.86
29	2.36	13.30	2.47	13.92	3.76	21.19	3.92	22.09
30	0.75	4.25	1.47	8.34	1.19	6.75	2.32	13.16
31	0.25	1.36	1.99	10.84	0.37	2.03	2.97	16.15
32	0.98	5.44	2.49	13.81	1.59	8.82	4.03	22.35
33	0.73	4.32	2.97	17.58	1.11	6.57	4.54	26.88
34	0.27	1.62	1.49	8.95	0.42	2.52	2.34	14.06
35	0.50	3.27	1.34	8.77	0.74	4.84	1.98	12.96
36	0.39	2.35	0.82	4.95	0.62	3.74	1.32	7.97
Mean	1.02	5.54	3.00	16.42	1.58	8.54	4.54	24.71
Groundnut + Red gram								
37	0.32	1.86	0.99	5.75	0.54	3.14	1.67	9.71
38	0.45	3.17	1.08	7.61	0.62	4.37	1.50	10.57
39	1.78	11.58	2.92	19.00	2.70	17.57	4.44	28.89
40	0.63	3.63	1.30	7.50	1.09	6.29	2.24	12.92
Mean	0.80	5.06	1.57	9.97	1.24	7.84	2.46	15.52
Mean	1.10	5.84	3.22	16.98	1.69	8.94	4.89	25.66
SD	0.96	4.77	2.52	13.07	1.48	7.33	3.77	19.12
Range	0.25 – 4.45	0.88- 19.69	0.28 – 6.89	3.65- 70.64	0.28 – 6.89	1.37- 30.49	1.22- 18.94	6.10- 105.93

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 15: Gravimetric and volumetric soil moisture content on 6th September 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	5.75	21.43	6.05	22.55	7.01	26.13	7.38	27.51
2	0.90	3.68	1.56	6.38	1.13	4.60	1.95	7.97
3	7.36	24.66	8.86	29.69	8.10	27.14	9.74	32.64
4	6.68	23.51	10.35	36.42	7.42	26.11	11.49	40.43
5	4.73	19.04	5.67	22.82	4.77	19.20	5.73	23.06
Mean	5.08	18.46	6.50	23.57	5.69	20.64	7.26	26.32
Maize								
6	1.97	7.80	2.53	10.02	2.64	10.45	3.39	13.42
7	1.32	4.60	6.42	22.37	1.77	6.17	8.61	30.00
Mean	1.65	6.20	4.48	16.19	2.20	8.31	6.00	21.71
Groundnut								
8	3.29	12.43	4.08	15.41	3.85	14.54	4.78	18.05
9	3.78	13.46	5.34	19.02	4.01	14.28	5.66	20.16
Mean	3.54	12.94	4.71	17.21	3.93	14.41	5.22	19.11
Groundnut + Red gram								
10	5.06	15.39	8.17	24.85	6.32	19.22	10.21	31.06
Mean	4.08	14.60	5.90	20.95	4.70	16.78	6.89	24.43
SD	2.23	7.60	2.75	8.85	2.44	8.21	3.12	9.78
Range	0.90 – 7.36	3.68-24.66	1.33 – 8.10	6.38-36.42	1.13 – 8.10	4.60-27.14	1.95 – 11.49	7.97-40.43
Red soils								
Bare								
1	0.89	3.72	1.21	5.06	1.45	6.06	1.98	8.27
2	0.65	3.24	6.42	32.01	0.90	4.49	8.80	43.88
Mean	0.77	3.48	3.82	18.53	1.18	5.27	5.39	26.08
Maize								
3	1.14	4.94	1.60	6.94	1.81	7.85	2.53	10.97
4	1.55	6.86	3.54	15.66	2.4	10.62	5.48	24.25
Mean	1.35	5.90	2.57	11.30	2.11	9.23	4.01	17.61
Bajra + Red gram								
5	1.81	9.31	2.33	11.98	2.51	12.91	3.24	16.66
6	0.94	4.40	0.98	4.59	1.47	6.89	1.52	7.12
7	0.31	1.39	0.45	2.01	0.51	2.28	0.73	3.26
Mean	1.02	5.03	1.25	6.20	1.50	7.36	1.83	9.02
Groundnut								
8	1.24	5.57	1.75	7.86	2.05	9.20	2.91	13.06

Contd.....

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	1.19	6.48	7.43	40.48	1.64	8.94	10.25	55.85
10	0.71	3.58	0.98	4.95	1.07	5.40	1.46	7.37
11	0.86	4.06	1.05	4.95	1.38	6.51	1.69	7.97
12	0.44	2.15	0.71	3.46	0.70	3.41	1.13	5.51
13	0.63	3.03	0.80	3.85	1.04	5.01	1.32	6.35
14	0.57	2.94	1.02	5.27	0.88	4.54	1.57	8.10
15	0.79	4.08	1.32	6.81	1.21	6.25	2.04	10.53
16	0.58	2.80	2.86	13.81	0.98	4.73	4.83	23.33
17	1.13	6.30	1.46	8.15	1.68	9.37	2.18	12.16
18	0.87	4.29	0.75	3.70	1.47	7.24	1.26	6.21
19	0.75	3.75	1.04	5.20	1.25	6.25	1.73	8.65
20	1.40	7.83	2.49	13.93	2.10	11.74	3.74	20.92
21	1.09	6.14	1.39	7.83	1.36	7.66	1.74	9.80
22	1.32	8.25	3.69	23.05	1.93	12.06	5.39	33.67
23	0.84	4.47	1.21	6.44	1.25	6.66	1.80	9.60
24	0.41	2.06	0.78	3.92	0.70	3.51	1.35	6.78
25	0.97	5.98	1.52	9.38	1.36	8.39	2.13	13.14
26	0.71	3.82	1.05	5.65	1.14	6.13	1.69	9.09
27	0.96	5.59	0.86	5.01	1.46	8.51	1.31	7.63
28	0.27	1.61	0.41	2.45	0.33	1.97	0.51	3.05
29	1.00	5.64	0.70	3.94	1.59	8.96	1.12	6.31
30	0.55	3.12	0.81	4.59	0.86	4.88	1.28	7.26
31	0.38	2.07	0.52	2.83	0.57	3.08	0.77	4.22
32	0.94	5.21	1.36	7.54	1.53	8.49	2.21	12.26
33	0.34	2.01	0.54	3.20	0.51	3.02	0.83	4.91
34	0.38	2.28	2.53	15.20	0.6	3.61	3.98	23.92
35	0.25	1.64	0.55	3.60	0.37	2.42	0.81	5.30
36	0.39	2.35	0.69	4.16	0.63	3.80	1.11	6.70
Mean	0.76	4.11	1.46	7.97	1.16	6.27	2.21	12.06
Groundnut + Red gram								
37	0.33	1.92	0.62	3.60	0.56	3.26	1.04	6.05
38	1.51	10.64	2.38	16.77	2.09	14.73	3.30	23.25
39	0.86	5.60	1.53	9.96	1.31	8.52	2.33	15.16
40	0.82	4.73	1.12	6.46	1.43	8.25	1.94	11.19
Mean	0.88	5.72	1.41	9.20	1.35	8.69	2.15	13.91
Mean	0.82	4.40	1.61	8.66	1.25	6.69	2.43	12.99
SD	0.39	2.20	1.48	7.95	0.56	3.10	2.06	11.02
Range	0.25 – 1.55	1.39- 10.64	0.37 – 2.51	2.01- 40.48	0.33 – 2.51	1.97- 14.73	0.51 – 10.25	3.05- 55.85

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 16: Gravimetric and volumetric soil moisture content on 22nd September 2006

Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
Black soils								
Bare								
1	5.04	18.79	8.64	32.21	6.15	22.92	10.54	39.29
2	1.03	4.21	3.32	13.57	1.29	5.26	4.15	16.96
3	7.79	26.10	22.89	76.70	8.57	28.72	25.18	84.37
4	10.22	35.97	21.53	75.77	11.34	39.91	23.89	84.07
5	6.42	25.84	18.90	76.07	6.49	26.12	19.09	76.83
Mean	6.10	22.18	15.06	54.86	6.77	24.59	16.57	60.31
Maize								
6	2.98	11.80	6.78	26.84	3.99	15.81	9.09	35.97
7	2.69	9.37	5.29	18.43	3.60	12.54	7.09	24.70
Mean	2.84	10.58	6.04	22.64	3.80	14.18	8.09	30.33
Groundnut								
8	3.70	13.97	8.19	30.93	4.33	16.35	9.58	36.18
9	7.97	28.38	14.50	51.64	8.45	30.09	15.37	54.74
Mean	5.84	21.18	11.35	41.29	6.39	23.22	12.48	45.46
Groundnut + Red gram								
10	4.98	15.15	12.03	36.59	6.23	18.95	15.04	45.75
Mean	5.28	18.96	12.21	43.88	6.04	21.67	13.90	49.89
SD	2.83	9.87	6.96	24.50	2.91	9.98	7.09	24.35
Range	1.03 – 10.22	4.21-35.97	1.51 – 11.34	13.57-76.70	1.29 – 11.34	5.26-39.91	4.15 – 25.18	16.96-84.37
Red soils								
Bare								
1	0.82	3.43	1.03	4.30	1.34	5.60	1.67	6.98
2	0.56	2.79	4.58	22.84	0.77	3.84	6.27	31.26
Mean	0.69	3.11	2.81	13.57	1.06	4.72	3.97	19.12
Maize								
3	1.40	6.07	4.62	20.03	2.21	9.58	7.31	31.69
4	3.69	16.33	5.87	25.97	5.72	25.31	9.09	40.22
Mean	2.55	11.20	5.25	23.00	3.97	17.45	8.20	35.96
Bajra + Red gram								
5	2.13	10.95	2.66	13.68	2.97	15.27	3.70	19.03
6	1.28	6.00	9.13	42.78	1.99	9.32	14.25	66.77
7	0.63	2.82	2.03	9.07	1.04	4.65	3.36	15.02
Mean	1.35	6.59	4.61	21.84	2.00	9.75	7.10	33.61
Groundnut								
8	1.71	7.68	3.12	14.01	2.84	12.75	5.17	23.21

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Sample No.	Soil moisture %							
	0-5 cm		5-10 cm		0-5 cm		5-10 cm	
	θ_w	% of FC	θ_w	% of FC	θ_v	% of FC	θ_v	% of FC
9	1.41	7.68	2.30	12.53	1.95	10.62	3.17	17.27
10	0.78	3.94	0.84	4.24	1.17	5.90	1.26	6.36
11	0.81	3.82	0.85	4.01	1.30	6.13	1.36	6.41
12	0.67	3.27	0.73	3.56	1.07	5.22	1.17	5.70
13	0.60	2.89	1.12	5.39	0.99	4.77	1.85	8.91
14	0.56	2.89	6.98	36.03	0.87	4.49	10.75	55.49
15	1.51	7.79	1.91	9.86	2.32	11.98	2.95	15.23
16	0.83	4.01	2.42	11.69	1.41	6.81	4.09	19.76
17	1.27	7.09	2.14	11.94	1.89	10.54	3.19	17.80
18	0.98	4.83	2.24	11.04	1.66	8.18	3.79	18.67
19	0.88	4.40	1.46	7.30	1.46	7.30	2.44	12.21
20	1.01	5.65	2.76	15.44	1.52	8.50	4.15	23.21
21	1.01	5.69	1.69	9.52	1.26	7.09	2.11	11.88
22	1.41	8.81	2.35	14.68	2.06	12.87	3.43	21.43
23	1.35	7.19	5.47	29.12	2.01	10.71	8.15	43.39
24	0.53	2.66	2.17	10.89	0.91	4.57	3.74	18.78
25	1.24	7.65	3.86	23.81	1.74	10.73	5.40	33.31
26	1.02	5.49	3.65	19.63	1.64	8.82	5.87	31.57
27	0.73	4.25	2.80	16.32	1.11	6.47	4.26	24.82
28	0.53	3.16	1.50	8.96	0.66	3.94	1.85	11.05
29	0.56	3.16	2.33	13.13	0.89	5.02	3.70	20.85
30	0.73	4.14	2.79	15.82	1.15	6.52	4.41	25.01
31	0.54	2.94	5.01	27.28	0.80	4.38	7.46	40.65
32	1.97	10.93	4.44	24.62	3.19	17.69	7.19	39.88
33	0.74	4.38	2.50	14.80	1.14	6.75	3.83	22.67
34	1.06	6.37	1.65	9.91	1.67	10.03	2.59	15.56
35	0.52	3.40	1.69	11.06	0.77	5.04	2.50	16.37
36	1.01	6.10	1.69	10.20	1.63	9.84	2.72	16.42
Mean	0.96	5.25	2.57	14.03	1.49	8.06	3.95	21.51
Groundnut + Red gram								
37	0.72	4.19	1.00	5.81	1.21	7.03	1.68	9.77
38	2.21	15.57	2.53	17.83	3.07	21.63	3.51	24.73
39	1.37	8.92	2.67	17.37	2.08	13.54	4.05	26.35
40	0.78	4.50	1.35	7.79	1.34	7.73	2.33	13.44
Mean	1.27	8.29	1.89	12.20	1.93	12.48	2.89	18.57
Mean	1.09	5.84	2.80	14.86	1.67	8.93	4.29	22.73
SD	0.61	3.23	1.79	8.78	0.93	4.73	2.76	13.37
Range	0.52 – 3.69	2.66-16.33	0.66 – 5.72	3.56-42.78	0.66 – 5.72	3.84-25.31	1.17 – 14.25	5.70-66.77

θ_w – Gravimetric soil moisture

θ_v – Volumetric soil moisture

Table 17: Particle size composition of surface soil samples

Sample No.	Gravel	Coarse sand	Fine sand	Total sand	Silt	Clay	Texture
	%						
Black soils							
1	3.98	16.12	27.13	43.25	20.46	36.29	cl
2	9.36	26.20	23.03	49.23	16.45	34.32	cl
3	4.95	18.34	22.86	41.20	20.07	38.73	c
4	3.46	17.21	23.81	41.02	19.58	39.40	c
5	3.85	18.21	24.37	42.58	20.13	37.29	c
6	6.38	19.34	30.87	50.21	18.06	31.73	cl
7	7.10	20.21	21.92	42.13	20.05	37.82	c
8	9.81	20.20	20.37	40.57	22.51	36.92	c
9	8.81	15.36	24.76	40.12	22.08	37.80	c
10	5.77	19.10	23.03	42.13	19.54	38.33	c
Mean	6.35	19.03	24.22	43.24	19.89	36.86	
SD	2.36	2.99	2.94	3.55	1.75	2.29	
Range	3.46 - 9.81	15.36 - 26.2	20.37- 30.87	40.12- 50.21	16.45- 22.51	31.73 - 39.4	
Red soils							
1	22.23	52.21	19.04	71.25	16.01	12.74	sl
2	20.16	53.21	24.44	77.65	12.36	9.99	s
3	20.36	50.01	27.76	77.77	12.13	10.10	sl
4	24.96	50.10	20.52	70.62	15.85	13.53	sl
5	20.09	57.12	19.21	76.33	13.80	9.87	s
6	29.42	56.31	24.02	80.33	10.00	9.67	s
7	40.16	59.26	19.10	78.36	12.18	9.46	s
8	25.26	52.10	22.10	74.20	15.60	10.20	sl
9	27.45	51.21	19.05	70.26	16.01	13.73	sl
10	34.25	52.20	18.50	70.70	16.01	13.29	sl
11	21.63	54.20	20.05	74.25	13.02	12.73	sl
12	24.55	52.20	20.30	72.50	14.20	13.30	sl
13	24.02	55.21	24.79	80.00	12.02	7.98	s
14	29.48	55.25	25.21	80.46	10.00	9.54	s
15	33.91	52.10	21.09	73.19	18.06	8.75	sl

Contd...

Sample No.	Gravel	Coarse sand	Fine sand	Total sand	Silt	Clay	Texture
16	25.43	56.20	23.01	79.21	8.03	12.76	sl
17	21.56	57.23	21.00	78.23	11.01	10.76	sl
18	23.16	51.30	19.35	70.65	15.03	14.32	sl
19	26.95	53.26	22.13	75.39	11.03	13.58	sl
20	22.59	55.13	19.57	74.70	16.01	9.29	s
21	25.16	50.10	26.14	76.24	13.73	10.03	sl
22	23.42	51.30	19.35	70.65	15.03	14.32	sl
23	27.79	53.25	25.40	78.65	12.60	8.75	s
24	25.53	51.98	24.36	76.34	11.35	12.31	sl
25	32.36	61.94	20.74	82.68	7.78	9.54	s
26	25.92	59.30	20.80	80.10	10.24	9.66	s
27	30.16	56.12	22.82	78.94	11.12	9.94	s
28	26.58	51.62	24.00	75.62	13.24	11.14	sl
29	27.56	52.31	26.01	78.32	10.03	11.65	sl
30	34.39	59.34	22.53	81.87	10.31	7.82	s
31	31.38	58.36	22.33	80.69	11.21	8.10	s
32	35.37	58.38	22.01	80.39	10.35	9.26	s
33	32.39	57.36	20.40	77.76	10.11	12.13	sl
34	24.31	59.64	18.72	78.36	12.52	9.12	s
35	41.58	59.16	20.09	79.25	9.52	11.23	sl
36	36.17	56.84	22.40	79.24	10.20	10.56	sl
37	35.16	57.23	20.00	77.23	12.94	9.83	s
38	27.15	55.21	21.00	76.21	14.01	9.78	s
39	27.12	56.00	21.88	77.88	12.02	10.10	sl
40	26.32	52.10	22.10	74.20	15.60	10.20	sl
Mean	27.84	54.83	21.83	76.67	12.56	10.78	
SD	5.41	3.18	2.37	3.43	2.47	1.84	
Range	20.09-41.58	50.0-61.94	18.51 - 27.76	70.26-82.68	7.7 - 18.06	7.82-14.32	

4.2.2 Soil depth (cf. Table 18)

The depth of black soils ranged from 102 to 115 cm with mean and standard deviation of 109.2 and 5.39 cm, respectively. The depth of red soil varied from 37 to 58 cm with mean and standard deviation of 48.35 and 6.97 cm, respectively.

4.2.3 Bulk density and Porosity (cf. Table 18)

The bulk density of black soil, ranged from 1.01 to 1.34 Mg per m³ with mean and standard deviation of 1.19 and 0.11 Mg per m³, respectively. The bulk density of red soils, varied from 1.36 to 1.73 Mg per m³ with mean and standard deviation of 1.55 and 0.10 Mg per m³, respectively.

The porosity of black soil ranged from 44.53 to 61.89 per cent with mean and standard deviation of 54.34 and 5.60 per cent, respectively. The porosity of red soil varied from 34.72 to 48.68 per cent with mean and standard deviation of 41.61 and 4.59 per cent, respectively.

4.2.4 Maximum water holding capacity (cf. Table 18)

The maximum water holding capacity of black soils varied between 37.69 to 54.25 per cent with a mean and standard deviation of 46.91 and 5.96 per cent respectively. On the other hand the maximum water holding capacity of red soils varied from 20.03 to 29.35 per cent with a mean and standard deviation of 24.18 and 2.72 per cent respectively. In general the black soils had a higher maximum water holding capacity than red soils. Half of the maximum water holding capacity is considered as field capacity of soils.

The field capacity of black soils on weight and volume basis varied between 18.85 to 27.13 and 24.46 to 32.88 per cent with a mean and standard deviation of 23.46, 2.98 and 27.58, 2.58 per cent respectively. On the other hand the field capacity of red soils on weight and volume basis varied from 10.02 to 14.68 and 14.19 to 23.93 per cent with a mean and standard deviation of 12.09, 1.36 and 18.85, 2.34 per cent respectively.

4.3 Chemical properties

4.3.1 Soil reaction (cf. Table 19)

The pH values in black soils ranged from 7.3 to 8.4. Their mean and standard deviation (SD) values were 7.73 and 0.26, respectively. Where as, the pH values of red soils ranged 6.2 to 7.6 with mean and SD of 6.79 and 0.30, respectively.

4.3.2 Electrical conductivity (cf. Table 19)

The EC values in black and red soils ranged from 0.41 to 1.20 dS m⁻¹ and 0.16 to 0.55 dS m⁻¹, respectively, indicating that the soils are non-saline.

The mean of EC values for black and red soil was 0.62 and 0.21 dS m⁻¹ with SD values of 0.29 and 0.10 dS m⁻¹, respectively.

4.3.3 Organic carbon (cf. Table 19)

The organic carbon content in black and red soils was ranged from 3.6 to 6.8 and 3.6 to 6.4 g kg⁻¹, respectively. The mean and SD for black and red soils were 4.73 and 4.82 and 0.64 and 0.68, g kg⁻¹ respectively.

4.3.4 Free calcium carbonate (cf. Table 20)

The free CaCO₃ content in black soils was ranged from 3.0 to 8.5 per cent with mean and standard deviation of 5.96 and 1.39 per cent respectively. On the other hand, the free CaCO₃ content in red soils ranged from 1.0 to 7.5 per cent with mean and standard deviation of 3.32 and 1.40 per cent respectively.

4.3.5 Free iron oxide (cf. Table 20)

The free Fe₂O₃ content in black soils was ranged from 3.60 to 5.70 per cent with mean and standard deviation of 4.43 and 0.54 per cent respectively. On the other hand, the free Fe₂O₃ content in red soils ranged from 3.60 to 7.90 per cent with mean and standard deviation of 4.73 and 0.96 per cent respectively.

Table 18: Physical properties of surface soil samples

Sample No.	Depth (cm)	BD Mg/m ³	Porosity	MWHC	FC (weight basis)	FC (volume basis)
			%			
Black soils						
1	102	1.22	53.96	43.97	21.99	26.83
2	102	1.25	44.53	39.14	19.57	24.46
3	115	1.10	58.49	54.25	27.13	29.84
4	115	1.11	58.11	51.20	25.60	28.42
5	115	1.01	61.89	49.20	24.60	24.85
6	102	1.34	48.30	37.69	18.85	25.26
7	110	1.34	49.43	42.83	21.42	28.70
8	110	1.17	55.85	45.26	22.63	26.48
9	111	1.06	60.00	52.98	26.49	28.08
10	110	1.25	52.83	52.60	26.30	32.88
Mean	109.2	1.19	54.34	46.91	23.46	27.58
SD	5.39	0.11	5.60	5.96	2.98	2.58
Range	102.0 - 115.0	1.01 - 1.34	44.53-61.89	37.69-54.25	18.85-27.13	24.46-32.88
Red soils						
1	46	1.63	38.49	25.18	12.59	20.52
2	46	1.37	48.30	25.16	12.58	17.23
3	58	1.58	40.38	29.28	14.64	23.13
4	37	1.55	41.51	27.98	13.99	21.68
5	58	1.39	47.55	29.16	14.58	20.27
6	54	1.56	41.13	29.19	14.60	22.78
7	54	1.65	37.74	25.16	12.58	20.76
8	45	1.66	37.36	26.59	13.30	22.08
9	45	1.38	47.92	22.31	11.16	15.40
10	42	1.50	43.40	20.03	10.02	15.03
11	45	1.61	39.25	25.80	12.90	20.77
12	45	1.59	40.00	24.50	12.25	19.48
13	47	1.65	37.74	23.54	11.77	19.42
14	45	1.54	41.89	23.09	11.55	17.79
15	45	1.54	41.89	26.84	13.42	20.67

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Sample No.	Depth (cm)	BD Mg/m ³	Porosity	MWHC	FC (weight basis)	FC (volume basis)
			%			
16	45	1.69	36.23	23.84	11.92	20.14
17	58	1.49	43.77	29.35	14.68	21.87
18	58	1.69	36.23	23.93	11.97	20.23
19	56	1.67	36.98	23.47	11.74	19.61
20	58	1.50	43.4	23.15	11.58	17.37
21	37	1.49	43.77	26.42	13.21	19.68
22	37	1.36	48.68	27.35	13.68	18.60
23	46	1.60	39.62	22.08	11.04	17.66
24	37	1.72	35.09	24.06	12.03	20.69
25	49	1.40	47.17	22.26	11.13	15.58
26	37	1.61	39.25	24.02	12.01	19.34
27	43	1.52	42.64	21.19	10.60	16.11
28	37	1.49	43.77	22.48	11.24	16.75
29	48	1.59	40.00	20.42	10.21	16.23
30	55	1.58	40.38	20.58	10.29	16.26
31	51	1.65	37.74	20.22	10.11	16.68
32	55	1.62	38.87	20.63	10.32	16.72
33	55	1.53	42.26	20.47	10.24	15.67
34	55	1.57	40.75	23.84	11.92	18.71
35	53	1.48	44.15	23.16	11.58	17.14
36	55	1.61	39.25	22.26	11.13	17.92
37	45	1.68	36.60	22.57	11.29	18.97
38	49	1.39	47.55	22.32	11.16	15.51
39	45	1.52	42.64	26.34	13.17	20.02
40	58	1.73	34.72	27.11	13.56	23.46
Mean	48.35	1.55	41.61	24.18	12.09	18.85
SD	6.97	0.10	4.59	2.72	1.36	2.34
Range	37.0 - 58.0	1.36 - 1.73	34.72 - 48.68	20.03 – 29.35	10.02 - 14.68	14.19 - 23.93

4.4 Fertility status

4.4.1 Available nitrogen (cf. Table 21)

The available nitrogen status in black soils was ranged from 189 to 278 kg per ha with mean and standard deviation of 203.3 and 18.3 kg per ha respectively. On the other hand, the available nitrogen content in red soils ranged from 170 to 291 kg per ha with mean and standard deviation of 214 and 30.8 kg per ha respectively.

Table 19: Chemical properties of surface soil samples

Sample No.	pH	EC (dS / m)	O.C (g/kg)
Black soil			
1	7.3	0.47	6.8
2	7.5	0.42	5.6
3	7.4	0.48	4.4
4	7.8	0.61	5.2
5	8.3	1.01	3.6
6	8.4	1.02	4.1
7	7.5	0.57	4.8
8	7.4	0.53	4.5
9	7.7	0.64	4.4
10	7.6	0.62	4.8
11	7.9	0.41	4.2
12	7.8	0.52	4.1
13	7.7	0.59	5.2
14	7.6	0.46	4.9
15	7.8	0.60	4.6
16	7.9	0.93	5.6
17	7.7	0.52	5.1
18	7.9	0.61	4.8
19	8.0	1.20	4.4
20	7.4	0.41	4.1
21	7.6	0.48	4.6
22	7.8	0.71	4.8
23	7.9	0.65	4.3
24	7.6	0.56	4.6
25	7.8	0.52	4.8
Mean	7.73	0.62	4.73
SD	0.26	0.21	0.64
Range	7.3 – 8.4	0.41 – 1.20	3.60 – 6.80
Red soils			
1	7.0	0.46	4.00
2	7.3	0.37	4.80
3	6.9	0.23	4.80
4	6.8	0.31	4.40
5	6.6	0.26	4.30
6	7.0	0.44	4.80
7	6.9	0.32	5.10
8	6.7	0.25	4.80
9	6.3	0.30	4.90
10	7.1	0.47	4.10

Contd...

Sample No.	pH	EC (dS / m)	O.C (g/kg)
11	7.2	0.47	5.20
12	6.9	0.23	5.00
13	6.7	0.28	5.20
14	6.8	0.21	5.30
15	7.6	0.55	6.20
16	6.7	0.19	5.40
17	6.5	0.37	5.20
18	6.3	0.16	5.60
19	6.8	0.19	5.40
20	6.4	0.17	6.00
21	7.0	0.48	6.20
22	6.9	0.36	4.80
23	6.3	0.26	5.20
24	6.8	0.21	5.20
25	7.0	0.39	6.40
26	6.8	0.29	5.10
27	6.7	0.25	4.80
28	6.5	0.17	4.40
29	6.6	0.19	5.00
30	6.7	0.34	4.80
31	6.3	0.26	5.20
32	6.4	0.25	5.60
33	7.1	0.38	4.40
34	7.4	0.43	4.80
35	7.2	0.34	5.20
36	7.3	0.38	4.00
37	7.1	0.24	4.40
38	6.9	0.39	4.80
39	7.0	0.47	5.20
40	7.1	0.51	6.00
41	6.7	0.27	5.60
42	6.5	0.28	5.20
43	6.9	0.16	4.40
44	7.3	0.35	5.20
45	7.0	0.24	4.00

Contd...

Sample No.	pH	EC (dS / m)	O.C (g/kg)
46	7.1	0.28	4.80
47	6.8	0.27	5.20
48	6.5	0.22	4.40
49	6.7	0.25	4.80
50	6.9	0.27	5.20
51	7.5	0.47	4.80
52	7.2	0.28	4.00
53	6.5	0.19	4.40
54	6.7	0.26	4.00
55	6.9	0.19	3.80
56	6.8	0.16	4.40
57	7.0	0.24	3.80
58	6.3	0.16	3.60
59	6.5	0.33	4.00
60	6.4	0.21	4.80
61	6.9	0.27	5.20
62	6.7	0.26	4.00
63	6.6	0.18	4.40
64	7.0	0.28	4.10
65	6.4	0.33	5.20
66	6.9	0.25	6.10
67	6.3	0.18	6.40
68	6.5	0.26	5.20
69	6.6	0.25	4.40
70	6.2	0.16	4.00
71	6.6	0.19	4.40
72	6.7	0.22	3.80
73	6.4	0.19	4.40
74	6.9	0.23	4.00
75	6.6	0.25	3.60
Mean	6.79	0.29	4.82
SD	0.30	0.10	0.68
Range	6.20 – 7.60	0.16 – 0.55	3.60 – 6.40

Table 20: Free CaCO₃ and Fe₂O₃ content in surface soil samples

Sample No.	CaCO₃ (%)	Fe₂O₃ (%)
Black soils		
1	7.5	5.1
2	3.5	4.1
3	3.0	4.4
4	3.5	4.4
5	4.5	4.0
6	5.5	4.1
7	4.5	5.7
8	5.0	4.6
9	6.5	3.6
10	8.5	4.9
11	6.0	4.1
12	5.5	4.0
13	7.0	4.2
14	6.0	4.0
15	7.0	4.2
16	6.5	4.7
17	7.0	5.1
18	6.5	4.4
19	7.0	5.1
20	8.0	3.6
21	6.5	4.0
22	6.0	5.1
23	5.5	4.1
24	7.0	4.2
25	5.5	5.1
Mean	5.96	4.43
SD	1.39	0.54
Range	3.0 – 8.5	3.6 – 5.7
Red soils		
1	3.0	4.7
2	2.0	4.5
3	2.5	4.6
4	3.0	4.6
5	4.5	4.5
6	2.5	4.1
7	2.0	4.2
8	3.0	3.6
9	6.5	4.4
10	4.5	4.5

Contd...

	CaCO₃	Fe₂O₃
11	4.5	4.5
12	3.0	4.2
13	3.5	4.1
14	5.5	7.2
15	4.5	6.6
16	5.0	4.6
17	6.0	5.2
18	6.5	6.1
19	4.5	3.6
20	5.5	5.1
21	6.5	4.9
22	5.5	5.2
23	7.5	4.6
24	5.0	4.2
25	3.5	3.4
26	3.0	4.4
27	2.0	4.6
28	3.5	3.6
29	2.5	4.0
30	1.5	4.9
31	2.0	5.2
32	2.5	4.2
33	3.5	4.1
34	3.0	4.1
35	2.5	3.6
36	2.0	4.0
37	3.0	4.0
38	3.5	4.2
39	4.5	3.6
40	5.0	5.1
41	2.5	5.9
42	4.5	5.2
43	3.5	5.0
44	5.5	4.1
45	3.5	6.4

Contd...

Sample No.	CaCO ₃	Fe ₂ O ₃
46	3.0	5.8
47	3.5	4.0
48	4.5	5.3
49	3.0	3.6
50	1.5	4.9
51	3.0	6.3
52	3.5	4.4
53	1.0	7.9
54	3.0	5.1
55	2.0	4.4
56	2.5	4.0
57	2.0	4.2
58	2.0	4.9
59	2.0	4.6
60	2.5	4.8
61	3.0	5.1
62	3.5	4.2
63	2.5	4.7
64	3.0	5.3
65	3.0	7.9
66	3.0	4.4
67	2.5	4.6
68	2.0	4.2
69	2.5	7.2
70	2.0	4.1
71	2.0	3.6
72	2.0	4.1
73	1.5	4.3
74	2.0	4.0
75	2.0	5.1
Mean	3.32	4.73
SD	1.40	0.96
Range	1.0 – 7.5	3.6 – 7.9

4.4.2 Available phosphorus (cf. Table 21)

The available phosphorus content in black soils was ranged from 20.60 to 36.60 kg P_2O_5 per ha. Mean and standard deviation for available phosphorus was 28.15 and 4.56 kg P_2O_5 per ha, respectively. The available phosphorus content in red soils was lower than in black soils and ranged from 13.90 to 36.60 kg P_2O_5 per ha with mean and standard deviation of 22.50 and 4.30 kg P_2O_5 per ha, respectively.

4.4.3 Available potassium (cf. Table 21)

Available potassium content in black soils was ranged from 151 to 327 kg K_2O per ha and was higher than that in red soils (126 to 327 kg K_2O per ha). Mean and standard deviation for available K of black and red soils were 274.8 and 42.2 kg K_2O per ha and 193.3 and 47.2 kg K_2O per ha, respectively.

4.4.4 Available sulphur (cf. Table 22)

The available sulphur content in black soils was ranged from 5.0 to 12.5 mg per kg with mean and standard deviation of 8.60 and 1.36 mg per kg, respectively. The available sulphur content in red soils was ranged from 5.0 to 18.8 mg per kg with mean and standard deviation of 8.2 and 2.52 mg per kg respectively. In general, red soils contained more available sulphur than black soils.

4.4.5 Exchangeable calcium and magnesium (cf. Table 22)

The exchangeable calcium content in black soils was ranged from 4.9 to 41.0 cmol (p+) kg^{-1} with mean and standard deviation of 27.6 and 10.48 cmol (p+) kg^{-1} , respectively. The exchangeable calcium content in red soils was ranged from 1.80 to 9.90 cmol (p+) kg^{-1} with mean and standard deviation of 3.60 and 1.46 cmol (p+) kg^{-1} respectively. In general, black soils contained high exchangeable calcium than red soils.

The exchangeable magnesium content in black soil was ranged from 1.00 to 9.70 cmol (p+) kg^{-1} with mean and standard deviation of 5.60 and 1.95 cmol (p+) kg^{-1} , respectively. The exchangeable magnesium content in red soils was ranged from 1.00 to 3.36 cmol (p+) kg^{-1} with mean and standard deviation of 1.47 and 0.47 cmol (p+) kg^{-1} respectively. In general, black soils contained higher exchangeable magnesium than red soils.

4.4.6 Available micronutrient status (cf. Table 23)

4.4.6.1 Available iron

Available iron content in black soils was low (4.01 to 9.35 mg/kg soil) compared with red soils (4.80 to 21.05 mg/kg soil). Mean and SD of iron content in black and red soils was 5.47 and 11.02 and 1.49 and 3.61 mg per kg, respectively.

4.4.6.2 Available manganese

The manganese content in black soils ranged from 5.13 to 15.50 mg per kg with mean and standard deviation of 7.40 and 2.65 mg per kg, respectively. The manganese content in red soils ranged from 6.16 to 26.81 mg per kg with mean and standard deviation of 14.31 and 4.30 mg per kg, respectively. All the samples were found to be in excess range.

4.4.6.3 Available zinc

The zinc content in black soils ranged from 0.54 to 1.98 mg per kg with mean and standard deviation of 0.81 and 0.38 mg per kg, respectively. The zinc content in red soils 0.51 to 1.99 mg per kg with mean and standard deviation of 1.20 and 0.43 mg per kg, respectively.

4.4.6.4 Available copper

The copper content in black soils was ranged from 0.43 to 1.44 mg per kg of soil with mean and standard deviation of 0.77 and 0.29 mg per kg, respectively. The copper content in red soils ranged from 0.21 to 1.93 mg per kg of soil with mean and standard deviation of copper content was 0.81 and 0.40 mg per kg, respectively.

Table 21: Available major nutrient status in surface soil samples of microwatershed

Sample No.	Available macronutrients (kg/ha)		
	N	P ₂ O ₅	K ₂ O
Black soils			
1	278	34.4	151
2	196	27.5	277
3	189	20.6	201
4	203	22.9	176
5	184	34.6	316
6	195	32.9	300
7	196	32.1	327
8	212	31.6	311
9	190	28.4	298
10	203	27.5	302
11	216	29.1	297
12	214	27.3	277
13	196	22.9	252
14	198	26.5	261
15	201	27.5	291
16	210	22.9	277
17	198	28.4	292
18	203	22.9	298
19	189	36.6	277
20	203	33.2	269
21	224	34.4	297
22	196	22.9	302
23	190	27.5	296
24	199	22.9	276
25	203	26.2	252
Mean	203.3	28.15	274.8
SD	18.3	4.56	42.2
Range	184 – 278	20.6 – 36.6	151 – 327
Red soils			
1	196	22.9	252
2	210	25.2	201
3	224	19.6	221
4	203	20.8	176
5	198	16.0	226
6	182	22.9	201
7	210	21.1	252
8	189	20.6	151

Contd

Sample No.	Available macronutrients (kg/ha)		
	N	P ₂ O ₅	K ₂ O
9	203	22.9	151
10	212	22.6	277
11	210	21.1	201
12	196	34.4	201
13	237	13.9	198
14	266	16.0	226
15	291	36.6	327
16	257	20.6	182
17	252	22.9	151
18	259	28.2	151
19	257	25.2	176
20	286	22.9	151
21	290	36.6	252
22	203	21.1	226
23	224	22.9	277
24	259	21.6	181
25	279	20.6	151
26	268	20.6	198
27	217	22.9	176
28	224	21.1	151
29	231	25.2	151
30	217	32.1	176
31	224	22.9	181
32	231	21.8	151
33	210	20.6	176
34	196	21.3	126
35	181	20.6	176
36	189	22.9	151
37	182	21.8	176
38	217	20.1	198
39	224	21.8	170
40	273	29.8	277
41	231	25.2	151
42	197	22.9	181
43	189	20.6	176
44	203	21.8	220
45	182	22.9	226

Contd...

Sample No.	Available macronutrients (kg/ha)		
	N	P ₂ O ₅	K ₂ O
46	196	14.9	126
47	224	20.1	176
48	182	18.3	151
49	217	20.6	198
50	210	22.9	302
51	203	22.0	176
52	189	20.6	226
53	196	18.3	151
54	175	21.8	126
55	182	20.1	277
56	189	21.8	220
57	196	22.0	198
58	175	22.9	226
59	196	21.8	176
60	224	34.4	126
61	231	25.2	298
62	210	22.9	176
63	196	27.5	151
64	196	22.9	210
65	217	25.2	201
66	224	21.8	198
67	279	22.9	126
68	196	22.0	151
69	189	22.9	126
70	182	16.0	252
71	210	20.6	269
72	170	16.0	261
73	189	18.3	151
74	182	20.1	173
75	170	22.9	151
Mean	214.0	22.5	193.3
SD	30.8	4.30	47.2
Range	170 – 291	13.9 – 36.6	126 – 327

Table 22: Distribution of secondary nutrients in surface soil samples of micro watershed

Sample No.	Ca	Mg	S
	cmol (p+) kg ⁻¹		mg/kg
Black soils			
1	10.6	3.2	5.0
2	15.3	3.1	10.0
3	14.9	1.0	10.0
4	4.9	3.9	12.5
5	23.6	4.5	8.9
6	25.1	5.6	9.2
7	23.7	5.9	7.5
8	25.7	6.1	8.4
9	30.1	5.9	8.8
10	31.7	4.0	7.5
11	30.6	5.0	8.3
12	32.1	4.5	8.2
13	33.1	2.9	7.5
14	32.2	6.1	8.3
15	35.6	7.3	9.2
16	38.0	7.2	6.3
17	34.3	5.9	8.7
18	32.1	6.2	8.4
19	41.0	9.6	8.8
20	36.2	5.9	8.5
21	34.5	7.2	8.6
22	37.2	9.7	10.0
23	32.1	6.1	8.5
24	31.7	6.2	9.1
25	23.7	5.9	8.8
Mean	28.6	5.6	8.6
SD	8.46	1.95	1.36
Range	4.9 – 41.0	1.0 – 9.7	5.0 – 12.5
Red soils			
1	5.0	1.1	6.3
2	2.3	2.2	5.0
3	2.2	1.8	6.0
4	2.0	1.0	5.0
5	3.9	3.4	6.2
6	3.2	1.9	5.0
7	2.8	1.2	3.8
8	1.6	1.0	6.3

Contd...

Sample No.	Ca	Mg	S
	cmol (p+) kg ⁻¹		mg/kg
9	2.2	1.0	5.0
10	3.4	2.1	7.5
11	2.2	1.0	6.3
12	2.8	1.2	6.3
13	3.0	1.0	11.1
14	3.9	3.4	6.3
15	6.2	1.1	5.0
16	4.6	1.2	8.8
17	3.0	1.0	5.0
18	2.2	1.8	7.5
19	2.7	1.5	6.8
20	1.9	1.1	6.3
21	4.6	1.2	5.0
22	4.8	1.2	8.8
23	6.6	1.0	6.3
24	4.6	1.2	9.6
25	2.7	1.5	8.8
26	2.8	1.2	9.8
27	3.3	1.6	7.5
28	3.0	1.0	6.3
29	2.7	1.5	7.5
30	3.6	1.2	10.0
31	4.2	2.0	11.3
32	2.7	1.5	8.8
33	3.3	1.6	7.5
34	4.6	1.4	13.8
35	4.2	1.6	10.0
36	5.1	2.3	10.0
37	3.3	1.6	7.5
38	3.6	1.2	8.8
39	5.4	2.3	7.5
40	9.9	1.6	8.8
41	4.2	2.0	11.3
42	5.1	2.0	10.0
43	5.2	1.6	8.8
44	4.9	2.0	6.3
45	4.7	1.6	7.5

Contd...

Sample No.	Ca	Mg	S
	cmol (p+) kg ⁻¹		mg/kg
46	5.1	1.9	10.0
47	4.6	1.4	7.5
48	2.9	1.3	11.3
49	3.3	1.6	7.5
50	4.8	1.7	8.8
51	7.3	1.0	8.8
52	5.1	1.3	7.5
53	1.9	1.5	10.0
54	2.2	1.2	10.0
55	2.9	1.3	8.8
56	2.9	1.6	6.3
57	1.8	1.0	7.5
58	1.9	1.1	8.8
59	2.2	1.2	10.3
60	3.4	1.8	18.8
61	3.3	1.1	11.3
62	3.8	1.2	7.5
63	2.3	1.3	8.8
64	3.3	1.1	11.3
65	5.9	1.9	16.3
66	3.4	1.2	7.5
67	3.8	1.2	8.8
68	2.3	1.0	6.3
69	2.1	1.2	8.8
70	3.8	1.5	7.5
71	2.3	1.30	6.3
72	2.3	1.2	7.5
73	2.4	1.3	6.3
74	2.1	1.0	5.0
75	2.2	1.6	7.5
Mean	3.6	1.47	8.2
SD	1.46	0.47	2.52
Range	1.8 – 9.9	1.0 – 3.36	5.0 – 18.8

Table 23. Available micronutrients status in surface soil samples of micro watershed

Table 23: Available micronutrients status in surface soil samples of micro watershed

Sample No.	Available micronutrients (mg kg ⁻¹)			
	Fe	Mn	Zn	Cu
Black soils				
1	9.08	15.50	0.97	1.31
2	6.49	8.89	1.55	1.35
3	9.35	10.15	1.71	1.44
4	7.53	11.68	1.98	1.27
5	4.01	6.24	0.65	0.59
6	4.83	6.54	0.69	0.61
7	4.52	6.22	0.75	0.67
8	5.01	7.56	0.86	0.72
9	4.42	6.51	0.63	0.61
10	4.08	4.91	0.73	0.77
11	5.06	6.25	0.60	0.79
12	4.37	6.78	0.72	0.68
13	6.30	4.90	0.87	0.80
14	4.13	6.01	0.57	0.60
15	5.69	8.97	0.54	0.59
16	5.52	4.08	0.59	0.72
17	5.01	6.75	0.61	0.69
18	4.95	5.99	0.61	0.65
19	5.06	6.03	0.95	0.72
20	3.87	5.69	0.47	0.40
21	4.13	6.01	0.57	0.60
22	6.19	5.13	0.80	1.11
23	4.36	6.99	0.70	0.49
24	5.69	8.97	0.54	0.59
25	7.01	12.36	0.64	0.43
Mean	5.47	7.40	0.81	0.77
SD	1.49	2.65	0.38	0.29
Range	4.01 – 9.35	5.13 – 15.50	0.54 – 1.98	0.43 – 1.44
Red soils				
1	11.06	12.04	1.13	0.63
2	13.41	14.83	1.88	0.76
3	14.13	16.51	1.20	0.47
4	12.42	24.81	0.98	0.36
5	10.74	15.47	0.51	0.41
6	11.77	10.13	0.78	0.47
7	09.96	16.11	0.79	0.63
8	13.62	13.48	0.79	0.21
9	13.41	15.13	0.90	0.26
10	09.80	16.31	1.78	0.45

Contd.

Sample No.	Available micronutrients (mg kg ⁻¹)			
	Fe	Mn	Zn	Cu
11	9.78	9.77	1.52	0.23
12	14.87	14.15	1.46	0.56
13	10.34	21.61	0.67	0.53
14	21.05	26.81	1.22	1.24
15	9.96	12.09	1.11	0.85
16	12.64	15.51	0.78	0.76
17	19.92	15.58	1.24	0.84
18	13.10	11.72	1.29	0.55
19	8.94	19.53	0.87	0.63
20	14.70	11.88	1.46	0.34
21	10.69	9.27	1.86	0.68
22	10.63	14.35	0.87	0.91
23	18.63	22.93	1.19	1.37
24	19.94	18.64	0.89	0.68
25	15.38	22.53	1.22	0.97
26	13.64	16.12	0.98	0.78
27	14.41	17.16	1.31	0.69
28	11.37	16.34	0.87	0.71
29	9.24	14.24	0.56	0.64
30	12.50	6.16	0.95	0.41
31	8.37	9.33	0.76	0.63
32	14.96	14.93	1.12	0.53
33	7.68	12.37	0.95	0.64
34	8.54	10.93	1.65	0.50
35	7.65	11.24	0.98	0.71
36	8.93	8.63	1.75	1.33
37	7.68	12.37	0.95	0.64
38	8.37	9.33	0.76	0.63
39	6.56	9.65	1.62	0.64
40	4.80	12.12	1.94	1.93
41	9.48	15.58	1.83	1.16
42	7.31	16.32	0.98	0.71
43	7.22	12.81	1.71	1.82
44	5.99	10.13	0.69	0.57
45	4.95	7.74	1.69	1.05

Sample No.	Available micronutrients (mg kg ⁻¹)			
	Fe	Mn	Zn	Cu
46	8.05	13.44	1.68	1.75
47	6.56	9.65	1.96	0.64
48	7.64	12.03	1.75	1.74
49	10.13	14.96	1.80	1.32
50	14.95	24.38	1.91	1.40
51	6.56	7.60	1.90	1.00
52	5.99	10.13	0.69	0.57
53	9.50	11.92	1.99	1.85
54	14.39	25.53	1.89	1.08
55	13.25	18.25	1.01	0.99
56	12.65	15.65	1.02	0.96
57	8.05	13.44	1.68	1.75
58	10.13	14.96	1.80	1.32
59	9.48	15.58	1.83	1.16
60	11.43	14.82	1.12	0.79
61	9.46	15.58	0.73	0.66
62	10.63	14.35	0.87	0.91
63	11.34	17.31	0.91	0.92
64	9.48	15.58	0.83	0.72
65	10.23	13.14	0.73	0.37
66	8.05	13.44	0.68	0.75
67	20.65	13.52	1.19	0.59
68	11.34	17.31	0.91	0.92
69	14.39	16.79	0.97	0.67
70	9.80	10.37	1.29	0.43
71	8.85	7.69	0.86	0.57
72	5.65	9.24	0.56	0.42
73	12.99	14.35	0.93	0.54
74	10.23	16.23	0.85	0.79
75	14.24	11.53	1.12	0.43
Mean	11.02	14.31	1.20	0.81
SD	3.61	4.30	0.43	0.40
Range	4.8 – 21.05	6.16 – 26.81	0.51 – 1.99	0.21 – 1.93

Table 24: Average productivity of crops during 2005 and 2006 in Bhanapur Microwatershed

Crops	Average yield (kg/ha)	
	2005	2006
Black soils		
Maize	3320	2130
Groundnut	700	400
Red gram	250	75
Red soils		
Maize	2860	1600
Groundnut	650	300
Bajra	800	200
Red gram	210	50

4.5 Productivity of major crops in watershed (cf. Table 24)

The yield data of different crops/cropping systems were collected during both (2005 and 2006) years is presented in Table 24.

In general, crop yield was low during both the years. However during 2005, among the crop/cropping systems, maize yield was higher followed by groundnut and the lowest yield was obtained in red gram under black soils. In red soils also maize yield was higher followed by bajra (800 kg/ha), groundnut and red gram.

During 2006, lower yield was recorded in all cropping systems. It was due to less rainfall received besides erratic rainfall pattern resulting crop suffering from water stress during the crop growth period.

5. DISCUSSION

Water being the most important factor for the growth of crops, attempts have been made from very early days to find out easily determined equilibrium points that would define the property of the soil with respect to its power to hold water. Adequate supply of soil water and nutrients from the integral part of operations for successful dry farming. Experiments so far conducted to assess the soil moisture variation and productivity constraints of soils at Bhanapur micro watershed, Koppal district, during the year 2005 to 2006. The results of investigation are discussed briefly in this chapter.

5.1 Soil moisture estimation by radar remote sensing

5.1.1 Volumetric soil moisture (θ_v) vs. backscatter coefficient (σ^0 , dB) (cf. Table 2)

Correlation analysis was performed to study the relationship between measured volumetric soil moisture (θ_v) content and corresponding backscatter coefficient (σ^0 , dB) values extracted from SAR data of 24th June 05, 13th July 05, 29th July 05, 17th August 05, 2nd September 05 and 21st September 05. A good correlation was observed between volumetric soil moisture content and backscatter coefficient σ^0 values, which started declining once the crop canopy or vegetation increased.

The higher correlation was observed in subsurface (5-10 cm) soil moisture over that of surface (0-5 cm) soil moisture, in both red and black soils as they had higher soil moisture in sub surface than in surface at all the sampling dates. In red soils high backscatter coefficient, were recorded for HH polarization of 13th and 29th July 05 data. Correlation between volumetric soil moisture content and backscatter coefficient (σ^0) at surface ($r = 0.498^{**}$ and $r = 0.439^{**}$ respectively) and subsurface ($r = 0.516^{**}$ and $r = 0.493^{**}$ respectively) soils was higher compared to other dates. At both dates the soil moisture content (cf. Table 6 and 7) was high. However correlation for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10 cm) and it was $r = 0.534^{**}$ and $r = 0.550^{**}$ respectively.

Positive but low correlation value was observed between θ_v and σ^0 for HH polarization of 24th June 05 data in both surface ($r = 0.435^{**}$) and subsurface ($r = 0.448^{**}$) compared to 13th July 05 and 29th July 05 data. The low correlation values were due to low soil moisture content during June in major part of the watershed as it was a beginning of monsoon. Poor correlation between θ_v and σ^0 at low soil moisture was also observed by Andrew and Edwin (2006). Correlation between θ_v and σ^0 of HH polarization was improved for mean soil moisture (0-10cm) of red soils ($r = 0.518^{**}$, 0.534^{**} and 0.550^{**} for soil moisture 24th June, 13th July and 29th July 2005 respectively).

The data on 17 August 05, showed positive correlation between θ_v and σ^0 for both HH and HV polarization at the two depths (cf. Table 2). Volumetric soil moisture content at 5-10 cm recorded high correlation with σ^0 of HH polarization than volumetric soil moisture content at 0-5 cm. That might be due to significant effect of surface roughness created due to intercultivation operation two days before sampling. Similar results were observed by Wickel *et al.* (2001). However correlation for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10cm) and it was $r = 0.472^{**}$.

For 2nd September 05 and 21st September 05 data, positive but poor correlation was observed between θ_v and σ^0 (HH polarization) in both surface ($r = 0.39^*$ and $r = 0.347^*$ respectively) and subsurface ($r = 0.451^{**}$ and $r = 0.348^*$ respectively) because, the backscatter coefficient decreases with increasing vegetation. According to Venkataratnam *et al.* (1993) and Bradly and Ulaby (1981), the vegetation reduces the sensitivity of microwave response to soil moisture variation. However correlation for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10cm) and it was $r = 0.449^{**}$ and $r = 0.409^{**}$ respectively.

Poor correlation values were obtained in black soils between volumetric soil moisture content and backscatter coefficient (HH polarization) for all data sets (cf. Table 2). This could be mainly because smooth surface roughness of black soils affecting the backscattered signal. Similar results were observed by Srivastava *et al.* (1997). However correlation for θ_v

and σ^0 (HH polarization) was slightly improved (cf. Table 2) for mean θ_v (0-10 cm) and remained non significant.

The higher correlation between volumetric soil moisture content of subsurface soil (5-10 cm) and backscatter coefficient for HH polarization than that of surface soil (0-5 cm) is an evidence to the fact that the penetration depth of ENVISAT ASAR C-band microwave is of order of 0-10 cm at the soil moisture conditions. Similar results have also been reported by Venkataratnam *et al.* (1993).

5.1.2 Regression analysis with θ_v and σ^0 (cf. Table 4)

The higher regression value was observed in subsurface (5-10 cm) soil moisture over that of surface (0-5 cm) soil moisture, in both red and black soils. In red soils high backscatter coefficient, was recorded for HH polarization of 13th and 29th July 05 data. Regression between volumetric soil moisture (θ_v) content and backscatter coefficient (σ^0) at surface ($R^2 = 0.248$ and $R^2 = 0.193$ respectively) and subsurface ($R^2 = 0.267$ and $R^2 = 0.244$ respectively) soils was higher compared to other dates. At both dates the soil moisture content (cf. Table 6 and 7) was high. However regression for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10 cm) and it was $R^2 = 0.289$ and $R^2 = 0.303$ respectively).

Low regression values were observed between θ_v and σ^0 for HH polarization of 24th June 05 and 17th August 05 data in both surface ($R^2 = 0.189$ and $R^2 = 0.189$ respectively) and subsurface ($R^2 = 0.201$ and $R^2 = 0.208$ respectively). The low regression values were due to low soil moisture content during June in major part of the watershed as it is a beginning of monsoon. However regression for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10 cm) and it was $R^2 = 0.269$ and $R^2 = 0.223$ respectively.

For 2nd September 05 and 21st September 05 data, very low regression values was observed between θ_v and σ^0 (HH polarization) in both surface ($R^2 = 0.152$ and $R^2 = 0.114$ respectively) and subsurface ($R^2 = 0.203$ and $R^2 = 0.121$ respectively) soils. However regression values for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10 cm) and it was $R^2 = 0.202$ and $R^2 = 0.167$ respectively.

The poor regression values were obtained in black soils between volumetric soil moisture content and backscatter coefficient (HH polarization) for all data sets (cf. Table 4). This may be due to smooth surface roughness of black soils, which affect the backscattered signal. However correlation for θ_v and σ^0 (HH polarization) was slightly improved for mean θ_v (0-10 cm).

5.2 Soil moisture status under different crop coverage through the dates of sampling

Gravimetric and volumetric soil moisture was estimated under different land use systems of arable (cultivated) and non- arable (bare) lands for different dates with two depths, surface (0-5 cm) and subsurface (5-10 cm) during 2005-2006.

5.2.1 Soil moisture monitoring during 2005

5.2.1.1 Soil moisture status on 24th June 2005

The soil moisture content of < 10 per cent was recorded in major part of the watershed (393.50 ha), but it was high (> 40 per cent) in 56.24 ha (Fig.5). The red soil showed low moisture value than black soils, due to shallow solum, coarse textured nature especially with high gravel content and low clay content with low soil moisture retention. The importance of clay in the retention of moisture was reported by Lund (1969). The moisture content of soils differed significantly among the land use system. The soil moisture content of black soil was high in groundnut based cropping system and was low in maize based cropping system as maize depletes more moisture than groundnut. In red soils, the highest moisture content was recorded in groundnut followed by bajra + red gram and lower in groundnut + red gram system.

The mean volumetric soil moisture content of black and red soils at the surface (0-5 cm) was very low (48.12 and 41.73 per cent respectively), when compared to their field

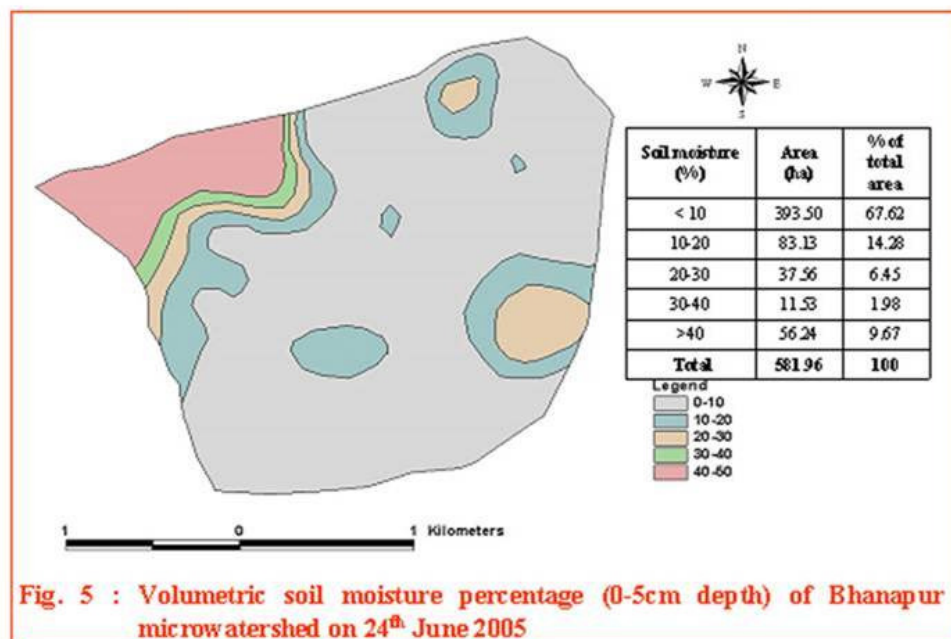


Fig 5. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 24th June 2005

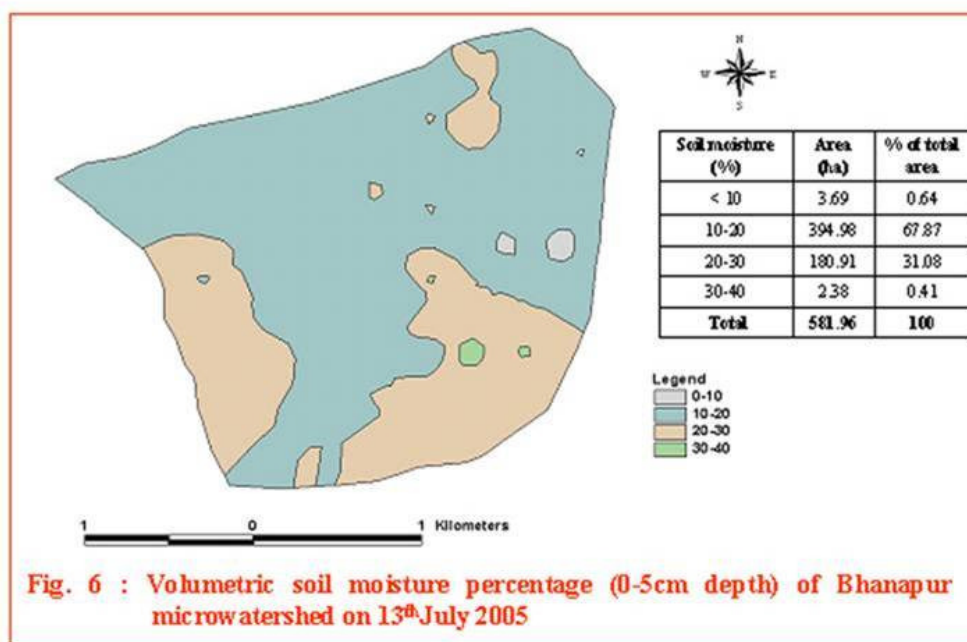


Fig 6. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 13th July 2005

capacity. In subsurface soils (5-10 cm) mean volumetric soil moisture was higher 90.24 and 84.15 per cent of field capacity.

5.2.1.2 Soil moisture status on 13th July 2005

As depicted in Fig. 6, 394.98 ha area had 10-20 per cent soil moisture, followed by 180.91 ha with 20-30 per cent and only 2.38 ha were under high soil moisture status (30-40 per cent). In both red and black soils, groundnut + red gram followed by groundnut land use systems had high soil moisture status than other cropping system and bare soils. As groundnut is spreading in nature, it covers the soil surface and acts as mulch. This has resulted in prevention of direct exposure of sunlight and in turn reduced moisture loss through evaporation.

The mean volumetric soil moisture content of black soils at the surface (0-5 cm) was very low (77.95 per cent of FC), when compared to their field capacity. In subsurface soils (5-10 cm) mean volumetric soil moisture was 106.30 per cent of field capacity.

The mean volumetric soil moisture content of red soils at the surface (0-5 cm) and subsurface soils (5-10 cm) was 90.36 and 116.57 per cent respectively when compared to their field capacity.

5.2.1.3 Soil moisture status on 29th July 2005

Major portion of the study area (217.51 ha) was with less than 10 per cent of soil moisture and only 96.69 ha (Fig. 7) was under >40 per cent soil moisture content. Slightly increase in soil moisture on 29th July 05 compared to previous two sampling dates was due to receipt of rain (18.8 mm) for four days prior to the sampling. The black soils recorded higher soil moisture than red soils. In general, soil moisture content increased with the increase in clay content and soil depth. Among the different cropping systems studied groundnut + red gram was recorded the highest soil moisture in both red and black soils. Red soils with maize recorded the low soil moisture content, as maize removes more moisture from the soil and also maize grown soils were low in clay content.

The mean volumetric soil moisture content of black and red soils at the surface (0-5 cm) and subsurface soils (5-10 cm) was 101.52, 121.70 per cent and 65.86, 85.33 per cent respectively when compared to their field capacity.

5.2.1.4 Soil moisture status on 17th August 2005

Soil moisture status on 17th August was 10-20 per cent (200.20 ha) in major portion of micro watershed, followed by <10 per cent (185.13 ha), 20-30 per cent (100.39 ha), >40 per cent (67.30 ha) and 30-40 per cent (28.94 ha). The decreasing soil moisture content in both red and black soils on 17th August 2005 compared to previous sampling dates was due to non receipt of rain and also extraction of soil moisture by the crops. Bare red soils recorded high soil moisture than the red soils with groundnut because of loss of soil moisture through evapotranspiration by the crop.

The mean volumetric soil moisture content of black soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was 88.62 per cent and 98.51 per cent of field capacity respectively.

The mean volumetric soil moisture content of red soils at the surface (0-5 cm) was (62.18 per cent of FC) low compared to soil moisture content in subsurface soils (5-10 cm) (78.70 per cent of FC).

5.2.1.5 Soil moisture status on 2nd September 2005

On 2nd September 2005 soil moisture status was low (<10 per cent) in major part of the watershed (218.56 ha), where as, it was high (>40 per cent) only in 96.90 ha area. In both red and black soils high moisture content was recorded in different land use system compared to previous date of sampling. Before soil sampling on 2nd September 2005 there was rain (30 mm) for two days and this resulted in the increase of soil moisture content.

The red soils showed low soil moisture values than black soils, which was due to low clay content resulting low soil moisture retention. The mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was 113.00 per

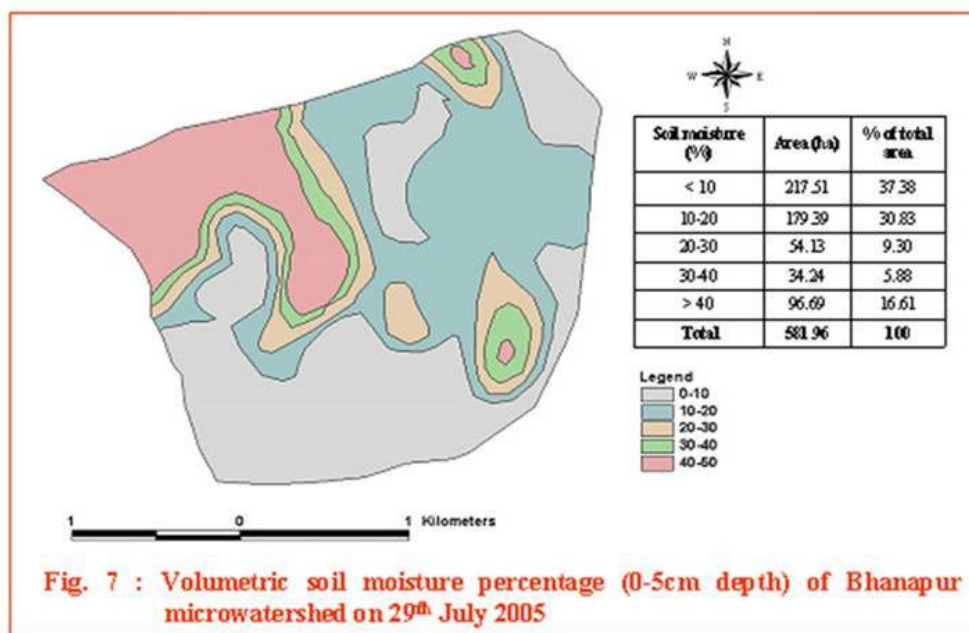


Fig 7. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 29th July 2005

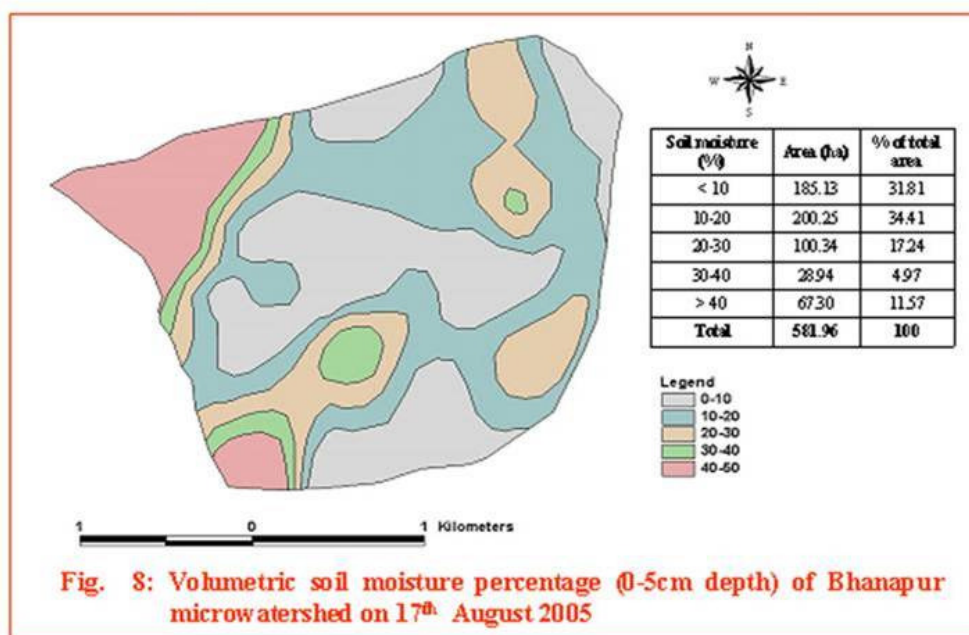


Fig 8. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 17th August 2005

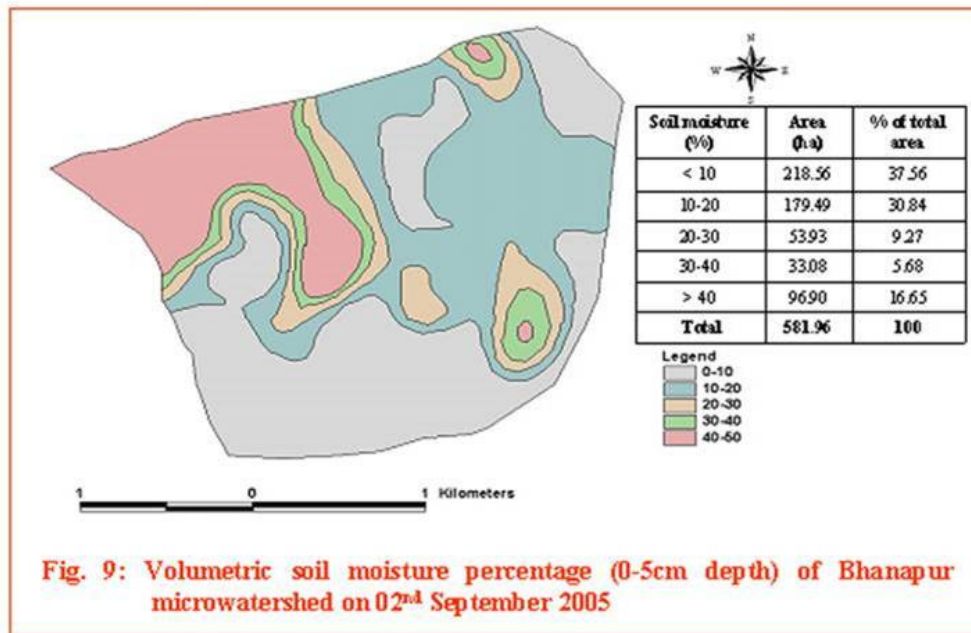


Fig 9. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 02nd September 2005

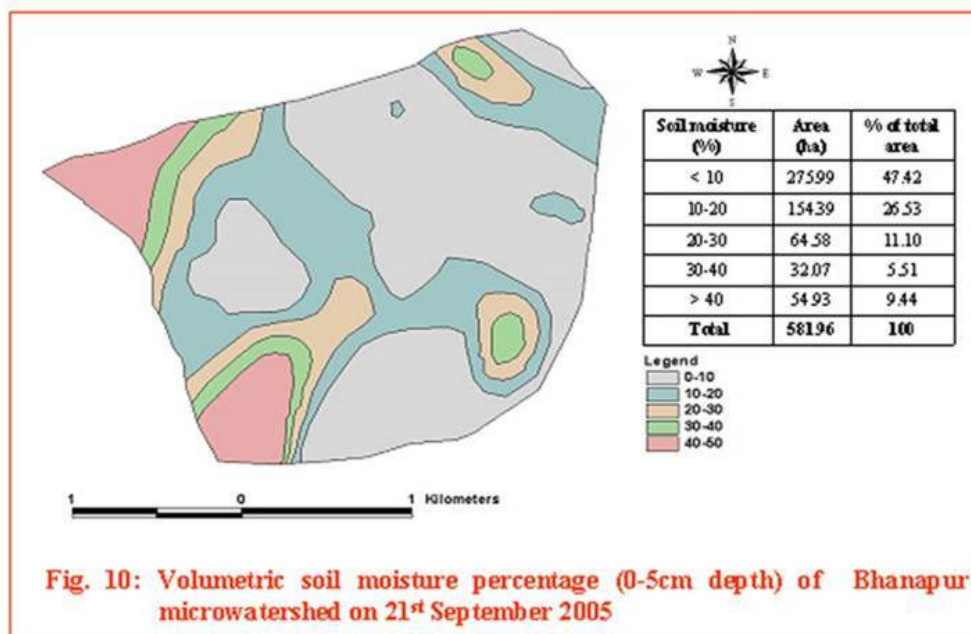


Fig 10. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 21st September 2005

cent, 128.54 per cent and 67.38 per cent, 84.92 per cent respectively when compared to their field capacity.

5.2.1.6 Soil moisture status on 21st September 2005

The area with soil moisture content of <10 per cent was 275.99 ha and only 54.93 ha (Fig. 10) recorded > 40 per cent soil moisture. The moisture content reduced drastically under all crop coverage especially in red soils, due to no rains from 2nd to 21st September 2005. Where as, black soil recorded higher soil moisture content than red soils. High clay content and more depth of black soils helped to retain more moisture.

The mean volumetric soil moisture content of black soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was high (102.22 per cent and 135.66 per cent respectively), when compared to their respective field capacity.

The mean volumetric soil moisture content of red soils at the surface (0-5 cm) was 43.10 per cent. It was low when compared to its field capacity. Where as, soil moisture content in subsurface soils (5-10 cm) was high (77.26 percent), when compared to its field capacity.

5.2.2 Soil moisture status during 2006

The low soil moisture content was recorded throughout the sampling dates of 2006 compared to 2005, which might be due to low rainfall resulting in drought conditions during the crop growth period (Appendix I).

5.2.2.1 Soil moisture status on 28th June 2006

As depicted in Fig. 11, an area of 249.73 ha was with < 5 per cent of soil moisture, followed by 155.86 ha with 5-10 per cent and only 38.06 ha was with relatively high soil moisture (> 25 per cent). In both black and red soils, groundnut + red gram crop fields were found to be high in soil moisture status than other cropping systems. Low moisture content was recorded in red soils than black soils, because of gravelly and coarse textured nature of soils with low water holding capacity.

The mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface (5-10 cm) was 30.72 per cent, 53.26 per cent and 23.64 per cent, 50.42 per cent of their field capacity, respectively.

5.2.2.2 Soil moisture status on 14th July 2006

Major portion of study area (432.05 ha) was under < 5 per cent soil moisture range and only 0.18 ha (Fig. 12) was with 15-20 per cent soil moisture. The decreasing soil moisture content in both red and black soils, on 14th July 2006 compared to previous dates, was due to no rain from 28th June to 14th July 2006. Red soils in maize fields recorded high soil moisture than other cropping systems, due to the supply of water from external source. Compared to red soils black soils retained more moisture because of high clay content and thick solum.

The mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface (5-10 cm) was low when compared to their field capacity.

5.2.2.3 Soil moisture status on 02nd August 2006

On 2nd August 2006, soil moisture status was low (< 5 per cent) in major part of the watershed (297.55 ha) where as, it was high (> 25 per cent) only in 71.72 ha area. In both red and black soils the moisture content of different land use systems recorded was high when compared to previous sampling dates. Before soil sampling on 2nd August 2006 there was rain (15 mm) for four days and this resulted in slight increase of soil moisture content. In black soil, groundnut + red gram recorded high soil moisture content compared to other cropping systems. The low moisture content was recorded in bare soil due to the direct sunlight falling on soil surface resulting loss of soil moisture through evaporation. In red soil, bajra + red gram recorded high soil moisture followed by groundnut + red gram, groundnut, maize and bare soils, it may be due to bajra and red gram having different root habits takes moisture from different depths.

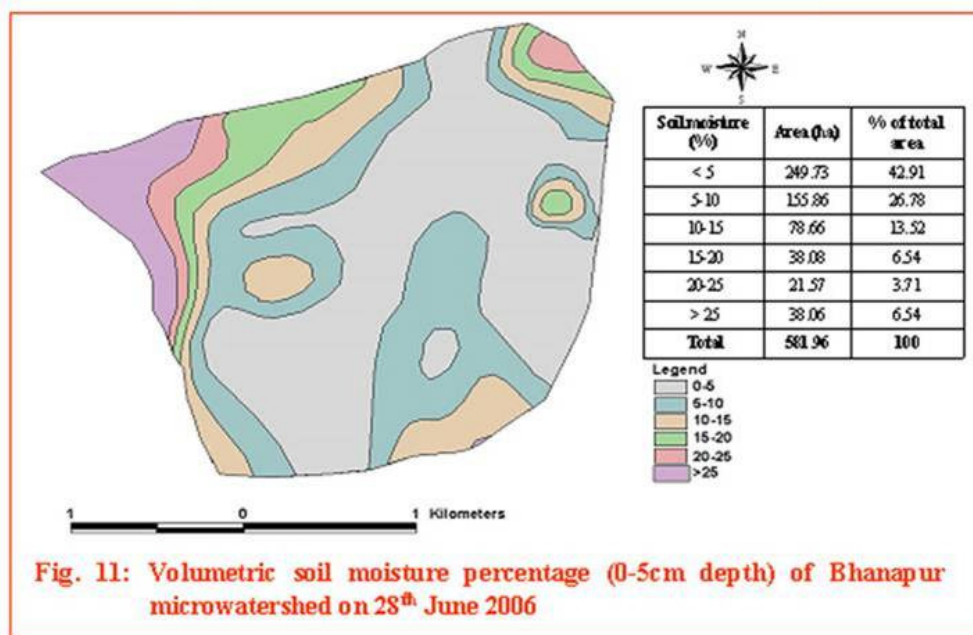


Fig 11. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur micro watershed on 28th June 2006

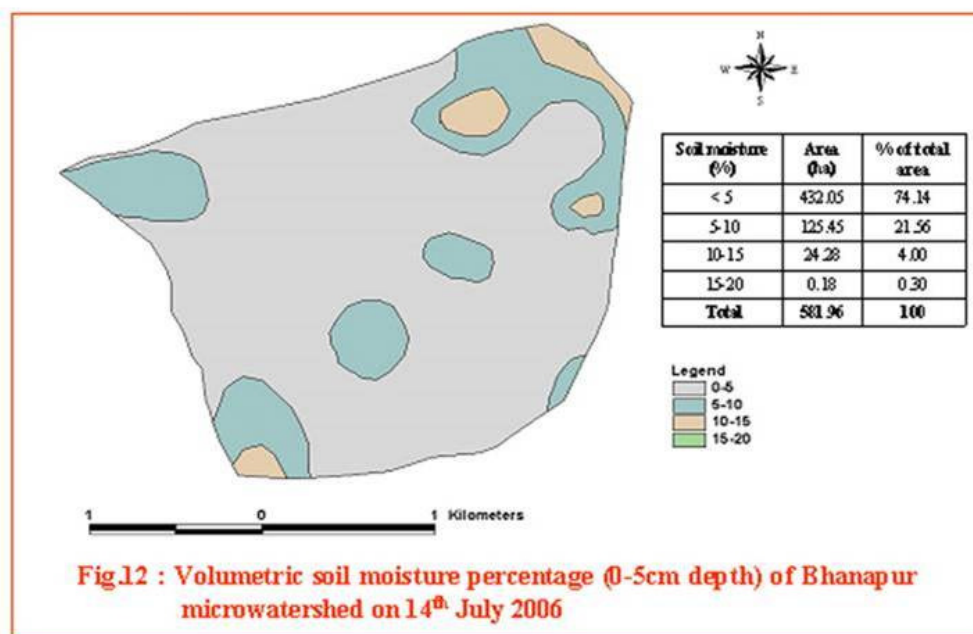


Fig 12. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur microwatershed on 14th July 2006

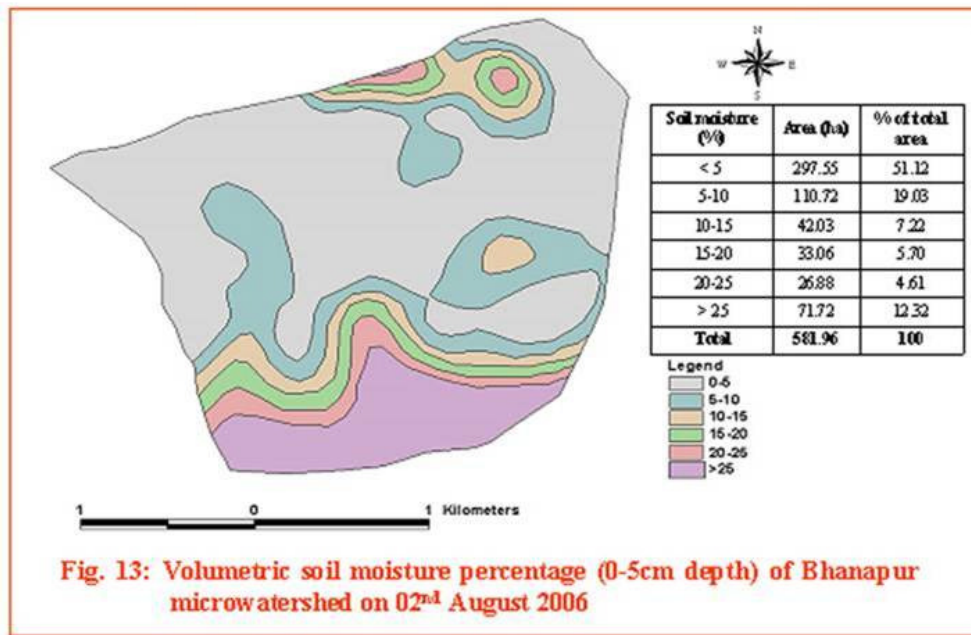


Fig 13. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur micro watershed on 02nd August 2006

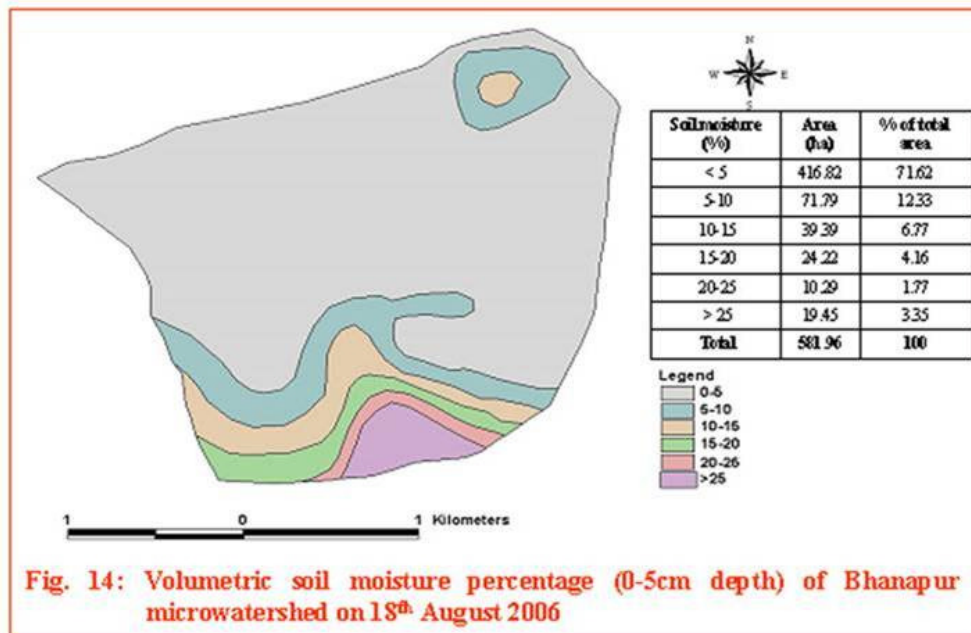


Fig 14. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur micro watershed on 18th August 2006

Compared to field capacity the low mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was observed (39.01 per cent, 77.35 per cent and 25.92 per cent 57.65 per cent of FC, respectively).

5.2.2.4 Soil moisture status on 18th August 2006

The soil moisture content of < 5 per cent was recorded in major part of the watershed (416.82 ha), but however it was > 25 per cent in 19.45 ha area (Fig. 14). The black soils showed high moisture values than red soils, due to deep solum, fine texture and high clay content with high soil moisture retention capacity. The soil moisture content of black soils was high in groundnut based cropping systems and was low in maize based cropping system. It was due to depletion of more moisture by maize than groundnut. In red soils, low moisture content was observed in all cropping systems except maize, maize had received water from external source.

The mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was 22.26 per cent, 45.67 per cent and 8.94 per cent, 25.66 per cent respectively and it was very low when compared to field capacity.

5.2.2.5 Soil moisture status on 06th September 2006

The soil moisture content of < 5per cent was recorded in major part of the watershed (458.17 ha), and 10-15per cent in 18.08 ha (Fig. 15). In both red and black soils, low soil moisture content was recorded in different land use systems, which might due to increasing crop canopy resulting loss of moisture through evapotranspiration by the crop. Compared to red soil black soils contained high soil moisture content. In general moisture content increased. Ali *et al.* (1966) also observed an increase in available water content with increase in clay and silt content in medium and fine textured soils.

Compared to field capacity, mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was low (16.78 per cent, 6.69 per cent and 24.43 per cent, 12.99 per cent respectively).

5.2.2.6 Soil moisture status on 22nd September 2006

As depicted in Fig. 17, a larger area (411.44 ha) had < 5 per cent soil moisture and only 1.52 ha was with soil moisture status of > 25 per cent. Slight increase in soil moisture content on 22nd September 2006, compared to previous sampling date was due to receipt of rain (14.6 mm) five days before soil sampling. The red soil recorded low soil moisture value, which is attributed to shallow solum, gravelly coarse texture and low clay content.

The mean volumetric soil moisture content of black and red soils at both surface (0-5 cm) and subsurface soils (5-10 cm) was 21.67 per cent, 49.89 per cent and 8.93 per cent, 22.73 per cent of FC, respectively and it was very low when compared to their field capacity.

The high soil moisture content was recorded in 2005 for the same period. Higher rainfall received during 2005 (400.63 mm) compared to total rainfall in 2006 (264.26 mm) it was responsible for high moisture content in soil in 2005. Scanty rainfall during 2006 and higher temperature lead to greater evaporation losses and lower relative humidity in the atmosphere, which in turn resulted in low soil moisture storage in the soil surface during 2006 compared to 2005.

Maximum soil moisture content was recorded in black soils than in red soils during both the years because of higher clay content. The higher soil moisture retention in fine textured soils (black soils) could be attributed to the greater surface area and pore space especially dominance of micro pores of the soils. Milford *et al.* (1961) reported that moisture retention is mainly a function of amount and nature of the clay. According to Ali *et al.* (1966) black soils having dominantly montmorillonitic type of clay mineral have higher moisture retentivity as compared to red soils dominated by kaolinitic clay. Since red soils of the watershed were gravelly, coarse textured with shallow solum, low clay content with high macro pores space accounted for low moisture retention. Premanathan (1963) studied the black and red soils of Madras state and observed a very close relation between clay content and moisture constants.

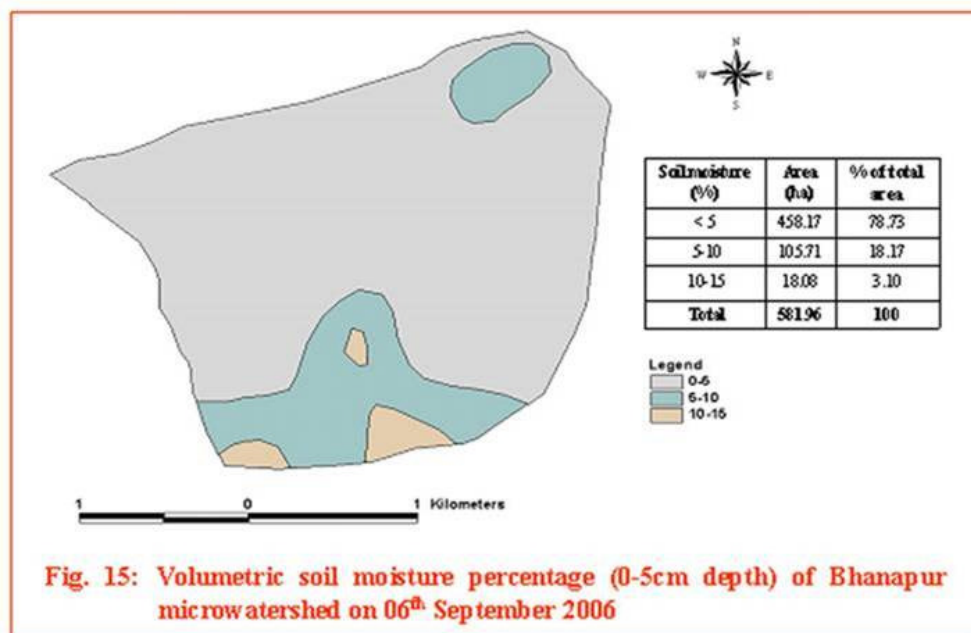


Fig 15. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur micro watershed on 06th September 2006

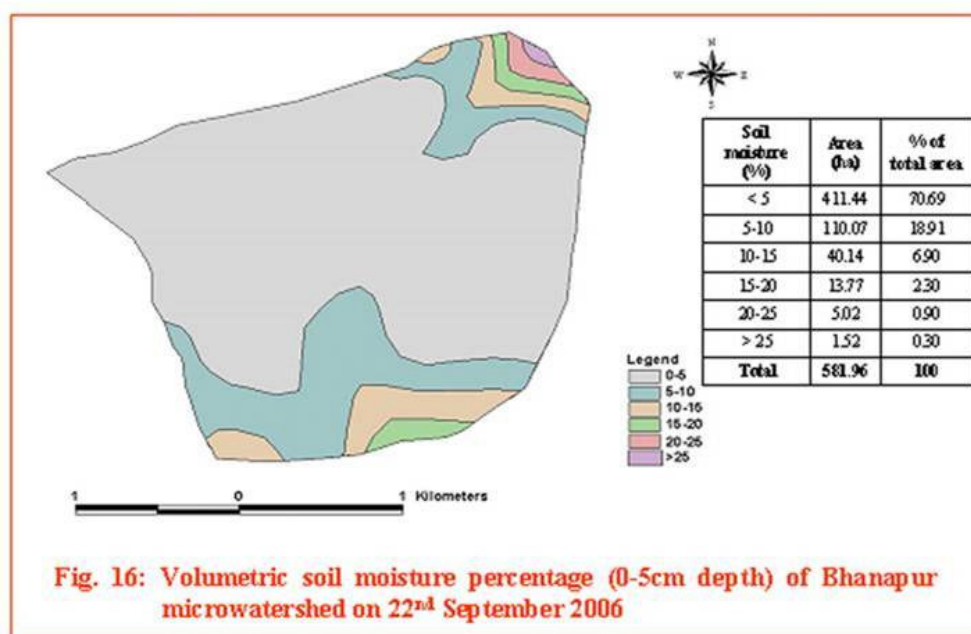


Fig 16. Volumetric soil moisture percentage (0-5 cm depth) of Bhanapur micro watershed on 22nd September 2006

Among cropping systems, groundnut + red gram followed by groundnut recorded higher soil moisture value in both red and black soils during both the years. Under maize and bare soils, low soil moisture was recorded during 2005. Some samples showed high soil moisture content during 2006, which might be due to supply of water through external source. A high soil moisture content was recorded in groundnut + red gram cropping system. This is attributed to different root habits of two crops, which absorb moisture from different depths. Also groundnut which was spreading type covered the soil surface and acted as mulch and minimizing the loss of moisture through evaporation.

Rainfall distribution pattern of 2005 and 2006 revealed that total rainfall of the study area was very low and distribution was erratic and it was not sufficient to raise a single crop successfully. Monitoring of soil moisture during 2005 and 2006 indicated that although, black soils have higher soil moisture retention capacity; they did not reach their maximum water holding capacity. However, black soils were near and excess of field capacity during active crop growing period. Red soils because of shallow solum thickness and gravelly coarse texture contained much lower soil moisture than their field capacity except during July 2005. Based on the rainfall distribution pattern and the results of two years soil moisture monitoring, it can be concluded that soil moisture is one of the major limitations for crop production in the Bhanapur microwatershed of Koppal district.

5.3 Physical properties

5.3.1 Particle size distribution

A perusal of the data on particle size distribution in soils revealed that soil texture of black soils varied from clay loam to clay in texture. Red soils varied in soil texture from sandy to sandy loam. The results on distribution of sand fraction in black soils are in accordance with the work of Dasog and Hadimani (1980) who reported that in vertisols of Karnataka the sand fraction as a whole is low, often less than 20 per cent in surface (plough layer) horizons. More of total sand in red soil could be attributed to the nature of parent rock, which is granite and granite gneissic complex containing more of quartz (Krishnamurthy, 1993).

The mean silt fraction in surface of black and red soils varied from 16.45 to 22.08 and 4.01 to 18.06 per cent respectively. The silt fraction in black soils recorded highest values than in red soils.

The mean clay content in surface of black and red soils varied from 31.73 to 40.23 per cent and 4.39 to 14.32 per cent respectively. High amount of clay was observed in black soils than in red soils. The high clay content of the soils could be because of the parent materials which have been subjected to quick weathering and the synthesis of clay sized fractions.

5.3.2 Bulk density and porosity

Despite of high clay content, generally high bulk density of black soil was due to the shrinkage of these soils upon drying (Table 17). In red soil, bulk density slightly decreased in the sub surface soil because of higher clay content. The results are in agreement with those of Ravikumar (2004) and Vinay (2006). Black soils recorded higher porosity (Fig. 20) than red soils due to high clay content.

5.3.3 Maximum water holding capacity

The maximum water holding capacity followed the trend of clay content both in black and red soils. In general, black soils had higher maximum water holding capacity than red soils (Table 18). Within red soils, some soils with higher clay content had higher maximum water holding capacity indicating positive correlation between clay and maximum water holding capacity. Challa and Gaikwad (1987) also had similar observation.

5.4 Soil chemical properties

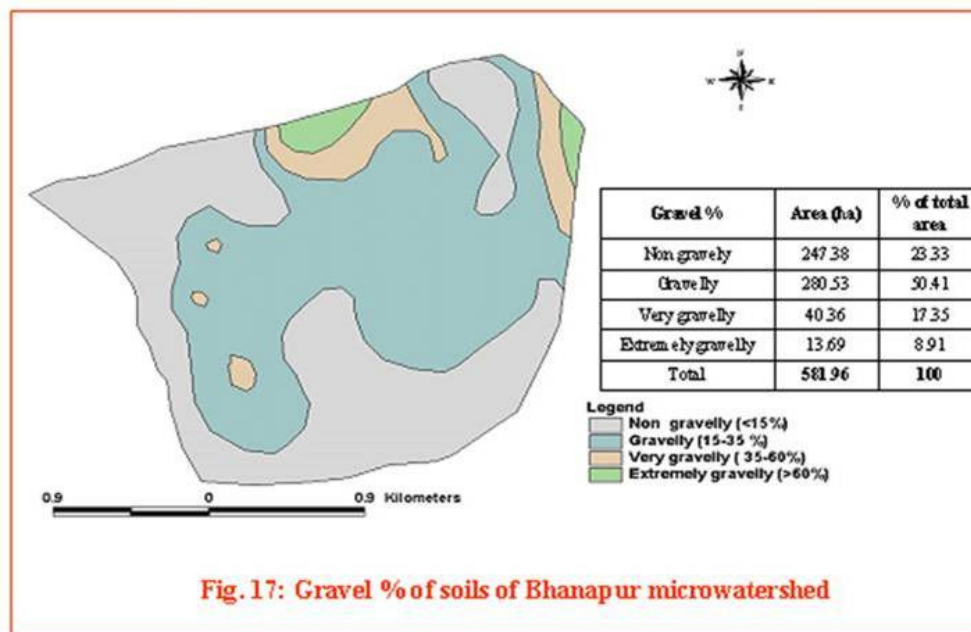


Fig 17. Gravel % of soils of Bhanapur microwatershed

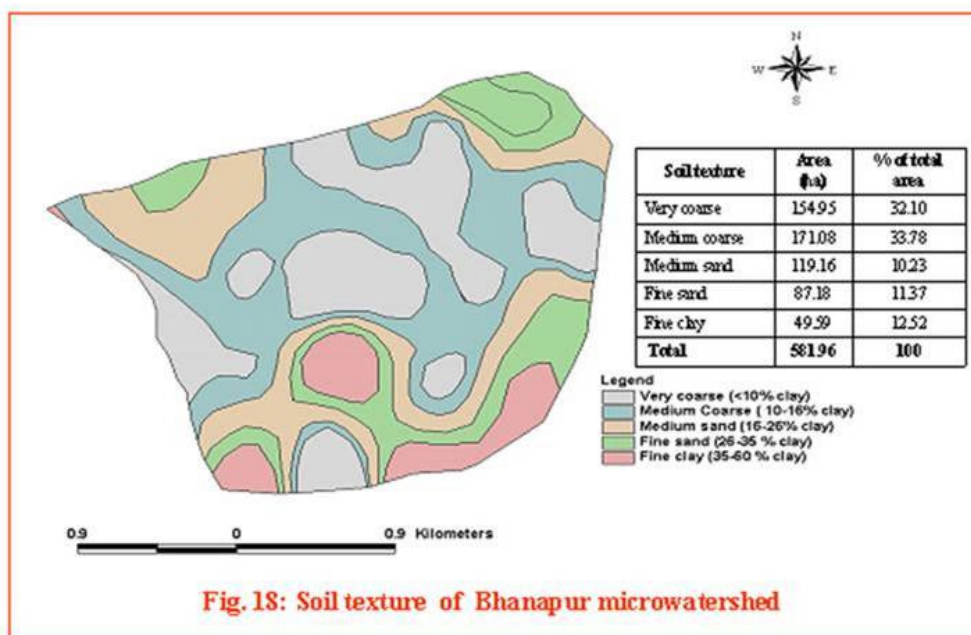


Fig 18. Soil texture of Bhanapur microwatershed

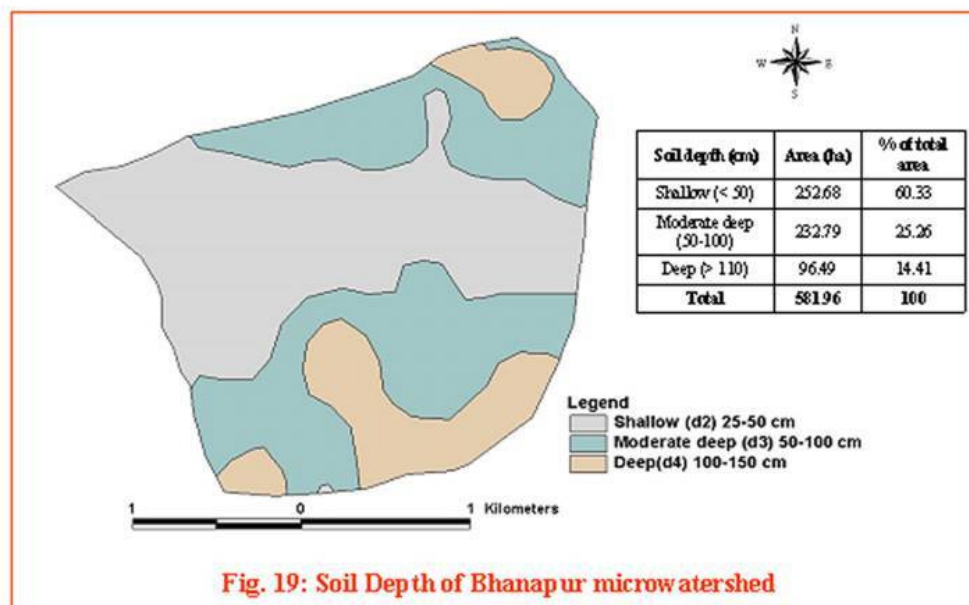


Fig 19. Soil Depth of Bhanapur microwatershed

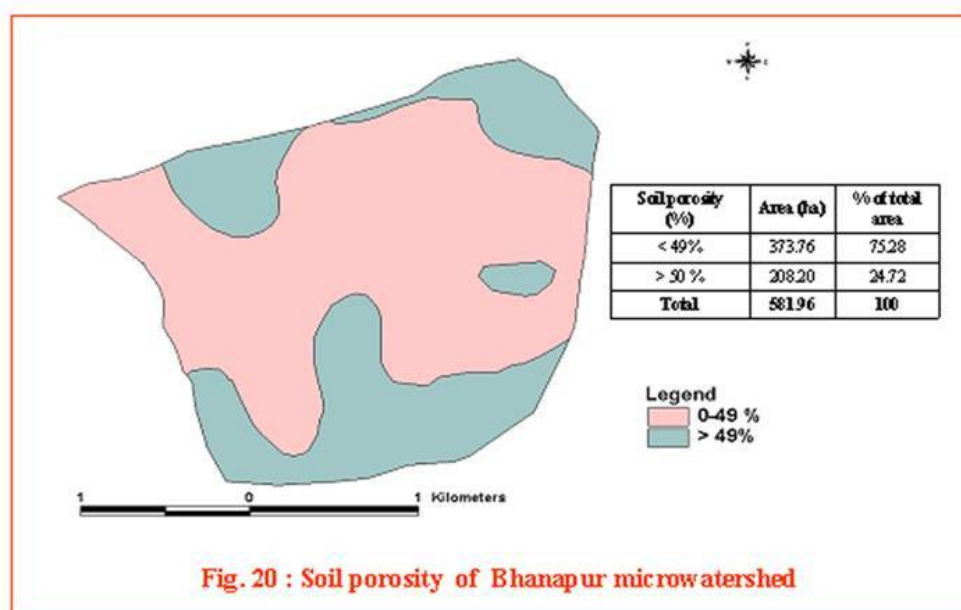


Fig 20. Soil porosity of Bhanapur micro watershed

5.4.1 Soil reaction

The soil reaction was neutral (6.5 – 7.5) in 535.36 ha and slightly acidic in 6.28 ha (Table 19). The acidic nature of red soils was due to acidic parent material, higher iron oxide content (Table 20) in soils of the study area. The soil reaction was alkaline (7.5 – 8.5) in 40.32 ha (Fig. 22) of black soils due to high calcium carbonate and exchangeable bases. These results are in accordance with the studies of Bhadrapur and Sheshagiri Rao (1979), Ravikumar (2004) and Vinay (2006).

5.4.2 Electrical conductivity

Major portion (571.01 ha) of the watershed was free of salinity problem because of free drainage condition (Fig. 23). Where as, an area of 10.95 ha have EC values of >1 dS per m. Sahu *et al*, (1990) also observed very low soluble salts in red soils. The black soils were relatively free from salts.

5.4.3 Organic carbon

The organic carbon content in the study area was low (454.13 ha) and medium (127.83 ha) category (Fig. 24). The low organic carbon content of the soils may be attributed to the prevalence of high temperature causing the organic matter degradation and removal at faster rate. This coupled with low vegetation cover, leaving less chances of accumulation of organic matter in the soil. These observations are in accordance with Govindarajan and Datta Biswas (1968). The soils of semi-arid region have low organic carbon than sub-humid soils (Jagadish Prasad and Gajbhiye, 1998). The organic matter build up in soils is related to natural vegetation, cropping history and temperature (Dudal, 1965).

5.4.4 Calcium carbonate content

The free CaCO_3 content in black and red soils ranged from 3.0 to 8.5 per cent and 1.0 to 7.5 per cent respectively. Krishnamurthy and Govindarajan (1977) reported the abundance of CaCO_3 in black soils than in red soils. Vertisols of India have CaCO_3 content generally ranging from 7.0 to 10.0 per cent (Dudal, 1965).

5.4.5 Free iron oxide

The free Fe_2O_3 content forms a part of total iron content in soil occurring as oxides and hydroxides. It is found in the form of coating on clay particle surfaces or in inter layer position. Dithionate extractable iron content of soil increases with depth. The increase is partly due to intense weathering as also observed by Biswas and Gawande (1962) in lower horizons of catenary soils of Chattishgarh basin (MP).

5.5 Nutrient status

5.5.1 Available nitrogen

The available nitrogen content was low (Fig. 25) in major portion of the study area (580.42 ha), which might be due to the arid environmental and low organic matter content in these soils. Only in about 1.54 ha, available nitrogen was medium. The variation in N content may be related to soil management; application of FYM and fertilizer to previous crop *etc*. The total nitrogen content in the soils is dependent on temperature, rainfall and altitude (Bijujoseph, 1994). Another possible reason may also due to low organic matter content in these areas due to low rainfall and low vegetation cover facilitate faster degradation and removal of organic matter leading to nitrogen deficiency. The medium nitrogen status was noticed in some area might be due to application of N-fertilizer coupled with high vegetative cover (Govindarajan and Datta Biswas, 1968).

5.5.2 Available phosphorus

The available phosphorus content was medium in major part of the watershed (555.25 ha), but it was low in 26.71 ha (Fig. 26). The red sandy soils shown low values of

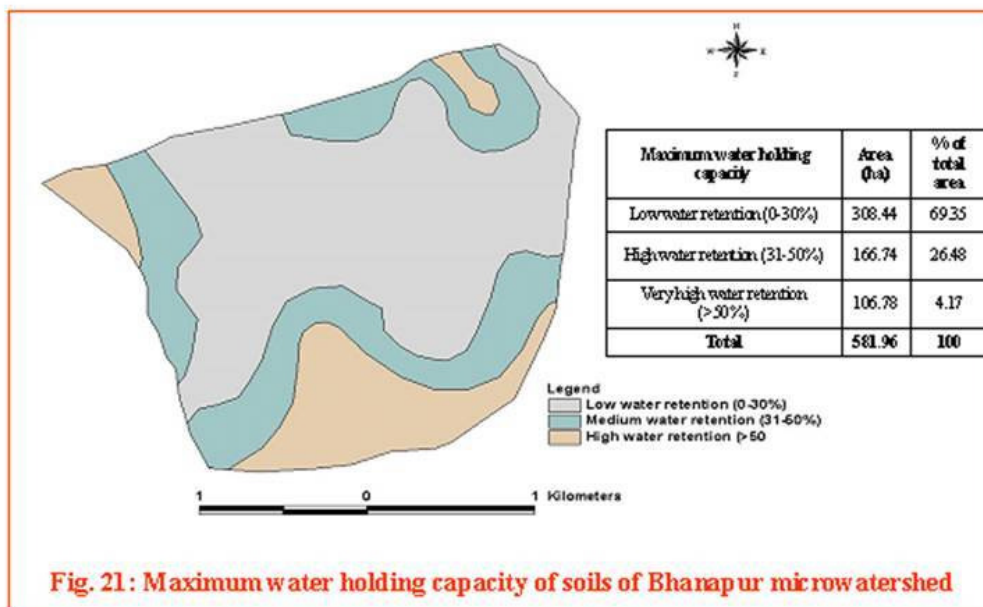


Fig 21. Maximum water holding capacity of soils of Bhanapur microwatershed

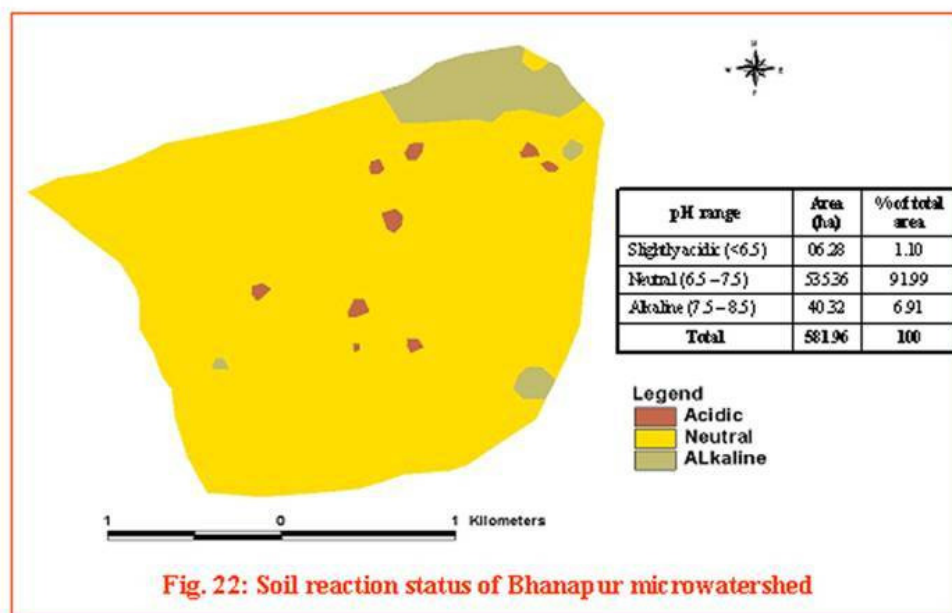


Fig 22. Soil reaction status of Bhanapur microwatershed

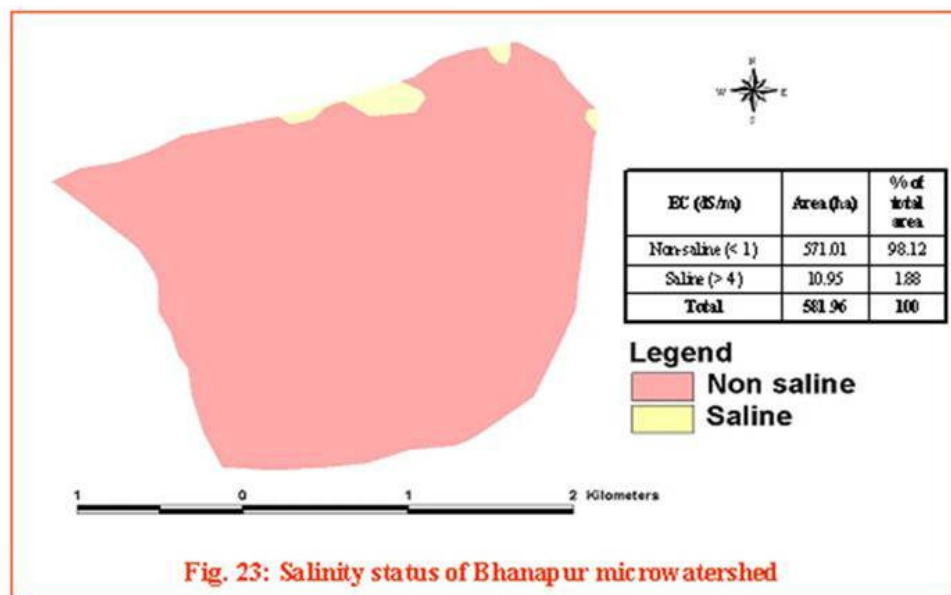


Fig 23. Salinity status of Bhanapur microwatershed

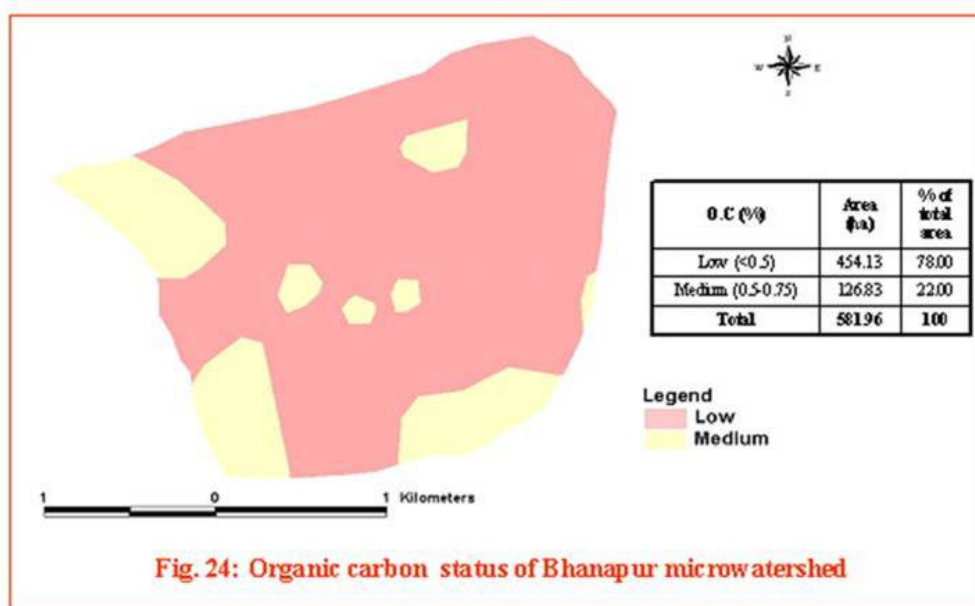


Fig 24. Organic carbon status of Bhanapur microwatershed

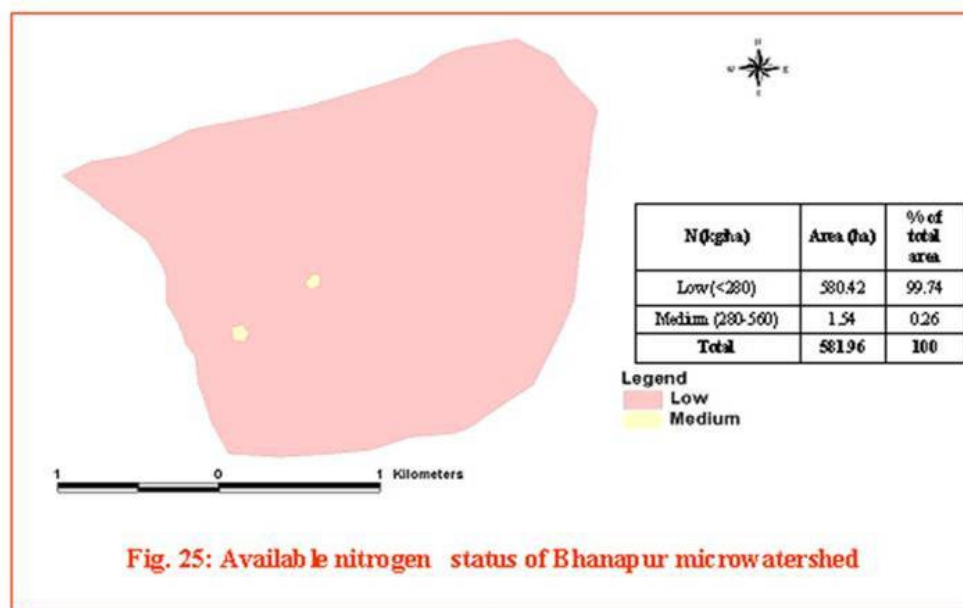


Fig 25. Available nitrogen status of Bhanapur microwatershed

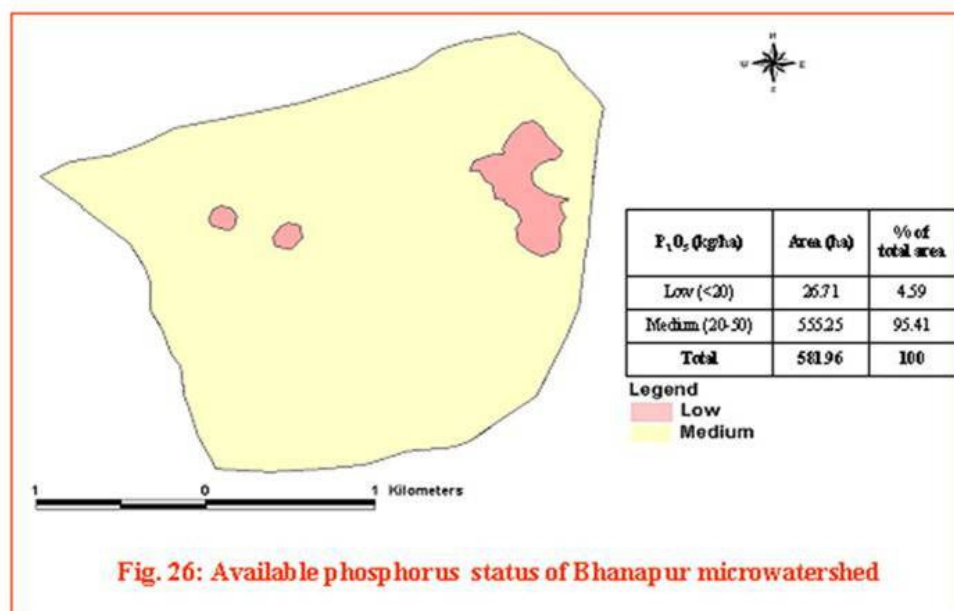


Fig 26. Available phosphorus status of Bhanapur microwatershed

available phosphorus, which may be due to low CEC, clay content and acidic soil reaction of <6.5 (Anon., 1989, Murthy, 1988 and Bopathi and Sharma, 2006). The present findings are in line with those of Motsara (2002) who depicted that majority of the soils in Karnataka were medium in phosphorous content.

5.5.3 Available potassium

The available potassium content in major portion of the study area was under medium and high category 365.65 and 150.31 ha (Fig. 27), respectively. Black soils shown higher values than red soils due to predominance of K rich micaceous and feldspars minerals in parent material. Similar results were observed by Patil and Sonar (1995), Pal (1985) and Ravikumar (2004). Major portion under medium (365.65) and low category (66.00 ha) were seen in the red soil areas, because these soils have less finer fractions in their soil. Joffee and Levine (1939) noticed that increase in pH and CEC increase the number of sites for K adsorption, but all these parameters are low in red soils in addition kaolinite type of clay mineralogy are the causes for their medium and low rating (Table 21).

5.5.4 Available sulphur

The area under medium and low category for sulphur was 164.64 ha and 417.32 ha (Fig. 28), respectively. Low and medium level of available sulphur was recorded due to lack of sulphur addition and continuous removal of S by crops. The some red soil samples shown more available sulphur values compared to black soils. Black soils have gypsuferous nature of sulphur which is non-available (Balanagoudar, 1989).

5.5.5 Exchangeable calcium and magnesium

Major portion of the study area was sufficient in exchangeable Ca and Mg status (Table 22). All the soils of the study area were high in exchangeable Ca and Mg contents. The deficiency of the exchangeable Ca contents was found in red soils, which may be due to easy leaching of bases and low organic carbon values. Anantharayana (1978) reported higher exchangeable Ca and Mg contents in black soils than red or laterite soils.

Availability of calcium and magnesium to the crops do not generally present problems in black soils, as these soils are calcareous in nature. The exchangeable Ca and Mg are attributed to the type and amount of clay, present in these soils. These results are conformity with the findings of Krishnamurthy (1993) and Alur (1994). High values of CEC and exchangeable Ca and Mg give an indication of dominance of smectite type of clay mineral as reported by Nandi and Dasog (1992).

5.6 Micronutrients

5.6.1 Available iron

Red soils fall under sufficient (496.50 ha) category for the Fe status (Fig. 29). Black soils fall under deficient (85.46 ha) and sufficient category for the Fe status. In black soils low Fe content may be due to precipitation of Fe^{2+} by CaCO_3 and decrease the availability (Table 23). Similar results were also observed by Ravikumar (2004).

The available iron in surface soils has no regular pattern of distribution as reported by, Nayak *et al.* (2000). This type of variation may be due to the soil management practices and cropping pattern adopted by different farmers. The report of wide variation in available Fe was made by Devaraj Urs (1979) in soils of TBP area of Karnataka and Tiwari *et al.* (1995) in soils of Uttar Pradesh.

5.6.2 Available manganese

The study area was sufficient in available manganese (Fig. 30), which may due to neutral to low pH and nature of the parent material as reported by Prasad and Sahi (1989).

5.6.3 Available zinc

Major portion of the study area (349.94 ha) was under sufficient rating for available zinc status (Fig. 31 and Table 23), as the soils were not subjected to intensive cultivation. The deficiency of the available Zn (232.02 ha) may be due, to high CaCO_3 and low organic carbon

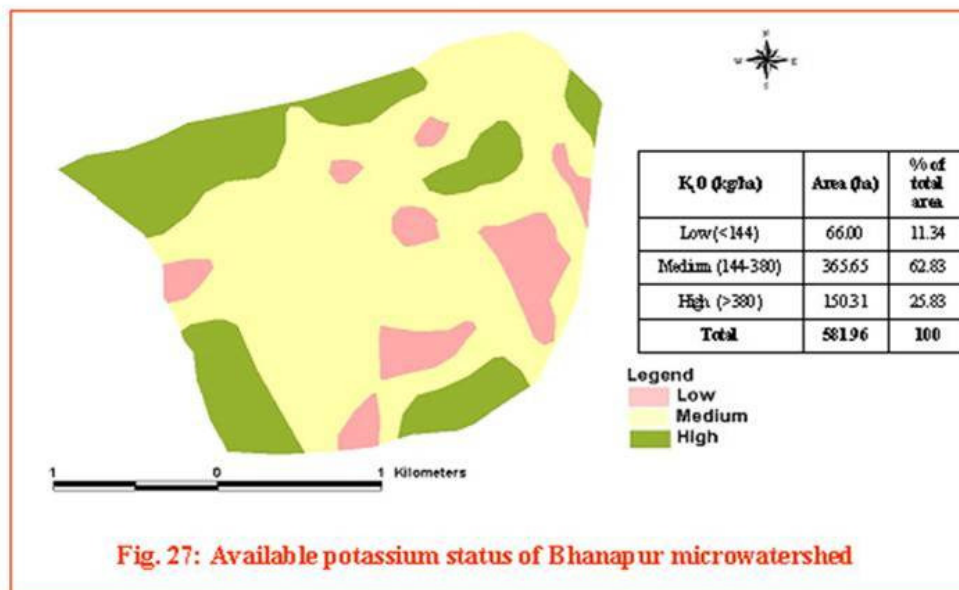


Fig 27. Available potassium status of Bhanapur microwatershed

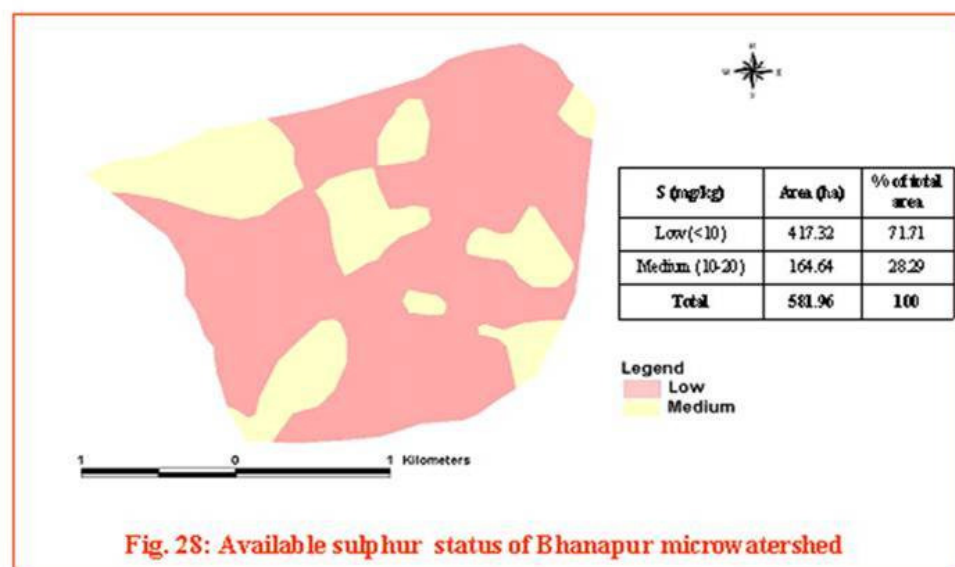


Fig 28. Available sulphur status of Bhanapur microwatershed

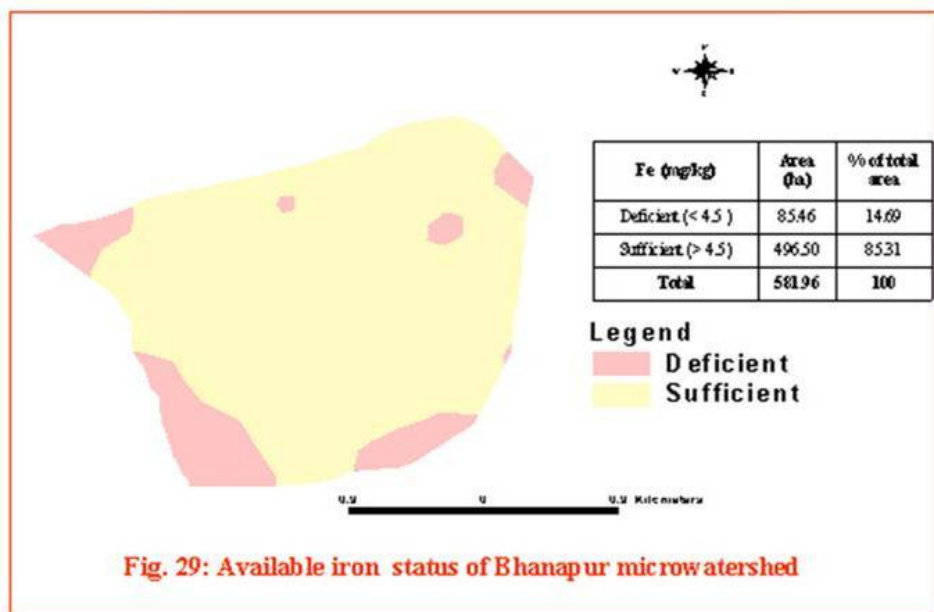


Fig 29. Available iron status of Bhanapur microwatershed

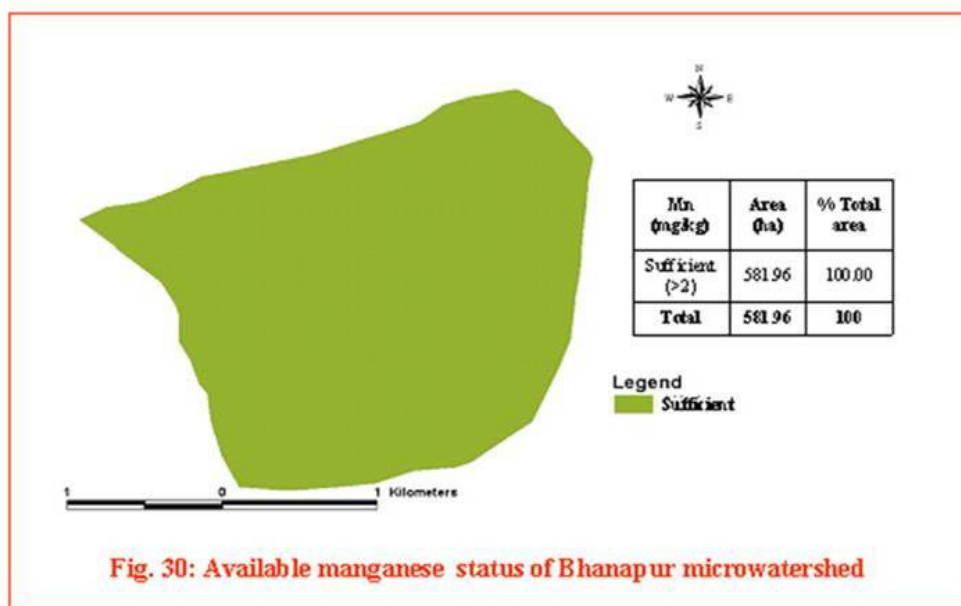


Fig 30. Available manganese status of Bhanapur microwatershed

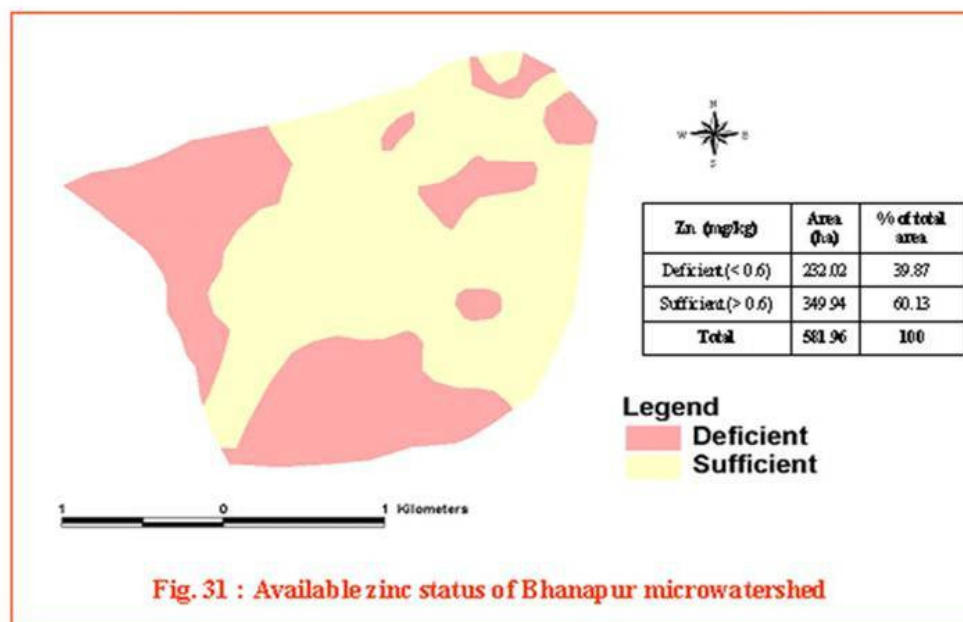


Fig 31. Available zinc status of Bhanapur microwatershed

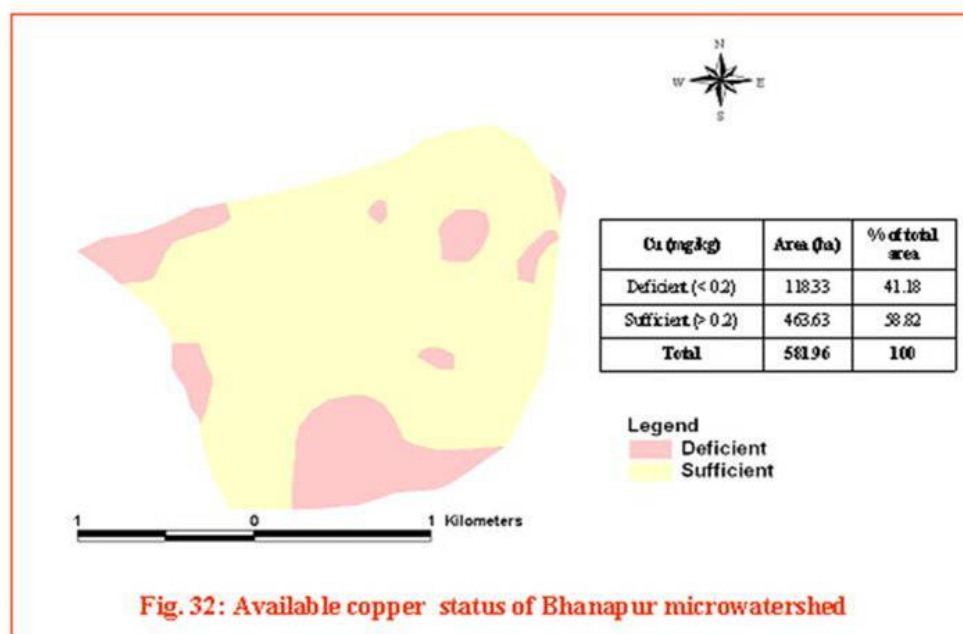


Fig 32. Available copper status of Bhanapur microwatershed

contents. These results are in agreement with the finding of Randhawa and Takkar (1975) and Pharande *et al.* (1996).

5.6.4 Available copper

Major portion of the study area (463.63 ha) was under sufficient rating for available copper status and some area was under deficient for available copper (118.33 ha) (Fig. 32 and Table 23). Raghupathi (1989) reported that available copper content in north Karnataka soils ranged from 0.4 to 1.2 mg kg⁻¹. Similar results were also observed by Ravikumar (2004).

The assessment of soil fertility status of Bhanapur microwatershed revealed that, among all the nutrients estimated, Nitrogen was the most deficient. The nitrogen deficiency is related mainly to organic matter status, as it is the major source of nitrogen. Growing of single crop per year, producing less biomass (groundnut, bajra, jowar) is the general practice in the study area. This practice might not have depleted the available nutrients including micronutrients (except zinc) thus restoring soil fertility status.

5.7 Soil productivity constraints

Productivity of the major crops grown in the watershed (both 2005 and 2006) was very low especially the productivity of crops on red soils. Based on the physico chemical properties, nutrients status and monitoring of soil moisture; following soil productivity constraints have been identified. Soil moisture, shallow solum depth, gravel content, coarse textured nature of soil and deficiency of nutrients. N, P, S, Zn and Cu are constraints in red soils. Where as N, S, Zn and Cu are the major constraints in the black soils.

5.8 Future line of work

- a. There is a need to quantify the influence of surface roughness on soil microwave emissivity and backscattering coefficient at microwatershed level.
- b. There is a need to thoroughly understand the influence of soil textural variations on the microwave response and develop algorithms to minimize it.
- c. There is a need to parameterize vegetation cover so that the influence of vegetation cover can be categorized as significant or insignificant on soil microwave emissivity or backscatter coefficient.

6. SUMMARY AND CONCLUSIONS

The idea of optimizing the utilization of the land resources with intensification of agriculture had resulted in the fast depletion of moisture and productivity of soil. It is therefore important to examine the soil moisture status and productivity constraints of soils from time to time. So, a systematic investigation was conducted on estimation of soil moisture status by RADAR microwave remote sensing and its monitoring and assessment of soil productivity constraints of the Bhanapur microwatershed (581.96 ha) in Koppal district under the agro-climatic zone 3 of Karnataka. The salient findings of the investigation are summarized below.

An extensive field sampling was conducted during 2005-2006 to estimate and monitor the soil moisture status at surface (0 – 5 cm) and subsurface (5 – 10 cm) soil. ENVISAT-1 ASAR data for 2005 and field observations were used for estimation of soil moisture. Fifty gravimetric soil samples (GT points) were collected at random in Bhanapur microwatershed and estimated with date of satellite pass. Backscatter (σ^0) values have been extracted for ENVISAT-1 images.

Correlation analysis was performed to study the relationship between volumetric soil moisture content and backscatter coefficient (σ^0). The correlation study showed an encouraging positive correlation of microwave backscatter value with the soil moisture at both surface and sub-surface soils. Significantly high correlation was obtained during 13th July 2005 followed by 29th July 2005 at subsurface (5 - 10 cm) soils. HH polarization showed better correlation between volumetric soil moisture and backscatter value. However, the relation was good with red soils and the relation was improved for 0 to 10 cm soil depth (mean of surface and sub-surface).

During 2006, soil moisture was low on all days of observation. Higher soil moisture content was recorded in black soils than red soils. However, compared to field capacity, soil moisture content was low in both the soils.

Black soils of the microwatershed were clay loam to clayey but red soils were sandy to sandy loam in texture. The maximum water holding capacity, FC and porosity were higher in black soils than in red soils. The bulk density of red soils was higher than black soils.

One hundred surface (0 – 30 cm) soil samples were collected at random from the study area and analyzed for pH, EC, OC, CaCO_3 , Fe_2O_3 and available nutrients. The pH of the soils of the study area was neutral to alkaline and free from salinity.

The organic carbon content of the soils of the study area was low to medium. The CaCO_3 and Fe_2O_3 content of the soils ranged from 3.0 to 8.5 and 1.0 to 7.9 per cent, respectively.

Available nitrogen content of the soils was low in the entire microwatershed (580.42 ha). The available phosphorus was low to medium and available potassium content of the soils was medium to high. The available sulphur content of the soils was low to medium.

The soils were sufficient in available iron and manganese. Zinc deficiency was observed in red soils, whereas black soils were deficient in copper. Zinc was the major constraint among micronutrients next to copper.

Crop yield was low during 2006 compared to 2005 due to drought condition prevailed during the crop growth period of 2006. In general crop yields were low in the microwatershed because of soil moisture and nutrient constraints (N, P, S, Zn and Cu).

Conclusions

1. A strong dependence of ENVISAT ASAR response on the soil moisture was observed in red soils.
2. High correlation coefficient was obtained with the 0 – 10 cm soil depth shows the penetration capacity of microwaves up to 10 cm.
3. HH polarization showed better correlation between backscatter coefficient and volumetric soil moisture than HV polarization.

4. The organic carbon, available nitrogen, phosphorus and sulphur content of the soils were low to medium.
5. Generally, soil productivity of the watershed was low *i.e.* soil solum, gravelly coarse texture and low organic matter and deficiency of N, P, S, Zn and Cu.

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Appendix I: Average rain fall of Bhanapur microwatershed area (Koppal District)

Week No.	Standard weeks	2005		2006	
		Average Rainfall (mm)	Date of rainfall	Average Rainfall (mm)	Date of rainfall
15	April 9-15	14.0	14	25.0	10
16	April 16-22	10.0	16 and 22	0.0	-
17	April 23-29	12.2	27	0.0	-
18	April 30-6 May	0.0	-	0.0	-
19	May 7-13	0.0	-	18.2	10
20	May 14-20	0.0	-	0.0	-
21	May 21-27	14.2	27	7.2	26
22	May 28-3 June	15.0	31	0.0	-
23	June 4-10	42.4	6	10.0	6
24	June 11-17	15.7	11 and 14	19.73	11,16 and 17
25	June 18-24	0.0	-	16.1	20 and 22
26	June 25-1 July	8.2	28	0.0	-
27	July 2-8	0.0	-	0.0	-
28	July 9-15	17.4	10,14 and 15	0.0	-
29	July 16-22	35.1	16 and 27	0.0	-
30	July 23-29	18.8	23,24,25 and 26	15.0	26
31	July 30-5 Aug.	0.0	-	11.5	Aug 4 and 5
32	Aug 6-12	0.0	-	0.0	-
33	Aug13-19	7.2	17	0.0	-
34	Aug 20-26	0.0	-	0.0	-
35	Aug 27-2 Sept.	40.6	31 and 2 Sept.	0.0	-
36	Sept 3-9	6.0	3 and 5	40.0	8
37	Sept 10-16	0.0	-	14.6	13 and 16
38	Sept 17-23	0.0	-	0.0	-
39	Sept 24-30	38.33	27,28 and 29	18.33	24,27 and 28
40	Oct 1-7	0.0	-	11.0	2
41	Oct 8-14	26.5	9 and 14	17.1	8 and 9
42	Oct 15-21	24.0	15 and 17	0.0	-
43	Oct 22-28	0.0	-	18.5	22 and 23
44	Oct 29-4 Nov	55.0	Nov 2	22.0	3
Total rainfall		400.63		264.26	

Appendix II: Global position of surface samples for analysis of soil moisture status

Sample No	Latitude	Longitude	Sample No	Latitude	Longitude
Black soils					
1	15° 23' 13.24" N	76° 1' 33.56" E	14	15° 23' 2.44" N	76° 2' 5.94" E
2	15° 23' 6.0" N	76° 2' 9.54" E	15	15° 23' 19.39" N	76° 2' 13.79" E
3	15° 24' 1.94" N	76° 2' 16.75" E	16	15° 24' 3.71" N	76° 2' 58.56" E
4	15° 24' 3.71" N	76° 2' 5.94" E	17	15° 24' 7.14" N	76° 2' 2.16" E
5	15° 23' 2.42" N	76° 2' 13.19" E	18	15° 24' 3.62" N	76° 2' 2.25" E
Red soils					
1	15° 23' 27.03" N	76° 1' 30.45" E	21	15° 23' 27.63" N	76° 2' 23.94" E
2	15° 23' 22.16" N	76° 2' 20.90" E	22	15° 23' 27.61" N	76° 2' 16.78" E
3	15° 22' 50.7" N	76° 1' 54.97" E	23	15° 23' 38.43" N	76° 2' 16.75" E
4	15° 23' 19.39" N	76° 2' 5.64" E	24	15° 23' 40.02" N	76° 2' 6.93" E
5	15° 23' 16.82" N	76° 1' 44.35" E	25	15° 23' 27.57" N	76° 2' 5.85" E
6	15° 23' 27.36" N	76° 1' 44.74" E	26	15° 23' 31.22" N	76° 2' 58.69" E
7	15° 23' 56.45" N	76° 1' 51.52" E	27	15° 23' 34.78" N	76° 1' 51.48" E
8	15° 23' 16.10" N	76° 1' 17.95" E	28	15° 23' 34.78" N	76° 1' 47.91" E
9	15° 23' 11.84" N	76° 1' 8.77" E	29	15° 23' 38.47" N	76° 1' 40.75" E
10	15° 23' 20.40" N	76° 1' 11.99" E	30	15° 23' 45.72" N	76° 1' 45.35" E
11	15° 23' 20.41" N	76° 1' 8.39" E	31	15° 23' 52.81" N	76° 1' 51.52" E
12	15° 23' 24.01" N	76° 1' 11.98" E	32	15° 23' 52.85" N	76° 1' 58.77" E
13	15° 23' 24.00" N	76° 1' 15.58" E	33	15° 23' 50.4" N	76° 1' 57.4" E
14	15° 23' 6.00" N	76° 1' 15.58" E	34	15° 23' 51.1" N	76° 2' 6.54" E
15	15° 23' 37.48" N	76° 1' 18.30" E	35	15° 23' 45.68" N	76° 2' 20.27" E
16	15° 22' 52.46" N	76° 1' 33.99" E	36	15° 23' 41.99" N	76° 2' 20.32" E
17	15° 23' 16.84" N	76° 1' 29.97" E	37	15° 23' 56.65" N	76° 2' 21.23" E
18	15° 23' 13.21" N	76° 1' 51.56" E	38	15° 23' 35.97" N	76° 1' 3.36" E
19	15° 23' 2.29" N	76° 1' 42.87" E	39	15° 23' 27.60" N	76° 1' 22.78" E
20	15° 23' 6.00" N	76° 1' 58.77" E	40	15° 23' 20.4" N	76° 1' 51.56" E

Appendix III: Global position of surface samples for analysis of nutrient status

Sample No	Latitude	Longitude	Sample No	Latitude	Longitude
Black soils					
1	15° 23' 14.0" N	76° 1' 35.6" E	14	15° 24' 5.3" N	76° 2' 0.9" E
2	15° 23' 3.4" N	76° 2' 6.1" E	15	15° 24' 7.8" N	76° 2' 1.2" E
3	15° 23' 5.0" N	76° 2' 9.6" E	16	15° 24' 1.8" N	76° 2' 2.6" E
4	15° 23' 3.2" N	76° 1' 11.9" E	17	15° 24' 1.5" N	76° 2' 6.1" E
5	15° 23' 54.9" N	76° 1' 51.1" E	18	15° 24' 0.5" N	76° 2' 6.7" E
6	15° 23' 56.9" N	76° 1' 50.6" E	19	15° 24' 17.9" N	76° 2' 7.3" E
7	15° 23' 56.6" N	76° 1' 52.4" E	20	15° 24' 20.9" N	76° 2' 9.3" E
8	15° 23' 49.9" N	76° 1' 40.3" E	21	15° 24' 1.2" N	76° 2' 8.7" E
9	15° 23' 51.1" N	76° 1' 50.4" E	22	15° 24' 1.0" N	76° 2' 8.8" E
10	15° 24' 0.9" N	76° 1' 53.8" E	23	15° 24' 0.5" N	76° 2' 15.3" E
11	15° 24' 1.2" N	76° 1' 54.2" E	24	15° 23' 51.1" N	76° 2' 18.4" E
12	15° 24' 15.6" N	76° 1' 56.9" E	25	15° 23' 50.1" N	76° 2' 21.1" E
13	15° 24' 9.0" N	76° 1' 59.5" E			
Red soils					
1	15° 23' 11.6" N	76° 1' 11.1" E	17	15° 23' 9.3" N	76° 1' 23.5" E
2	15° 23' 15.2" N	76° 1' 12.2" E	18	15° 23' 20.5" N	76° 1' 23.7" E
3	15° 23' 16.2" N	76° 1' 12.4" E	19	15° 23' 19.7" N	76° 1' 23.6" E
4	15° 23' 19.3" N	76° 1' 12.6" E	20	15° 23' 9.3" N	76° 1' 23.5" E
5	15° 23' 20.2" N	76° 1' 13.5" E	21	15° 23' 15.7" N	76° 1' 30.7" E
6	15° 23' 21.0" N	76° 1' 10.2" E	22	15° 23' 14.5" N	76° 1' 34.5" E
7	15° 23' 23.9" N	76° 1' 10.6" E	23	15° 23' 15.1" N	76° 1' 42.3" E
8	15° 23' 24.1" N	76° 1' 11.2" E	24	15° 23' 16.7" N	76° 1' 20.6" E
9	15° 23' 23.5" N	76° 1' 13.3" E	25	15° 23' 18.4" N	76° 1' 47.2" E
10	15° 23' 22.5" N	76° 1' 14.1" E	26	15° 23' 16.7" N	76° 1' 33.6" E
11	15° 23' 26.3" N	76° 1' 14.4" E	27	15° 23' 19.7" N	76° 1' 50.8" E
12	15° 23' 31.9" N	76° 1' 17.8" E	28	15° 23' 9.8" N	76° 1' 41.1" E
13	15° 23' 30.4" N	76° 1' 15.7" E	29	15° 23' 5.1" N	76° 1' 53.3" E
14	15° 23' 26.3" N	76° 1' 24.6" E	30	15° 23' 12.3" N	76° 1' 50.6" E
15	15° 23' 4.5" N	76° 1' 15.4" E	31	15° 23' 11.3" N	76° 1' 50.8" E
16	15° 23' 3.3" N	76° 1' 22.1" E	32	15° 23' 9.0" N	76° 1' 50.2" E

Appendix III contd.....

Sample No	Latitude	Longitude	Sample No	Latitude	Longitude
33	15° 23' 8.4" N	76° 1' 50.1" E	55	15° 23' 34.5" N	76° 1' 53.2" E
34	15° 23' 8.5" N	76° 1' 53.1" E	56	15° 23' 40.1" N	76° 1' 46.1" E
35	15° 23' 7.9" N	76° 1' 55.1" E	57	15° 23' 37.2" N	76° 1' 45.1" E
36	15° 23' 6.3" N	76° 2' 2.3" E	58	15° 22' 34.0" N	76° 1' 46.7" E
37	15° 23' 9.0" N	76° 2' 3.4" E	59	15° 22' 36.9" N	76° 1' 41.6" E
38	15° 23' 53.9" N	76° 1' 51.1" E	60	15° 22' 37.3" N	76° 1' 42.6" E
39	15° 23' 2.9" N	76° 2' 26.1" E	61	15° 22' 38.2" N	76° 1' 41.0" E
40	15° 23' 14.6" N	76° 2' 27.1" E	62	15° 22' 39.6" N	76° 1' 42.3" E
41	15° 23' 21.0" N	76° 2' 26.7" E	63	15° 22' 40.2" N	76° 1' 44.0" E
42	15° 23' 23.4" N	76° 1' 59.3" E	64	15° 22' 42.9" N	76° 1' 43.6" E
43	15° 23' 27.3" N	76° 2' 24.6" E	65	15° 22' 44.1" N	76° 1' 44.8" E
44	15° 23' 25.6" N	76° 2' 23.5" E	66	15° 22' 45.6" N	76° 1' 45.6" E
45	15° 23' 26.5" N	76° 2' 20.1" E	67	15° 22' 49.1" N	76° 1' 50.7" E
46	15° 23' 27.8" N	76° 2' 16.2" E	68	15° 22' 50.2" N	76° 1' 50.6" E
47	15° 23' 30.4" N	76° 2' 15.1" E	69	15° 22' 52.5" N	76° 1' 52.6" E
48	15° 23' 31.4" N	76° 2' 14.5" E	70	15° 22' 50.8" N	76° 2' 13.9" E
49	15° 23' 30.4" N	76° 2' 10.6" E	71	15° 22' 49.6" N	76° 2' 12.3" E
50	15° 23' 32.7" N	76° 2' 9.5" E	72	15° 22' 44.6" N	76° 2' 12.1" E
51	15° 23' 29.7" N	76° 2' 4.1" E	73	15° 22' 45.8" N	76° 2' 15.7" E
52	15° 23' 30.3" N	76° 1' 58.7" E	74	15° 22' 44.2" N	76° 1' 15.6" E
53	15° 23' 31.3" N	76° 1' 59.7" E	75	15° 22' 43.3" N	76° 1' 18.0" E
54	15° 23' 32.7" N	76° 1' 52.8" E			

Appendix IV: Ratings adopted for interpretation of soil productivity constraints

Parameter	Rating
Soil reaction	Slightly acidic (< 6.5) Neutral (6.5 – 7.5) Alkaline (7.5 – 8.5)
Electrical conductivity (dS/m)	Non-saline (< 1 dS/m) Saline (> 4 dS/m)
Organic carbon (%)	Low (< 0.5%) Medium (0.5 – 0.75 %)
Available nitrogen (kg/ha)	Low (<280 kg/ha) Medium (280 – 560 kg/ha)
Available phosphorus (kg/ha)	Low (< 20 kg/ha) Medium (20 – 50 kg/ha)
Available potassium (kg/ha)	Low (<144 kg/ha) Medium (144-380 kg/ha) High (>380 kg/ha)
Available sulphur (mg/kg)	Low (< 10 mg/kg) Medium (10 – 20 mg/kg)
Available Fe (mg/kg)	Deficient (< 4.5 mg/kg) Sufficient (> 4.5 mg/kg)
Available Zn (mg/kg)	Deficient (0 – 0.6 mg/kg) Sufficient (> 0.6 mg/kg)
Available Cu (mg/kg)	Deficient (< 0.2 mg/kg) Sufficient (> 0.2 mg/kg)
Available Mn (mg/kg)	Excess (>2 mg/kg)

ESTIMATION AND MONITORING OF SOIL MOISTURE BY RADAR REMOTE SENSING TECHNIQUE AND IDENTIFICATION OF SOIL PRODUCTIVITY CONSTRAINTS IN BHANAPUR MICROWATERSHED

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ABSTRACT

A systematic investigation was conducted on estimation of soil moisture status by RADAR microwave remote sensing and assessment of soil productivity constraints of the Bhanapur microwatershed in Koppal district under the agro-climatic zone 3 of Karnataka.

An extensive field sampling was conducted during 2005 and 2006 to estimate and monitor the soil moisture status at surface (0-5 cm) and subsurface (5-10 cm) soil. ENVISAT-1 ASAR data for 2005 and field observations were used for estimation of soil moisture and backscatter values have been extracted from ENVISAT-1 images. Correlation study showed an encouraging positive correlation of microwave backscatter value (HH polarization) with the soil moisture at both surface and sub-surface soils. However, the relation was good with red soils and improved for 0-10 cm soil depth. During 2006, soil moisture was low on all the days of observation. Higher soil moisture content was recorded in black soils than in red soils.

The microwatershed consists of both red and black soils in association. Texture of Black soils was clay loam to clayey and that of red soils was sandy to sandy loam. The maximum water holding capacity, FC and porosity were higher in black soils than in red soils. The bulk density of red soils was higher than black soils. The soils were slightly acidic to alkaline in nature with low to medium organic carbon content. The CaCO_3 and Fe_2O_3 content of the soils ranged from 3.0 to 8.5 and 1.0 to 7.9 per cent, respectively.

Crop cutting experiments showed that yield of crops was low especially during 2006 compared to 2005. The mapping of soil moisture and available nutrient status by GIS technique indicated that N, P, S, Zn and soil moisture are major constraints in both black and red soils of Bhanapur microwatershed. Soil moisture was more critical during 2006.