Measuring Agricultural Sustainability in Rainfed Regions in India – Spatial Evaluation of Watershed Projects

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Abstract: Watershed development project is a popular NRM and agriculture development strategy in rainfed agriculture. The program has attracted huge investments since its initiation in 1980s in the country. Till date several phases of watershed projects have been implemented under guidelines that have been modified at regular intervals to adapt to changing situations. However use of tools of Geomatics makes the task manageable and provides the facility to measure the immeasurable, namely sustainable development. This paper presents a methodology developed to measure sustainable agriculture in rainfed regions. The paper discusses how the methodology was used to monitor changes in treated watersheds in two districts – Nalgonda and Rangareddy in AP, India. Temporal study since 2006 helped in indicating which aspects of watershed development projects were critical and contributed to sustainability. This information could be vital for the PIA of the projects who can use the information for mid-term correction or for overhauling the whole projects based on actual requirements in the field. Study indicated that although full sustainability has not been achieved, watershed development program was found to be useful and had contributed positively to agricultural development in rainfed regions.

Assessment of sustainability of watershed projects using GIS and remote sensing tools was carried out in eight micro-watersheds in four villages in Rangareddy (RR) and Nalgonda districts since 2006. Area under four villages encompassing over 6000 ha of agricultural land located in various blocks in Nalgonda and Rangareddy in southern Telengana region encompassing AESR 7.2 were studied to measure agricultural sustainability. Over 450 farm households were surveyed annually using two structured questionnaire developed for monitoring and evaluation (M&E) of watershed projects at household and field/watershed levels. Fifty- one indicators were initially constructed with a score card and by 2009 it was possible to identify 13 critical indicators that were found to be critical for sustainable agriculture. Out of these, six indicators were found to contribute over 68% towards sustainable development in rainfed agriculture in AESR 7.2. During 2012 it was possible to segregate the monitoring indicators from the evaluation indicators. Each of the four villages selected for the study, could be divided into 7 to 19 micro-watersheds, out of which one treated and one untreated micro-watersheds covering an area of 100 - 150 ha each, were selected for the study. All watershed projects were implemented under DPAP and NWDPRA guidelines during 1998-2004. Since April, 2008 watershed development guidelines have been changed, however, the information generated from this study is valuable as it shows how tools of Geomatics can be used to carry out spatial evaluation of watershed projects and measure agricultural sustainability that is considered 'immeasurable'. This is indeed a notable progress and as Geomatics provides a valuable tool to measure 'sustainable development', progress can be ensured as it now becomes an entity that can be monitored and evaluated.

Based on temporal analysis of the watershed projects in Telengana region in AP, it was seen that the project had contributed positively albeit marginally to sustainable development. Twelve indicators were identified as critical for Monitoring and Evaluation (M&E) procedure. Two evaluation methods one empirical employing PCA analysis and traditional method and another using Geomatics - *Raster CalculatorTool* in *Spatial Analyst Module*ofArcGIS software, were developed. The results corroborated well with the field level study. A DSS for evaluation of watershed projects is being developed.

Introduction

Watershed development projects have been the basis of natural resource management and

Table 1. Study area

District	Name of Agency	Name of Watershed	Location (Toposheet no.)	Funding Agency
Rangareddy	DPAP, Govt. of AP	Dontanpalli, Shankarpalli Mandal	56 K / 3	MORD
Rangareddy	PROGRESS	Pamana, Chevella Mandal	56 K / 3	MORD
Rangareddy	DOA	Chintapatla, Yacharam Mandal, near Ibrahimpatnam	56 K / 12	MOA
Nalgonda	DPAP, Govt. of AP	Gollapalli, Chintapalli Mandal	56 L / 13	MORD

agricultural development in the rainfed regions in India. The program attracted huge investments since its initiation in 1980s and since 2008 a common set of guidelines were announced for implementation of the projects by various agencies in the country. Till date several phases of watershed projects have been implemented under a series of guidelines that have been modified at regular intervals to adapt to changing situations. Monitoring and evaluation of watershed projects have always been a challenge and under the ICAR National Fellow scheme awarded to the first author, tools of Geomatics were used to make this manageable. This paper presents a methodology developed to measure sustainable agriculture in rainfed regions. The paper discusses how the tools of Geomatics were used to monitor changes in eight treated and untreated watersheds in two districts – Nalgonda and Rangareddy in AP, India since 2006.

Area under four villages encompassing over 6000 ha of agricultural land located in various blocks in Nalgonda and Rangareddy in southern Telengana region encompassing AESR 7.2 were studied to measure agricultural sustainability (Table 1). Over 450 farm households were surveyed annually using two structured questionnaire developed for monitoring and evaluation (M&E) of watershed projects at household and field/watershed levels. Fifty-one indicators were initially constructed with a score card and by 2009 it was possible to identify 12 critical indicators that were found to be critical for sustainable agriculture. Out of these six indicators were found to contribute over 68% towards sustainable development in rainfed agriculture in AESR 7.2. During 2012 it was possible to segregate the monitoring indicators from the evaluation indicators.

Each of the four villages selected for the study, could be divided into 7 to 19 micro-watersheds, out of which one treated and one untreated micro-watersheds covering an area of 100 - 150 ha each, were selected for the study. All watershed projects were implemented under DPAP and NWDPRA guidelines during 1998-2004. Since April, 2008 watershed development guidelines have been changed, however, the information generated from this study is valuable as it shows how tools of Geomatics can be used to carry out spatial evaluation of watershed projects and measure agricultural sustainability that is considered ‘immeasurable’. This is indeed a notable progress and as Geomatics provides a valuable tool to measure ‘sustainable development’, progress can be ensured as it now becomes an entity that can be monitored and evaluated.

Based on temporal analysis of the watershed projects in Telengana region in AP, it was seen that the project had contributed positively albeit marginally to sustainable development. Twelve indicators were identified as critical for Monitoring and Evaluation (M&E) procedure. Two evaluation methods one empirical employing PCA analysis and traditional method and another using Geomatics - *Raster Calculator Tool* in *Spatial Analyst Module* of ArcGIS software, were developed. The results corroborated well with the field level study. A DSS for evaluation of watershed projects is being developed.

Materials and methods

To evaluate impact of watershed development program (WDP) and consequent changes in watersheds, a complete methodology was evolved. Evaluation procedure comprised of field work for soil sampling and conducting socio-economic survey, lab work including database creation, construction of relevant indicators, interpretation of satellite data and mapping, and finally analysis of impact of WDP and study of change in the watersheds. In this paper a brief description of the methodology is presented along with the spatial tool developed and used for the objective evaluation of watershed projects in

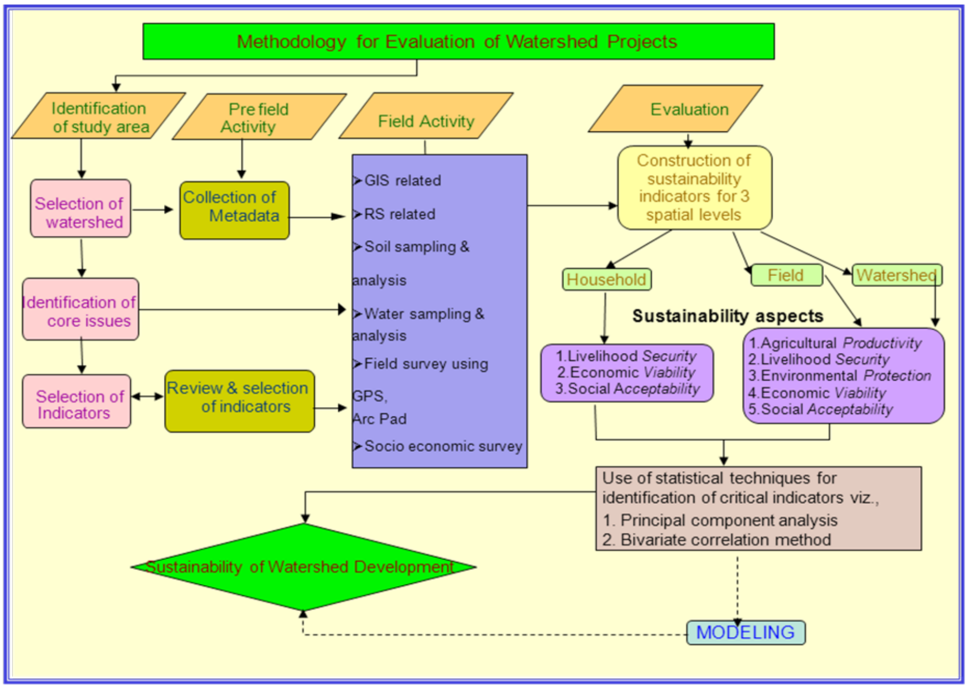


Fig. 1: Methodology for evaluation of watershed projects

the study area (Kaushalya et. al. 2009; 2010; 2011). The complete procedure developed and applied for this study is indicated in Fig. 1.

Using the methodology indicated in Figure 1 and use of statistical techniques like Principal Component Analysis (PCA) and Bi-Variate Correlation Technique (BVC) on the data collected annually, twelve critical monitoring indicators were identified. It also indicates that out of these, six indicators were found to be vital as they contributed over 68% of sustainability at three spatial levels – household, field and watershed levels. In the same process, 6 critical evaluation indicators were identified. These evaluation indicators are non-plastic or non-correlated and hence ideal for evaluation of watershed projects. Using these sets of indicators a spatial evaluation tool was developed using Spatial Analyst module of ArcGIS. The entire procedure of monitoring and evaluation (M&E) has been developed into a two-level procedure and the details are presented in this paper.

Monitoring & Evaluation (M&E) Procedure

The two-level procedure for M&E comprised of Level-1 where empirical method could be used and Level-2 where Geomatics based tool was to be used.

Level – 1: Empirical method for M&E

Level- 1 is based on empirical method for monitoring & evaluation of watershed projects. After identification of critical indicators as indicated in Table 2, a method was evolved to make quantitative indicators viz., 'crop production' and qualitative indicators like 'status of S&WC structures' comparable. This was essential to make the whole procedure objective, measurable and robust. This also makes it possible to compare the performance of indicators. For this a concept of Threshold Value (TV) was devised. It was assumed that the state of NRM and agriculture in a treated watershed would be better than elsewhere and hence TV would be higher in case of all farmers and land holdings in treated watersheds. TV was derived as 20% above the mean based on community performance, in case of any indicator (Gomez et al., 1996).

Where only qualitative data were to be considered for analysis, then maximum score was assigned to TV. Ratio for each indicator was calculated by dividing actual value by corresponding TV. For finding out sustainability, the value against each of the twelve indicators is averaged and a Composite Sustainability Index (CSI) is determined for each household/ field (land-holding) / watershed.

Table 2. Critical Indicators for monitoring sustainability of WDP

House-hold	Field-level	Watershed-level	Contribution of indicators *(weight in %)*		
			House-hold	Field-level	Watershed-level
Improving availability and encouraging cultivation of fodder			50	1.6	3.5
Improving nutritional security	Increasing total crop production		25	14.1	7.8
Reducing input cost	Increasing gross agricultural income		25	9.9	7.8
	Maintaining S & WC structures			19.7	17.9
	Large scale adoption of soil moisture conservation measures			15.5	17.9
	Encouraging farm OM recycling			5.5	13.4
	Improving gainful employment			9.9	3.5
	Practicing Crop Contingency Planning			4.5	8.6
	Improving security of tenure			1.6	7.8
	Increasing Crop Diversity (No. of crops/Cultivated area)			5.3	3.5
	Improving availability of water for irrigation			3.2	3.5
	Increased role of extension agents	Increase in cultivated area		9.4	4.9

Depending on the CSI value, sustainability for each field is determined as follows: CSI < 0.25 (Unsustainable); 0.25 – 0.5 (Poor); 0.5 – 0.75 (Moderately sustainable) and > 0.75 (Fairly sustainable).

Level – 2: Spatial analysis for M&E at watershed-level

Spatial analysis enables one to assess the impact of WDP on various bio-physical matrixes of agricultural systems at a watershed-level. While statistical technique like PCA and BVC could help in empirical analysis of WDP at household- and field- levels, the GIS facility enables overlaying of various thematic maps to understand the impact of WDP at watershed- level, considering it as one unique entity which would otherwise have not been possible. Thematic maps pertaining to various M&E indicators as described in the previous tables were drawn. The *Raster Calculator Tool* in *Spatial Analyst Module* of ArcGIS software, helped in overlaying the thematic maps both vector and raster images, assigning scores as per estimated Threshold Values (TV) derived from empirical methods. While some values could be derived directly viz., agricultural production or income, others had to be interpolated on a spatial basis viz., Soil OC and slope etc., that were derived and then used for thematic mapping and evaluation. The spatial tool treats the watershed as a unit area and not as an aggregate of various fields / land holdings or land parcels.

For raster based evaluation, each Survey No. / Land holding was considered to be a polygon and scores derived for an indicator was assigned one value for a polygon in each thematic layer pertaining to an identified sustainable indicator. In this manner thematic layers were created for twelve Monitoring Indicators as indicated in ***Table 2*** out of which six indicators were identified as critical evaluation indicators. For each indicator a raster layer was created from the vector polygon layer with corresponding attribute values by using conversion options in ArcGIS. Indicators were weighted using *Raster Calculator* in Geospatial Analyst Tool in ArcGIS. As mentioned earlier, the respective weight had been estimated statistically for each indicator through PCA. The weights for each critical indicator is listed against it and indicated in Table 2.

To assess agricultural sustainability achieved in individual farm holdings (Survey No.) within a watershed, the weighted thematic layers were summed and normalized with aggregate weight. Figure 2 indicates the working of Spatial Analysis Tool to evaluate sustainability at the watershed- level.

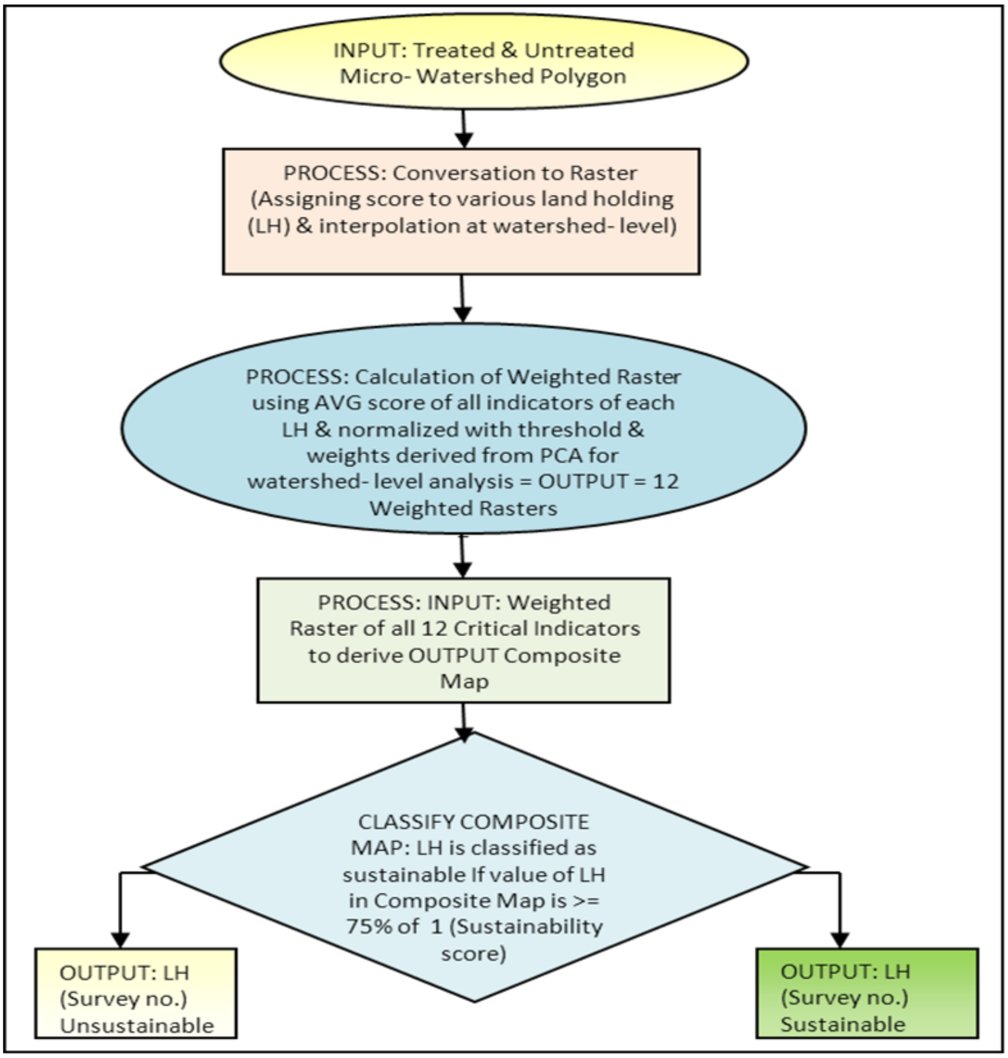


Figure 2: Scheme for spatial evaluation of sustainability at watershed-level

Results and discussion

Trend in change in treated micro-watershed

To analyse a change in treated micro-watershed (TMW), the change were identified after field survey and analysis of satellite data (Table 3). It may be seen that in case of one TMW in Chintapatla village, four indicators pertaining to *Environment Protection* were achieved, while in Pamana and Gollapalli the soil and water conservation (SWC) structures had not been looked after and hence declined. In case of Dontanpalli village, the WDP lost prominence as there had been massive land use land cover change (LULC) due to rapid pace of development in Hyderabad urban agglomeration. In case of *Economic Viability*, four indicators were evaluated. Analysis indicated that in case of Chintapatla and Gollapalli villages, a positive gain was achieved contrary to the treated watershed in Pamana. For *Agriculture Productivity*, four indicators were analyzed. Except for a decline in *availability of irrigation facility* in all three TMW, other aspects had been achieved. In case of *Livelihood Security* only one indicator - *gainful employment* - was found critical and study indicated that all TMW had gained positively as a result of WDP than in untreated micro-watershed (UTMW) in the respective villages.

Evaluation of WDP using empirical method (Level – 1)

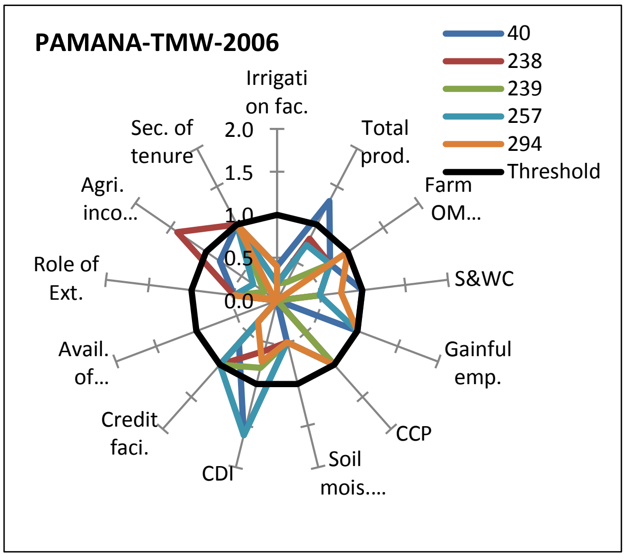
M&E of sampled watersheds in Rangareddy and Nalgonda districts was carried out during 2012 like in previous years. Household, Field survey and Focus Group Discussion (FGD) were held for e.g., in Pamana village

Table 3. Monitoring of WDP in study area using empirical method

Sustainable Aspect	M & E Indicators	Types of Watersheds							
		Chintapatla		Gollapalli		Pamana		Dontanpalli	
		TMW	UTMW	TMW	UTMW	TMW	UTMW	TMW	UTMW
Environ. Protect.	S& WC measures	1	0	0	0	0	1	1	1
	Soil moisture conservation	1	0	0	0	1	1	1	1
	Farm OM recycling	1	1	1	1	1	1	0	0
	Security of tenure	1	1	1	1	1	1	1	1
Economic Viability	Agriculture income	0	0	1	1	0	0	0	0
	availability of fodder	1	1	0	0	0	0	0	0
	Credit facility	1	1	1	1	1	1	1	1
	Crop Diversity Index	1	1	1	1	1	1	1	1
Agri. Prodvty	Contingency Crop Planning	1	1	1	1	1	1	1	1
	Agriculture production	1	0	1	1	1	1	0	0
	Role of extension agent	1	1	1	1	1	1	1	1
	Availability of irrigation facility	0	0	0	0	0	0	0	0
Livelihood Security	Gainful employment	1	1	1	1	1	1	1	1
Total		11	8	9	9	9	10	8	8

Note: score 1 = Increasing trend; 0 = Decreasing trend.

during post-*Kharif* season in November, 2012. Thirty-five households in TMW in Pamana who operated 65 land-holdings, and were surveyed and their fields and agricultural activities, evaluated. In UTMW taken as control within the same village, 17 households with 22 land parcels were also evaluated. The 12 critical monitoring indicators and one unique evaluation indicator as indicated in were used to monitor and evaluate the watersheds. Sustainability Index was derived from the Mean Value of 13 indicators for each sample farm / land-holding. It was seen that Survey No. 242 in TMW and 220 in UTMW were found to be fairly sustainable although they did not score '1'. Cob-web diagram was used to indicate the comparative performance of various indicators in both types of watersheds. Three indicators that imparted a fair amount of sustainability to agriculture in the TMW were increase in



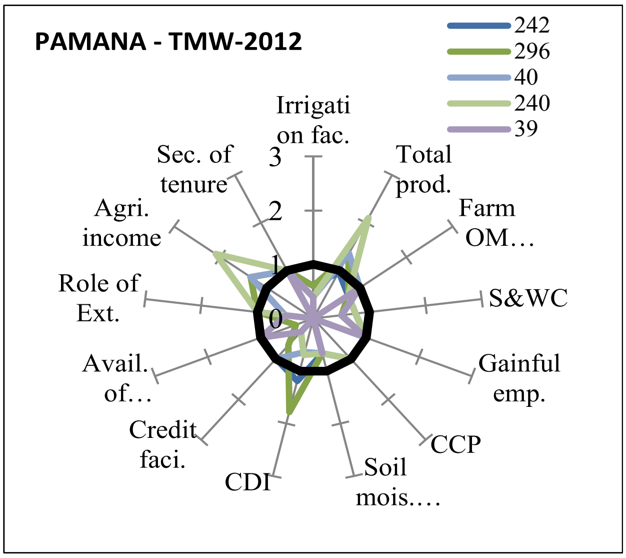


Fig. 3: Cob-web diagrams to indicate relative gain in sustainability in Pamana treated watershed through the years

agriculture production, agriculture income and Crop Diversity Index (No. of crops / unit area). However in UTMW, CDI was seen to be poor (Figure 3).

Evaluation of WDP in Pamana, indicates that no farmer attained complete sustainability. Figure 3 indicate the comparative situation in treated and untreated MW. The axis emanating from the central hub denotes the various critical indicators used for the evaluation. The thick grid line denotes the Threshold Value. The other lines indicate the gains made by leading farmers in respective watersheds.

Similar analysis was undertaken in case of other villages also. In Chintapatla watersheds, survey of 30 households operating on 65 farm holdings in TMW and 23 households with 16 farm holdings in UTMW was surveyed during October 2012. Two holdings in UTMW were found to be sustainable and while one Survey No. in TMW was found to be fairly sustainable. Like Pamana, WDP in Chintapatla has also lent sustainability through gains in *Agriculture production, Agriculture income* and the Crop Diversity Index (*CDI).*

A similar exercise was undertaken in case of Gollapalli watersheds. Survey of 28 households with 38 farm holdings in TMW and 29 households with 38 farm holdings in UTMW was carried out during September 2012. Two holdings in both - TMW and UTMW were found to be fairly sustainable. However, situation in UTMW was better. *Agriculture production, Agriculture income* and *CDI* have imparted fare degree of sustainability as in other watersheds.

Trend in sustainability achieved through WDP during current decade

In Pamana TMW, Survey No. 296 was found to be sustainable. In UTMW land holding (Survey no.) 227 was assessed to be sustainable. A brief description of the farming activity of each of these farmers is given below to show how they had achieved agricultural sustainability. One farmer named *Sakali Vittalaiah* who owned 2.5 ha in Survey no. 296 also owned a bore-well and cultivated cotton and carrot. From cotton he achieved a harvest of 20q/ ha and got an income of Rs. 68750/ha. Previously he used to cultivate vegetables, maize and paddy and was able to grow only 32q/ha and but earned Rs.74375/ha. This decline in income was seen due to avoiding paddy cultivation owing to fall in ground -water table. It was seen that the farmer practiced compartmental and contour bunding and incorporated FYM in soils and followed fertilizer recommendation. He had a bore- well in his field and had adopted S& WC measures, practices soil moisture conservation techniques besides soil amendments like FYM, vermin- compost and undertakes summer ploughing. The temporal trend in impact of WDP in Pamana has also been indicated in Figure 4**.**

Evaluation of WDP in Pamana

Evaluation of impact of WDP indicated that net area under sustainable agriculture increased marginally from 53.63 ha accounting for 40% area in TMW in 2006 to 57.0 ha (43%) during 2012. In case of UTMW the gain was also impressive. Extent of sustainable agriculture increased from Nil in 2006 to over 16.23 ha (16%) by 2012. In Pamana village, WDP was impressive till 2008; however since then there has been a decline in agricultural activity due to major changes in LULC in that region due to growth of Hyderabad metropolitan region.

As mentioned earlier, the spatial evaluation method treats the watershed as a unit area and not as an aggregation of different field holdings or land parcels. Under spatial evaluation the weighted thematic layers were summed and normalized with aggregate weight according to procedure developed under the NF scheme. According to spatial analysis, the evaluation results were comparable. Thus it may be appropriate to state that both methods – Empirical and Spatial as illustrated in this paper are robust for use in M&E of WDP. While Level -1 can be used by PIA who doesn't have GIS facility, the level-2 provides a powerful tool to evaluate WDP projects and its impact on sustainable development like never before. Evaluation of NRM projects like WDP stand to gain by the application of tools of Geomatics as discussed in this paper

Conclusion

Based on temporal analysis of WDP in the four villages in Nalgonda and Rangareddy districts, it may be stated that WDP in Chintapatla had achieved more than the other two watersheds namely, Gollapalli and Pamana.

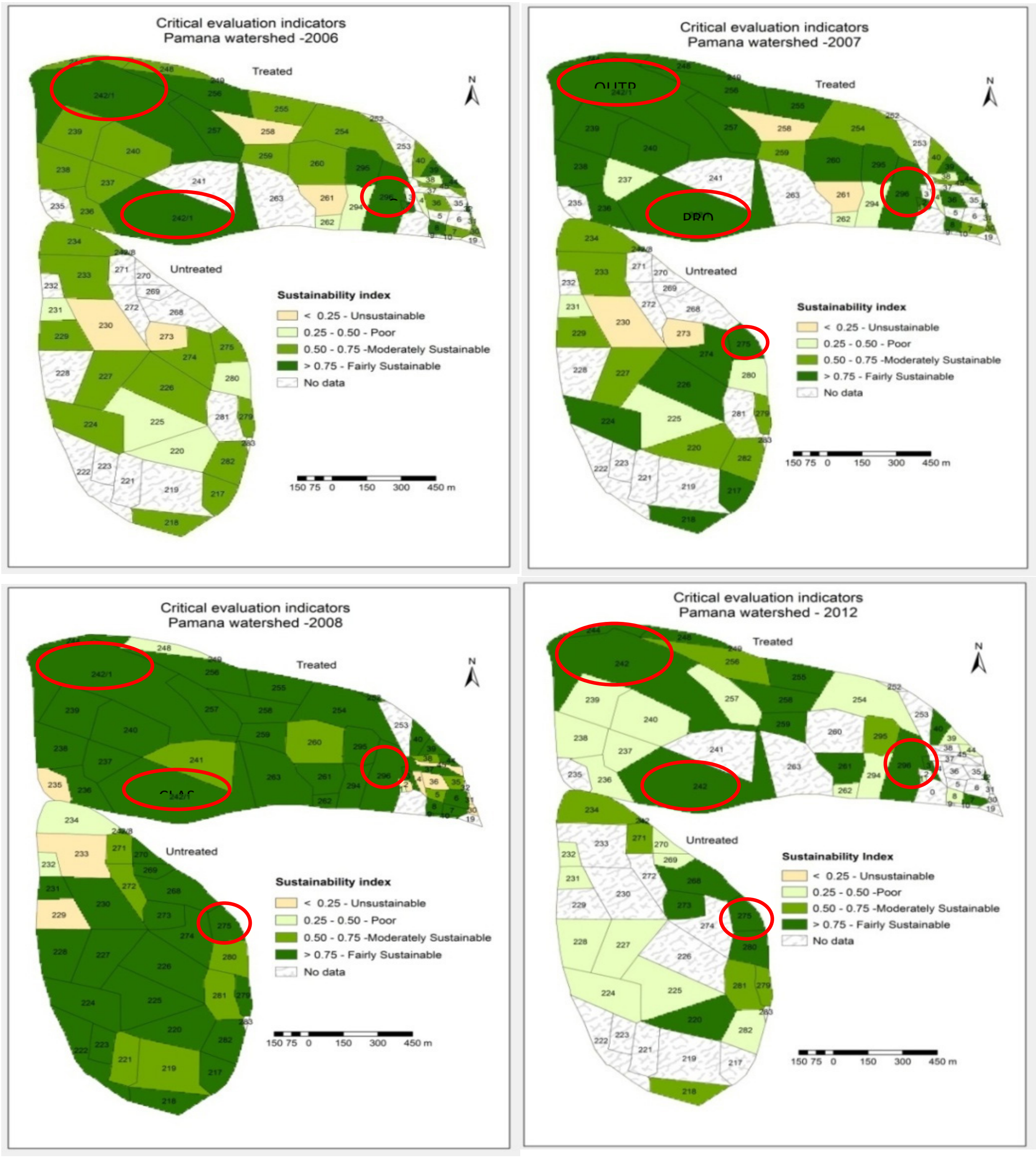


Figure 4: Evaluation of sustainability of Pamana watersheds

In Pamana, situation in UTMW seemed better due to gains from proximity to TMW and also to the market. Twelve Monitoring Indicators including four Evaluation Indicators and one unique evaluation indicator namely *Credit Facility* were used to monitor and evaluate eight sample watershed projects in Rangareddy and Nalgonda districts in AP that were being assessed since 2006 onwards. The results of M &E based on Empirical method have been described here. For spatial evaluation of sustainability a *Raster Calculator Tool* in *Spatial Analyst Module* of ArcGIS software was used to perform M&E of the watershed projects.

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Empirical and Spatial as illustrated in this paper are robust for use in M&E of WDP. While Level -1 can be used by PIA who doesn't have GIS facility, the level-2 provides a powerful tool to evaluate WDP projects and its impact on sustainable development like never before. Evaluation of NRM projects like WDP stand to gain by the application of tools of Geomatics as discussed in this paper.

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