Toolkit for Evaluating Sustainability of Watersheds in Rainfed Regions

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1. Introduction

Rainfed agro-ecological regions (AER) which encompass the semi-arid tropics (SAT) and hot dry and moist sub-humid regions of India, extends over 76.74 m ha out of the total geog. area of 90.4 m ha in the states of Andhra Pradesh (AP), Maharashtra (MAHA), Karnataka (KAR) and Tamilnadu (TN) in Peninsular India. In India as a whole, arid AER account for 33.98 m ha (10.36 %) while semi-arid AER cover 95.09 m ha (28.98%) with a transitional belt of 3.19 m ha or 1 % of the land area. Thus, rainfed AER is important for the country as a whole and watershed-based development has been accepted as an important component in the schemes for economic planning for development in this region.

The rainfed AER encompassing Peninsular India receives an average annual rainfall of 500 mm (300-800 mm), which occur in 52 - 55 rainy days. Over 50 per cent of this rainfall occurs by way of thunderstorm that lasts for a few hours. Considering such a rainfall pattern, it is essential to harvest, store and use rainwater for undertaking agriculture and other allied activities for the rest of the year. Intensive rainfall events induce severe soil erosion in bare or sparsely vegetated land that is common in the region. Watershed Development and Management Program was initiated during 1980s to address these limitations of the rainfed AER (Planning Commission, 2001). Soil and Water Conservation Structures (S&WC) viz., check-dam, stone weirs, contour bund, live bunds, vegetative cover, key-line plantation, grass way etc. were planned to provide impediments to overland - runoff which induce soil erosion and depletion of nutrients from agricultural fields. Structures were laid to guide runoff to designated farm ponds and tanks for water harvesting on the surface, besides impounding water for facilitating deep percolation for groundwater recharge. Thus, Watershed Development Program (WDP) was considered the most comprehensive program for achieving agricultural and ecological sustainability in the rainfed regions in India. A hallmark of WDP was the implementation of improved land management practices (LMP) for each aspect of agriculture and rural life in the rainfed regions. As India envisages sustaining an agricultural growth rate of 4.0 to 4.5 per cent in order to reduce food insecurity and poverty, while increasing rural purchasing power, it is essential to strive for achieving sustainable development through watershed development.

2. Watershed Development Program (WDP) in India

One of the primary reasons, in favor of watershed-based development in rainfed AER, is the enormous cost of major water projects like the under-construction Narmada river-valley project. Hence emphasis was shifted to augmenting water resources through small and decentralized projects and the WDP for rainfed regions in rural India, have remained the accepted strategy for rural transformation. The Watershed Projects have been undertaken under six major national programs, viz. Drought-Prone Area Program (DPAP), Desert Development Program (DDP), National Watershed Development Project for Rain-fed Area (NWDPRA), Watershed Development in Shifting Cultivation Areas (WDSCA), Integrated Watershed Development Project (IWDP) and Employment Assurance Scheme (EAS) etc. by four Central Ministries of Govt. of India namely, Ministry of Rural Development (MORD), Agriculture (MOA), Environment & Forestry (MOEF) and Water Resources (WR). Significantly, 70 per cent of funds for watershed development in India are being spent under these six major programs. There are also, a lot of commonality in the WDP undertaken by these four ministries, in view of which, a inter-ministerial sub-committee was constituted in 1999, to evolve a common approach and principles for undertaking of WDP in India. Government of India has also drawn an ambitious 25-years Perspective Plan for an holistic and integrated development of rainfed areas in the country on watershed -basis, for covering an area of app. 63 m ha at an estimated cost of Rs. 76,000 c*rore* or USD 1520 m (Planning Commission, 2005). However, experts like – Dr. M.S. Swaminathan and Dr. C.H. Hanumantha Rao (MORD 1994) besides others, have expressed their reservation in the manner in which the project is being implemented, although several modifications were implemented in the program since its inception in the year 1983. A Technical Committee Report submitted to the Department of Land Resources (MORD) in January 2006 (Parthasarathy, 2006), estimates that at current level of outlay, it may take 75 years to complete watershed treatment in India. The Committee opined that if S&WC measures needed to be completed by 2020, the Government must allocate Rs. 10,000 crore (USD 20 m) annually for the purpose, for the next 15 years.

3. Evaluation of impact of Watershed development Program (WDP) in India

A few evaluation studies have been undertaken to assess impact of WDP in rainfed regions of India. Notable among them are by John Kerr & Sanghi (1992); Kerr *et al.,* (2002), Amita Shah *et al.,* (2004), Joshi *et al* (2005), Sreedevi *et al* (2004), Wani *et al* (2002,2003) Mishra *et al* (2004) Sharma *et al* (2005) Singh (2000), Ram Babu & Dhyani (2005), Samra (2005), Sharda (2005), Mandal *et. al.,* (2005), Singh *et. al.,* 2005), Omprakash *et al*., (2004), and J. Venkatehrwarlu (no year mentioned)- published by MANAGE. Besides these, there are a few studies on Review of Policy on Watershed Development of Andhra Pradesh Government (Oliver Springate – Baginski *et al*., 2004), Watershed Development Program in India (Hanumantha Rao, 2000), Costs of Resource Degradation like Groundwater Depletion in Andhra Pradesh (Ratna Reddy, 2003), Sustaining Rural Livelihood in Fragile Environments (Ratna Reddy *et al*, 2004), etc.

Most of these studies have evaluated the impact of package of practices implemented under WDP. The earlier studies were based on qualitative data with some quantitative information for which econometric analysis had been performed (Kerr *et al.,* 2002). All these studies faced two major problems due to which their scope of analysis was restricted. Firstly, baseline information of watershed villages is extremely difficult to obtain from Project Implementing Agencies (PIA) as there were no systematic method or process put in place to collect and archive them; hence meaningful evaluation was always difficult. Next, periodic monitoring of WDP was neither undertaken by PIA nor the funding agency. As a consequence, most evaluation studies were forced to report on qualitative information only. These problems had been widely discussed and in more recent WDP, amendments have been made and a definitive process has been put in place to avoid similar problems. The ICRISAT study of *Adarsh* Watershed in *Kothapally* is excellently documented as the watershed was developed by them and as a farmer participatory consortium model for efficient use of NRM was put in place (Sreedevi *et al*., 2004). P.K. Joshi *et al* (2005) undertook meta-analysis of over 311 watershed projects and documented efficiency, equity and sustainability benefits. The authors point out that mean B: C ratio of a watershed program in the country was quite modest at 2.14. Internal rate of return was 22 % that was comparable with many other rural developmental programs. The *Manchal* Project (Singh, 2000) was developed by MANAGE and the economic evaluation carried out by them indicated a positive impact on the village economy.

To address these lacunae with reference to evaluation of sustainability of watershed projects in India, two research projects were undertaken at CRIDA under the *Ad-hoc* scheme and the ICAR National Fellow Scheme to develop a methodology and a toolkit for evaluation of watershed development projects in the peninsular region of India since 2004. For this purpose, tools of Geo-informatics like GIS, Remote sensing techniques, DGPS and Spectro-radiometer were used to supplement information generated from actual field survey, soil analysis and socio-economic survey conducted in the selected watersheds and villages. Databases were created in ***MS-Access*** and thematic maps were drawn using ArcGIS. Multi-spectral satellite data were procured from NRSA for pre-project period i.e., 1998 and post-project periods, i.e., 2004 to 2006. The satellite imageries were interpreted to understand the processes of change using various indicators. A methodology was thus developed to generate baseline information for pre-project period for various parameters from field and satellite data which were in turn, used as sustainability indicators to assess sustainability of watersheds projects. In Figure 1 the modular scheme of the evaluation study has been depicted. The impact of non-implementation of WDP was compared in an untreated watershed in the vicinity for a clearer understanding.

4. Pre-field Activity

For evaluation of Watershed Development Projects (WDP) it is essential to select watersheds based on some pre-determined criteria. For our study in the AESR 7.2, five treated and an equal number of untreated micro-watersheds were selected in the districts of Rangareddy and Nalgonda in AP. The watersheds are located in the rural-urban divide zone at a distance 70 km from Hyderabad Urban Center. The pre-field activities undertaken prior to evaluation of the watersheds have been described in brief here.

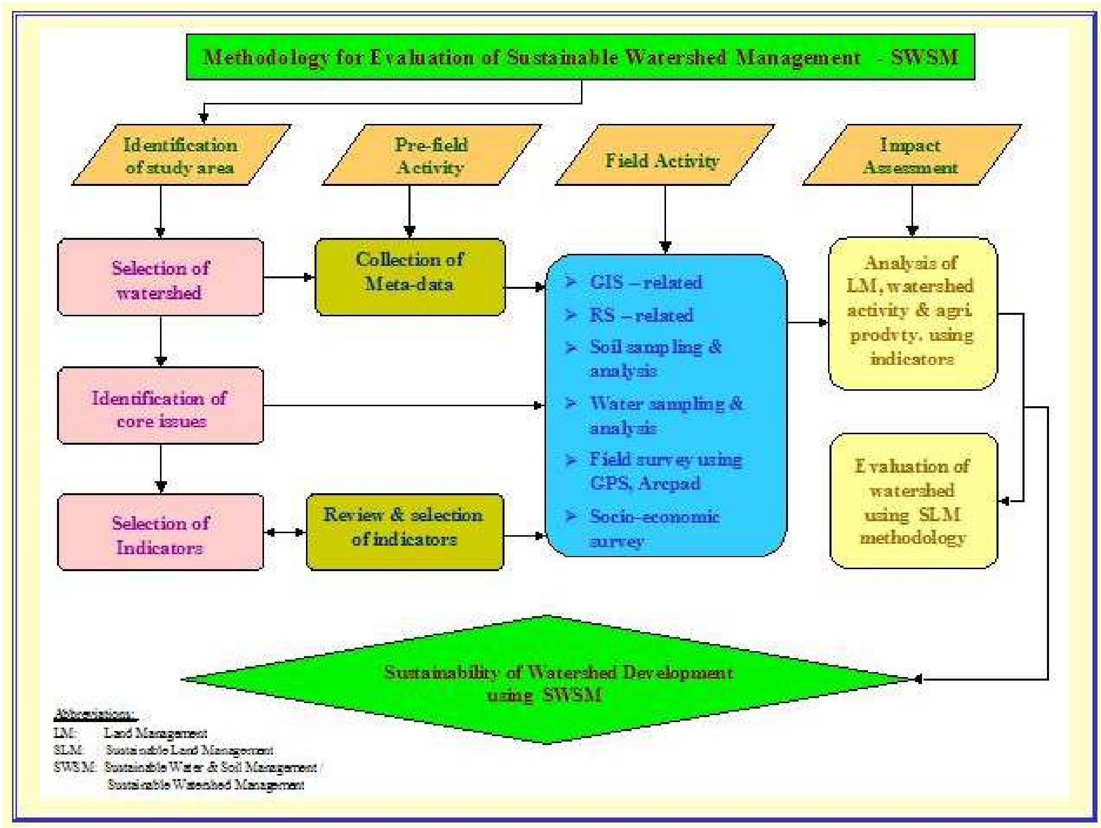

Fig.1: Multidisciplinary methodology used to evaluate sustainability of WDP.

4.1. Selection of watersheds based on some criteria -

Our objective was to analyse which programs and agencies had implemented a sustainable watershed project in the study area. Hence projects developed by various agencies like the Dept. of Agri, Govt. of AP, - a line dept., NGO, research organization like CRIDA, MANAGE, NIRD, etc. was chosen for the study. As each of these PIA lay emphasis on various aspects, the outcome of the projects are very different. To capture these variations leading to difference in outcome of WDP five treated micro-watersheds were selected in five villages namely - Chintapatla near Ibrahimpatnam in Yacharam Mandal, Pamana in Chevella Mandal and Dontanpalli in Shankarpalli Mandal, Channareddiguda in Manchal Mandal – all in Rangareddy district and Gollapalli in Chintapalli Mandal in Nalgonda District.

4.2. Characterization of resource base in selected watersheds -

The resources available in the various watersheds were surveyed and mapped using ArcGIS. Detail of this technique has been added in a later section in this paper.

4.3. Identification of core issues that affect agriculture in watersheds -

After reconnaissance survey of selected watersheds and discussion with key informants, core issues that impact agriculture in the selected watersheds were identified. As these need to be addressed first to achieve sustainable development, the evaluation study and methodology is developed to address these issues

4.4. Identification and construction of relevant sustainability indicators -

Based on the core issues, relevant indicators were developed to evaluate the various aspects of sustainable development. A set of fifty indicators was developed to evaluate the watershed projects under the NF scheme.

4.5. Methodology for identifying critical indicators -

A methodology was developed to identify critical indicators for evaluating sustainability of watershed projects. The merits of this methodology are that it is helps in a quantitative evaluation that facilitates comparison of situation between two watersheds besides enabling mapping thus making the evaluation process easy, objective and useful. Wherever direct indicators were unavailable, surrogate indicators were developed and used for evaluation.

5. Field Activity

Fieldwork is an integral and crucial part of the study. At the initial stage a reconnaissance survey was undertaken in each of the watersheds identified for study. A transact walk was undertaken to survey the selected watersheds and villages for agricultural resource characterisation. A DGPS was used to geo-reference all resources and boundaries in the study area. Soil sampling sites and S&WC structures were also geo-referenced. Soil samples were brought to lab for analysis. In the next phase interviews of farm households were carried out using two structured questionnaires.

5.1. Watershed Survey - Transact Walk -

5.2. Geo-referencing of sites using DGPS -

A Trimble DGPS (Differential Global Positioning Systems) unit consisting of a base and a rover unit was used for geo-referencing the GCP, soil sampling sites, soil profile sites and

S&WC structures in the study area. The unit was also used to update landholding boundaries that had changed owing to sub -division and fragmentation of land after mapping of the original cadastre (Photo 1).

Photo 1: Geo-referencing a check-dam in Pamana village near Chevella, RR District.

5.3. Measuring spectral signatures & collection of ground -truth information-

On an average more than a dozen visits was required to be taken for collection of ground truth information and for verification of the same in the field in each site annually during the study. Several of these trips were exclusively undertaken during cropping season for collection of spectral signatures of crops to facilitate interpretation of satellite data with reference to crop cover, change in land use and land cover and resultant NDVI conditions. A *Spectral Library* was developed to store typical spectral signature of various objects on ground during various seasons for facilitating interpretation of satellite data. Photo 2 indicates the use of a spectro-radiometer in the field.

Photo 2: Using a handheld spectro-radiometer (*Analytical Instruments Ltd*. USA) to collect spectral signature from paddy field at early growth stage in Gollapalli village.

5.4. Soil sampling

Mapping of soil fertility status is an essential requirement for analysing impact of improved practices implemented under watershed development projects. Over 450 soil samples were collected from various sites in the study area and analysed for 12 physico-chemical and biological parameters in the lab using standard methods.

5.5. Soil profile study

One typical soil profile was cut in each of the study site for establishing a baseline for facilitating long-term sustainability studies.

5.6. Socio-economic survey

Two questionnaires were specifically prepared for conducting socio-economic surveys at household and village-level in each of the study area. The questionnaire were structured in a manner so as to collect information for each for each of the sustainability indicator identified for the purpose. Wherever direct indicators were not available, information for surrogate indicators were collected.

5.7. Participatory Rural Appraisal (PRA)

A PRA was conducted specifically to identify core issues that affect agriculture in each of the watershed village.

6. Activities undertaken in Laboratory

The study involved several activities to be undertaken in the GIS, Soil Chemistry & Soil Physics Labs. While the interpretation and analysis of satellite data was undertaken in the GIS lab, storage and preparation of soil samples for analysis and finally batch-wise, analysis of soil samples was carried out in the Soil Physics and Soil Chemistry labs at the institute.

6.1. Applications in *ArcGIS* for analyzing sustainability of watershed projects -

One of the highlights of the research program was the application of GIS technique for evaluation of impact of LMP on rainfed agriculture. Watersheds were delineated and mapped using ArcGIS (ver. 9.0) software (Fig. 2). All corollary data had to be collected and collated before preparation of map overlays for the study. Thematic maps for various aspects like slope, soil fertility status, cereal yield, etc., were prepared for deriving sustainability indicators (Fig. 3). Map overlay of two or more themes helped in deriving numeric value for Sustainable Indicators. For instance, to evaluate impact of S&WC measures on soil fertility status and crop yield, overlay of maps of treated micro-watershed (TMW) with slope, soil macro - nutrient status. Correlation of location of S&WC measures with NDVI was deemed essential. Overlay of village cadastre over this outlay helped in quantifying the designated Sustainable Indicator. Other maps like NDVI derived from satellite data or land use and land cover maps helped in deriving and quantifying other sustainable indicator in a similar manner essential for evaluating NRM status in each land holding in the watershed.

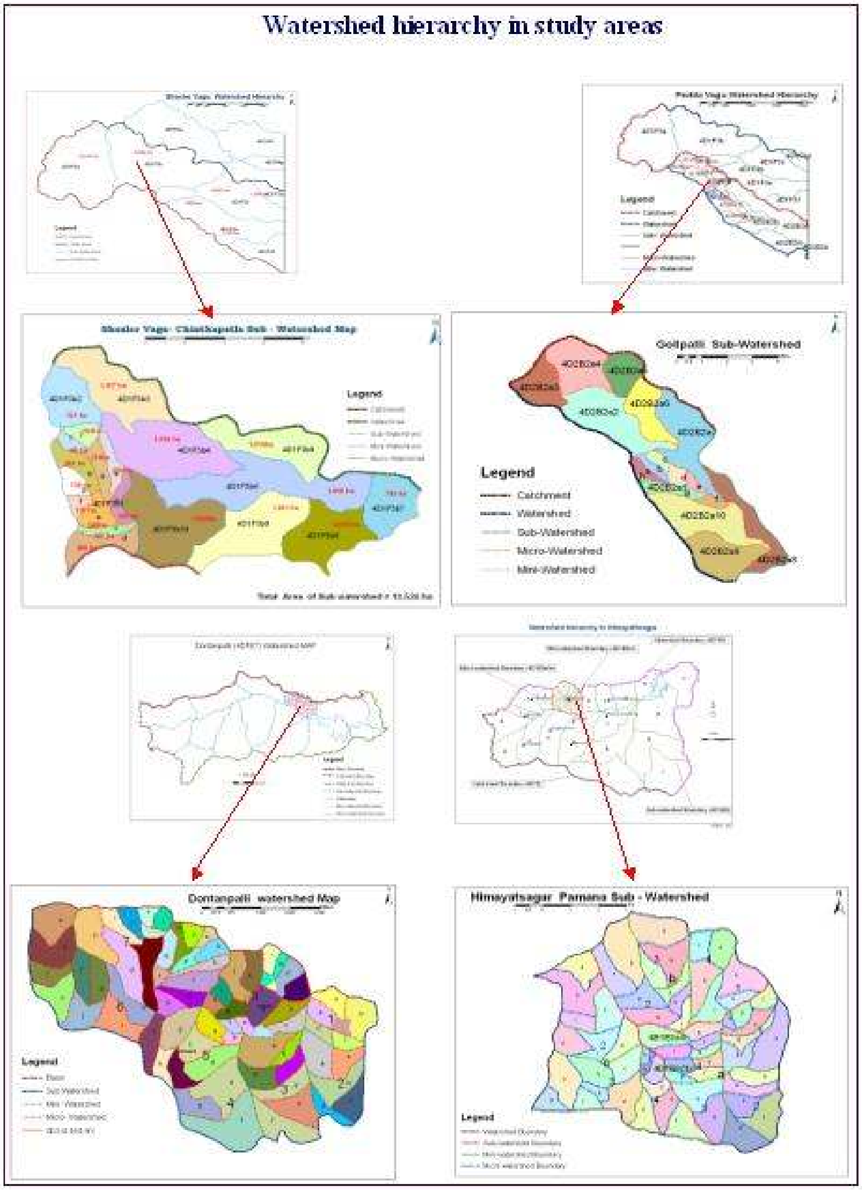

Figure 2: Delineating watershed boundaries using ArcGIS

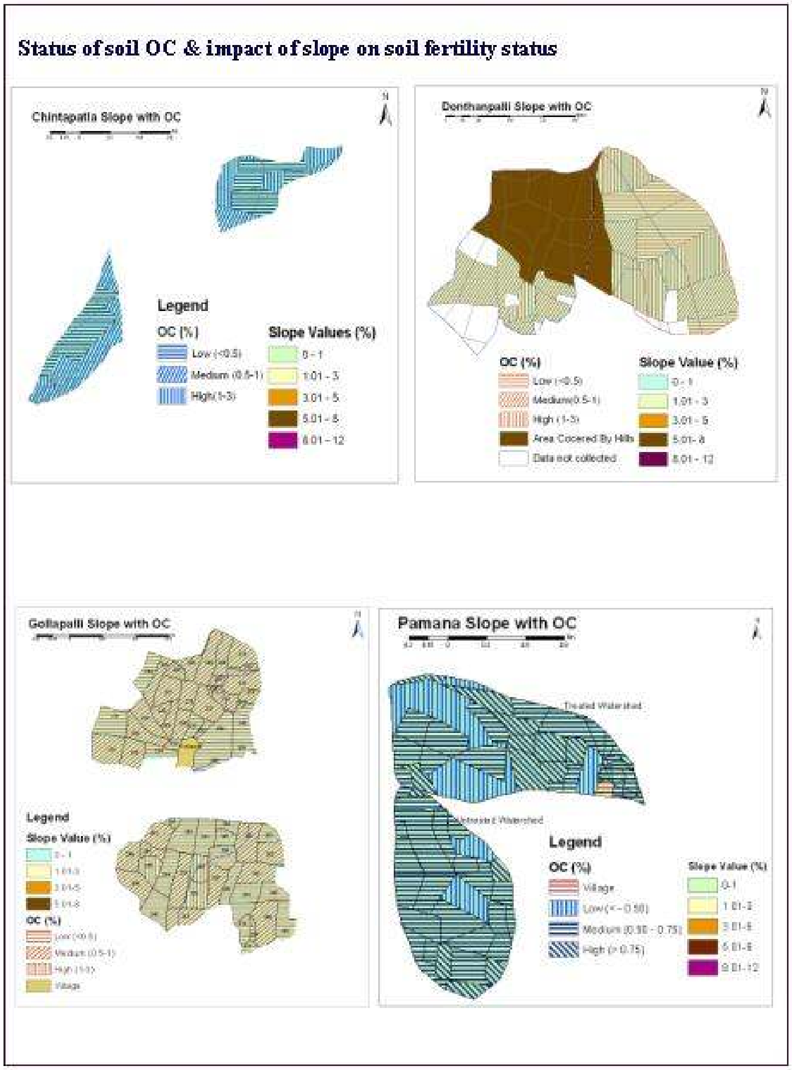

Figure 3: Map overlay to derive sustainability indicators of soil fertility and slope.

6.2 Use of Geographical Positioning System (GPS)

An important highlight of the study likes the geo-referencing of various aspects of land management practices (LMP), natural resources management (NRM) and agricultural production systems (APS). After post-processing of GPS control points collected in the field, the data were imported and overlaid on the ArcGIS coverage and satellite data of the study areas. Using GPS points obtained using a *Trimble GeoXT* DGPS unit, a Digital Terrain Model (DTM) were prepared for each of the micro-watersheds. GPS units were used to update field boundaries in the village cadastre, to site S&WC structures in the watershed maps and satellite imagery and for preparing soil characteristic maps for the study. An important aspect of use of the DGPS unit was its help in creation of a geo-referenced database that is absolutely critical for undertaking long-term sustainability studies in future.

6.3 Interpretation of satellite data

For evaluating sustainability of watershed projects it was essential to compare the situation prevalent prior to implementation of WDP with the post implementation scenario. For this purpose, satellite data were procured from NDC, NRSC located in Hyderabad. Digital satellite data of IRS – 1D LISS III were procured for the pre–project period study for generating baseline info. As WDP were initiated in 1999 and 2000 in the study period, satellite data of two seasons viz., pre- and post monsoon data for 1998 and 1999 were procured from NRSA and interpreted using ERDAS *Imagine* (ver. 9.0). Analysis was undertaken to understand change in land use and land cover, drainage network, spread in extent of water bodies, NDVI, degradation of land, soil erosion, etc. The satellite data were also used to update maps that which had been mapped in 1970-71. The new road network, rail alignment and river network had to be mapped using *Virtual GIS* – a module of ERDAS software and incorporated into ArcGIS for preparing the DTM and for surface analysis of study area. The sustainability indicators pertaining to slope, NDVI, deforestation, change in land use and land cover, crop diversity etc., could be obtained only from the satellite data. Periodic study of the situation in subsequent years was facilitated in a similar manner. Satellite data of IRS 1D were procured for the period 2000 to 2004. For 2005 and 2006 IRS P6 LISS III data were procured. To analyse change that had occurred in 2006, satellite data of IRS P6 LISS 4 - MX with 5 m resolution was procured and studied. To facilitate interpretation of satellite data handheld portable spectro-radiometer was used to collect spectral reflectance in fields. Use of remote sensing technique in the present study was found to be absolutely essential not only for increasing our understanding of various nuances of agriculture, but also to interlink the impact of various aspects of NRM on agriculture.

6.4 Studies on soil fertility status

Over 450 composite soils samples collected from the farmers' field in the ten micro-watersheds during 2005 and 2006 were analysed for 12 physico-chemical parameters. Soil samples were shade – dried, ground and sieved with 0.5 mm sieve and a sample of 50-100 gm was taken and stored for carrying out analysis for OC content. The rest of the soil was again sieved with a 2 mm sieve and a sample of 250 gm was drawn for undertaking the rest of analysis. Soil physico-chemical parameters analysed were pH, EC, CEC, Organic Carbon content, major nutrients - N, P, K, micro-nutrients - Cu, Fe, Mn and Zn. Biological properties analyzed were Microbial Biomass Carbon (MBC) and Dehydrogenase assay (DHA).

6.5 Creation of Database for field and watershed - related data

As mentioned earlier, the entire study helped to generate a large volume of data that was required to be archived in a format that would be readily usable at a subsequent period. As a result, a digital framework was developed and the data generated from each of the sub-program was stored utmost case has been taken to a relive the data which would be critical for developing applications at a later date.

The database consists of socio-economic, soils and land management related information that were used to prepare GIS coverage for socio-economic analysis and evaluation of LMP and WDP. The database is compatible with other national databases and could be easily shared and integrated.

7. Evaluation of agricultural sustainability in watershed projects

The methodology created facilitates evaluation of impact of WDP on state of agriculture, cropping pattern, soil fertility status, water availability, rural livelihood options and economic condition of farm households in treated micro-watersheds. The impact can be compared with the situation prevalent in an untreated micro-watersheds in the vicinity. It was assumed that such a comparison would help in a rational understanding of impact of improver practices as extraneous advantages or disadvantages of geographical, topographical or economical situations to both or/ either of the micro-watersheds could be nullified.

7.1. Thematic mapping, overlay & analysis – *application of GIS*:

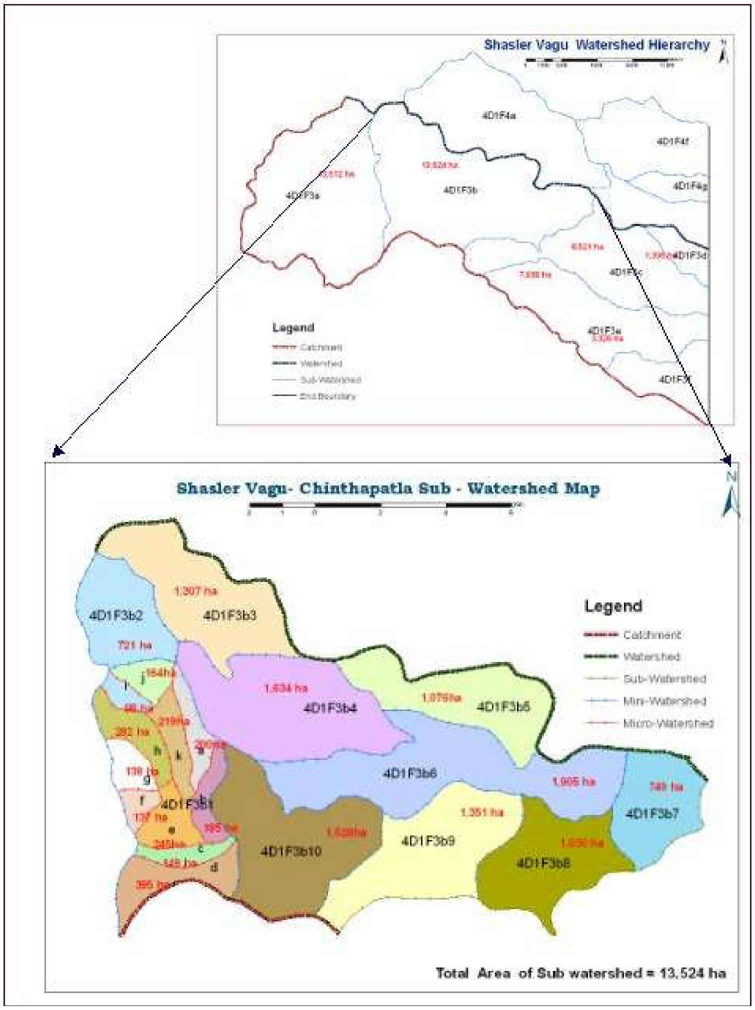

Figure 4: Regional watershed hierarchy of Chintapatla village.

7.2. Land use and cover change studies (LCCS)

The land cover change were identified and mapped for deriving baseline data for constructing the sustainability indicators (Fig. 5).

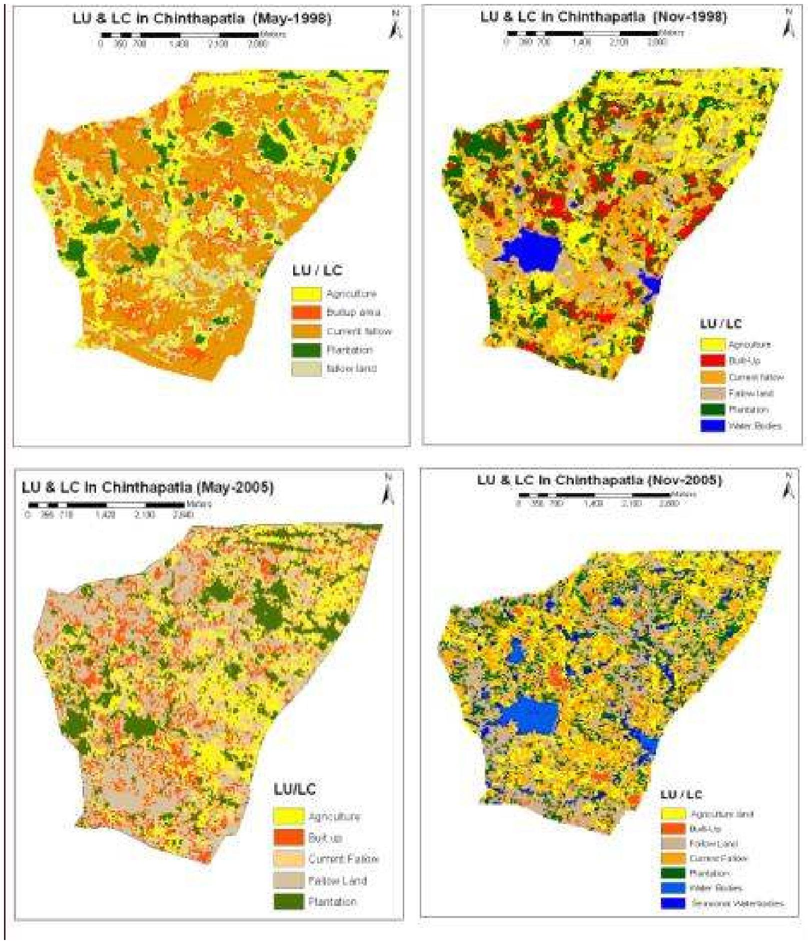

Fig. 5: Land utilization pattern in Chintapatla village in pre-and post monsoon periods prior to, and after implementation of WDP in the village.

8.0 Conclusion

In order to evaluate sustainability of WDP, it is essential to undertake a multidisciplinary approach using the tools indicated in this paper. Soil fertility status was evaluated in conjunction with socio-economic conditions prevalent in the selected watersheds. Application of GIS & RS were found to be useful to geo-reference sustainability indicators and in construction of baseline information for pre-WDP period so as to facilitate a comparison of the situation. Study of ten micro-watersheds in the five villages in AESR 7.2 undertaken during 2004-2008, indicates that rainfed agriculture on its own, has not been found to be very profitable which has lead to migration by rural population within the region to the urban areas. It was seen that most villages are predominantly peopled by marginal and small farmers and any rural development programs including WDP, must be fine–tuned for them, if sustainability has to be achieved.

References

Amita Shah, Devlal, R., Joshi, H., Desai, J., Shenoy, R., 2004. Benchmark Survey for Impact Assessment of Participatory Watershed Development Projects in India. Report submitted by GIDR, Ahmedabad to Planning Commission, Government of India, New Delhi, 117 pp.

Babu Ram and Dhyani B.L (2005) Impact Assessment of Watershed Technology in India Pp 176 to 186.

Hanumantha Rao, C.H., 2000. Watershed Development in India – Recent experience and emerging issues. Economic & Political Weekly, 32, 3943 – 3947.

Joshi, P.K., Jha,A.K., Wani, S.P., Laxmi Joshi and Shiyani R.L (2005) Meta -Analysis to Assess Impact of Watershed Program and Pepole's Participation Pp 1to 17.

Kausalya Ramachandran, Mishra, P.K. & Padmanabhan, M.V., 2001. Watershed Development Planning for Semi-arid Telengana Region in India using GIS. Indian J. Soil Cons. 1, 73-76.

Kerr, J., Sanghi, N.K. (1992): Indigenous Soil and Water Conservation in India's Semi-arid Tropics. Gatekeeper Series No. 34. Sustainable Agriculture & Rural Livelihood Program, IIED. 28 pp.

Omprakash, Reddy, Y.V.R., Shastry, G., 2004. Evaluation of Watersheds in India. International Book Distributors, Dehradun, India, 153 pp.

Parthasarathy, S., 2006. From Hariyali to Neeranchal, Report of the Technical Committee on Watershed Program in India, Submitted to Department of Land Resource, Ministry of Rural Development, Government of India, New Delhi. 222 pp.

Planning Commission, 2001. Report of the Working Group on Watershed Development, Rain-fed Farming and NRM for the X Five Year Plan. Government of India, New Delhi. 72 pp.

Planning Commission, 2005. Mid-term Appraisal of the 10 Five-year Plan (2002-2007), Government of India, New Delhi. pp. 187 – 236.

Ratna Reddy, V., Gopinath Reddy, M., Malla Reddy, Y.V., Sousson, J., 2004. Sustaining Rural Livelihood in Fragile Environments: Resource Endowments or Policy Interventions? Working Paper no.58, CESS, Begumpet, Hyderabad, India. 33 pp.

Singh, J.P (2000) Economic Evaluation of Manchal Watershed National Institute of Agriculture Extension Management Rajendranagar, Hyderabad – 30 Pp 1 to 99.

Sreedevi, T.K, Shiferaw, B and Wani, SP. (2004): Adarsha watershed in Kothapally: understanding the drivers of higher impact. Global Theme on Agroecosystem Report no. 10 Particulars 502 324, Andhra Pradesh India: International Crops Research Institute for the Semi-arid Tropics. 24 pp.

Samra J. S. (2005) Resource Conservation and Social Uplift net through participatory Watershed Management, *In*: (ed) Sharada V. N, Dadhwal K. S., Dhyani S. K., G.P. Jayal G. P., Dogra P., Rajendra A., & Khola O.P.S (2005) Resource Conserving technologies for social upliftment, IASWC, CSWCRTI, Dehradun – 248195, Uttaranchal.

Sharda V.N. (2005) Conservation Technologies for Sustainability, *In*: (ed) Sharada V. N, Dadhwal K. S., Dhyani S. K., G.P. Jayal G. P., Dogra P., Rajendra A., & Khola O.P.S (2005) Resource Conserving technologies for social upliftment, IASWC, CSWCRTI, Dehradun – 248195, Uttaranchal

Mandal D., Ratan Singh and Dadhwal K.S. (2005) Environmnetal Suitability Index for Mountainous Watershed: A Quantitative Approach, *In*: (ed Sharada V.N., et al (2005) Resource conservation technologies for social upliftment, IASWC, CSWCRTI, Dehradun – 248195, Uttaranchal.

Singh R.K., Prasad S.N., Ashok Kumar, Parandiyal A.K., Somasundaram J., and Sethy B.K. (2005) Impact Assessment Index: A Methodology Frame Work for Monitoring Success of Watershed projects, *In*: (ed) Sharada V.N., et al (2005) Resource conservation technologies for social upliftment, IASWC, CSWCRTI, Dehradun – 248195, Uttaranchal.