RESEARCH ARTICLE

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Benchmarking the Impact of Micro Watersheds of Sabarkantha and Aravalli Districts of Gujarat, India

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ABSTRACT

Background: An integrated watershed management approach adopted in the recent decade caters to the management of natural resources and the overall economic improvement of the region. Watershed projects need to be evaluated after implementation to know the effectiveness of programmes on rural economic enhancement of beneficiaries.

Methods: The present study describes the identification of impact indicators that play the important role in the measurement of watershed performance. The impact of micro watersheds was calculated on hydrological, agricultural, social and economic parameters in study area. To examine this impact, the WPBI (Watershed Performance Benchmarking Index) was designed from the evaluation of 10 impact indicators for these parameters based on Analytic Hierarchy Process (AHP). The calculated WPBI was then applied with multiple linear regression to find the relationship coefficients for estimating the regression WPBI. Comparing both WPBI values, the difference in WPBI was calculated for validation of regression model.

Result: The results of the analysis indicate that the changing of impact values of these 10 indicators has a significant impact on WPBI. Based on the impact indicators and WPBI, the watershed projects were benchmarked to compare the effectiveness of implementation of watershed projects under different watershed schemes.

Key words: Analytic Hierarchy Process (AHP), Watershed performance benchmarking index (WPBI), Watershed benchmarking, Watershed impact assessment, Watershed evaluation.

INTRODUCTION

Participatory watershed development has proven to be an attractive approach to rural development in recent decades. Projects and programs have been implemented across Latin America, Africa and South Asia, but perhaps it is India where the approach is most popular and sustainable (Rajora, 2002). The development of watersheds in India has a long history that started immediately after the planning stage. Several projects are under implementation and several are completed in Gujarat's Sabarkantha and Aravalli districts. To evaluate the effectiveness of these projects on different parameters, the changes in hydrological, agricultural, economic and social parameters before and after implementing watershed projects were studied in this research work. Various indicators to measure the changes in different parameters include the reduction in soil erosion, increase in ground water table, agriculture productivity, economic and other social indicators. (Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, 1997) provided various empirical equations for estimating the factors for calculation of soil erosion by RUSLE. (Ziller and Phibbs, 2003) integrated social impact into cost-benefit analysis followed by a participatory method. (Rama Chandrudu, 2006) studied various impact and process indicators of impact assessment in this study. (Wani *et al*., 2011) also studied different performance indicators based on performance criteria and the measures for indicators. Many other researchers *i.e.*, (V R Reddy, 2000), (Thomas *et al*., 2009), (Mazumdar, 2004), (V. Ratna Reddy *et al*., 2012), (Dev *et al*., 2017) have worked on impact of watershed development program after implementation and have given replicable models for other areas to make natural resources management practices sustainable.

This study also concentrated on the impact of watershed projects on the participation of people through local institutions in watershed management and their resultant impact on the region's society, economy and environment.

This research focuses on the overall impact of watershed management in the development of Sabarkantha and Aravalli districts based on micro watershed projects under IWDP, DPAP and IWMP watershed schemes. It also highlights the issues relating to their management and implementation, including community participation in managing the natural resources of the watersheds.

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Materials and Methods

Study area

The study was conducted in micro watershed development projects of Sabarkantha and Aravalli districts of Gujarat, India as shown in Fig 1. Latitudinal and longitudinal extent of the basin are between 23.5138°N and 72.7361°E. respectively. The maximum temperature of the study area ranges between 40°C to 42°C and minimum temperature ranges between 9°C to 11°C and the mean relative humidity was approximately 49.6 percent. The average rainfall of study area was 731 mm. This region is an extension of the Aravalli Hills, with a mix of dry deciduous, Procopius and thorny scrub arid forest. The major land use/land cover scenario of the study area include cultivated land, shrub land, forest land, grass land and water bodies. Cultivated land is situated on the steep and undulating slope and mostly, there are conservation measures implemented in different schemes. Sand, loamy and medium black are the three main types of soil found in almost entire districts.

Study method

A set of indicator questions for questionnaire survey, was developed to collect the ground-level agricultural and socio-economic data to evaluate the effects of watershed project implementation. Revised Universal Soil Loss Equation (RUSLE) carried out the soil erosion estimation and change in groundwater was estimated by well inventory and water table fluctuation method. All evaluated indicator values were used to develop the watershed performance benchmarking index (WPBI) for ranking and indexing watershed projects implemented in the study area through the concept of AHP.

Methodology

There were around 180 watershed projects implemented in these districts under IWDP, DPAP and IWMP. Amongst them, 19 watershed projects were selected for study by random sampling covering all three schemes. The hydrological, agricultural, social and economic parameters were considered to evaluate watershed projects in the study area. The parameters before and after watershed implementation were calculated to observe the changes after implementation. In this study, the selected indicators for these parameters have been denoted as per following: (i) Reduction in soil erosion-RSE, (ii) Increase in groundwater table-IGWT, (iii) Change in crop productivity-CCP, (iv) Change in cropping intensity-CCI, (v) Increase in livestock-ILS, (vi) Increase in employment-IEM, (vii) Increase in saving and expenditure capacity-IEX, (viii) Reduction in migration-RMI, (ix) Increase in income-IIN and (x) Benefit-cost ratio-BCR.

The measurement and calculation of the reduction in soil erosion were carried out through the Revised Universal Soil Loss Equation (RUSLE). The measurement and calculation of the increase in groundwater table were carried out by the water table fluctuation method through the well inventory. The agricultural and socio-economic indicators were calculated by the questionnaire survey, joint field visits of the watershed area and beneficiaries and focused group discussions with village communities. The initial data related to the study area's physical environment and the socio-economic condition is collected from the watershed from July 2000 to June 2018 from the project implementing agency and DRDA, Sabarkantha. Data related to the climatic conditions like rainfall, temperature, humidity, etc. total area, population, soil data and status of the local community were collected from the respective government departments and various agencies.

The Analytic Hierarchy Process (AHP) is a method for organizing and analyzing complex decisions using mathematics and psychology. It was developed by (Saaty, 1987) and has been refined ever since. AHP tool was used to obtain different criteria weights for each indicator and Watershed Performance Benchmarking Index (WPBI) was then calculated based on the criteria weights. The equation developed for WPBI was then validated by statistical analysis and regression to check the significance of the regression model. Finally, the WPBI was calculated based on regression coefficients. Based on the values obtained for each indicator and WPBI, the watershed projects were compared and identified the issues and challenges in implementing watershed projects. The resources of Government Engineering Colleges of Modasa and Godhra affiliated with Gujarat Technological University, Ahmedabad, Gujarat have been utilized for some practical and procedural activities during the study during the years 2015 to 2022.

Results and Discussion

Results of the watershed impact parameter for IWDP, DPAP and IWMP projects

The percentage changes in a watershed impact indicator RSE were calculated by RUSLE, IGWT by water table fluctuation and well inventory and other socio-economic indicators were calculated from the data obtained through questionnaire survey of households for selected watershed projects after implementation of the watershed programs as per Table 1.

Calculation of WPBI based on criterial weights by AHP:

Watershed performance benchmarking index (WPBI) is designed based on the linear relationship between the impact indicators calculated for selected watershed projects as per following equation.

$$Y= \beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6+\beta_7X_7+\beta_8X_8+\beta_9X_9+\beta_{10}X_{10} \quad .....(1)$$

Where,

Y= WPBI,

X_1= (RSE) Reduction in soil erosion.

X_2= (IGWT) Increase in ground water table.

X_3= (CCP) Change in crop productivity.

X_4= (CCI) Change in cropping intensity.

X_5= (ILS) Increase in Livestock.

X_6= (BCR) BC ratio.

X_7= (IIN) Increase in income.

X_8= (IEM) Increase in employment.

X_9= (IEX) Increase in saving and expenditure capacity.

X_{10}= (RMI) Reduction in migration, b_1 to b_{10} Co-efficients.

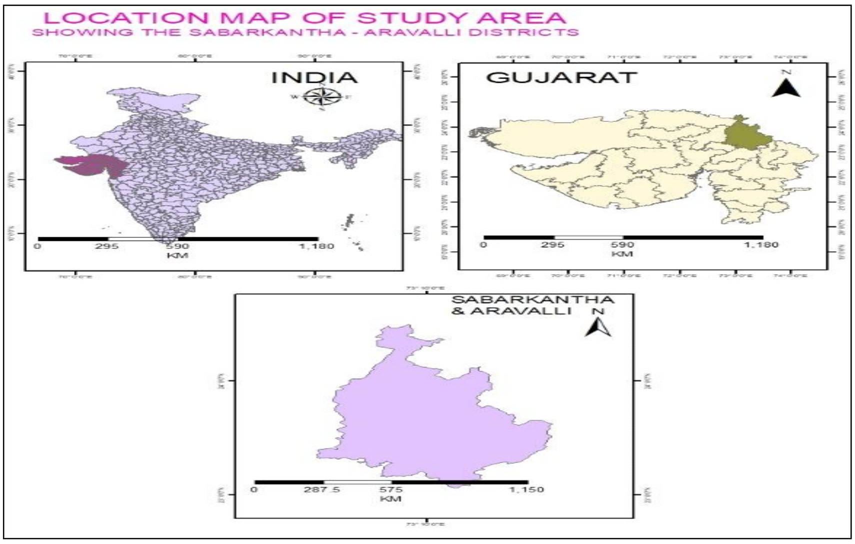

Fig 1: Map showing Study area (Sabarkantha and Aravalli Districts of Gujarat, India).

Table 1: Watershed impact parameter values for IWDP, DPAP and IWMP projects.

Name of scheme	Name of project	RSE	IGWT	CCP	CCI	ILS	BCR	IIN	IEM	IEX	RMI
IWDP	Rellavada	60.78	13.48	115.28	3.02	133.33	9.03	283.74	11.22	63.33	70.00
	Kadvadi	27.01	2.55	141.87	2.76	40.00	8.82	214.38	14.29	26.67	78.95
	Valuna	30.33	29.44	128.06	41.76	150.00	5.11	328.35	39.80	88.33	81.25
	Modarsumba	111.01	23.20	132.53	17.76	127.78	5.72	297.25	44.90	96.67	78.26
	Shika Kampa	26.20	17.16	128.72	1.42	136.84	8.32	262.67	42.86	88.33	92.31
	Dahegamda	53.22	12.78	155.39	20.62	110.00	6.04	315.59	14.29	55.00	75.00
	Unchi Dhanal	26.68	14.04	136.82	3.44	150.00	9.21	365.29	18.37	68.00	70.59
	Limda	96.93	17.30	145.98	3.30	64.29	4.54	224.46	20.41	81.67	73.33
	Dhansor	77.58	19.57	136.88	12.00	81.25	5.73	268.13	13.27	98.33	71.43
	Sunsar	44.77	22.95	150.20	2.62	110.00	6.08	322.65	19.39	83.33	71.43
	Raheda	55.86	29.01	148.52	1.26	154.55	5.98	365.56	18.37	75.00	75.00
	Ravol	91.47	20.53	141.15	0.18	85.71	2.41	244.95	17.35	73.67	76.47
	Dotad	93.92	25.71	144.16	3.08	127.27	6.75	320.85	20.41	100.33	75.00
	Finchod	91.87	17.94	141.16	2.48	111.11	6.70	321.86	19.39	73.33	60.00
DPAP	Molli	86.84	8.70	139.68	9.83	54.55	3.46	241.32	9.18	42.00	52.94
	Parsoda	92.15	10.39	136.76	2.56	81.82	4.17	256.64	8.16	52.67	78.57
	Vankaneda	76.98	19.31	145.45	4.93	61.54	6.10	224.33	12.24	57.00	58.33
IWMP	Ajwas	58.64	28.00	134.61	10.84	95.35	5.61	268.42	35.71	98.33	78.00
	Dhemada	80.56	18.38	120.02	3.10	116.46	5.48	291.21	40.82	109.67	80.68

Table 2: Normalized pairwise matrix with criteria weights.

	RSE	IGWT	CCP	CCI	ILS	BCR	IIN	IEM	IEX	RMI	Criteria weights
RSE	0.3295	0.4363	0.3939	0.2903	0.2813	0.3333	0.1933	0.2174	0.1648	0.1860	0.2826
IGWT	0.1098	0.1454	0.1313	0.2903	0.1406	0.2000	0.1160	0.1553	0.1648	0.1628	0.1616
CCP	0.1098	0.1454	0.1313	0.0968	0.1406	0.2000	0.1546	0.1242	0.1319	0.1163	0.1351
CCI	0.1098	0.0485	0.1313	0.0968	0.0938	0.1333	0.1160	0.0932	0.0989	0.0698	0.0991
ILS	0.0549	0.0485	0.0438	0.0484	0.0469	0.0222	0.0387	0.0311	0.0989	0.0233	0.0457
BCR	0.0659	0.0485	0.0438	0.0484	0.1406	0.0667	0.3093	0.2174	0.1648	0.1163	0.1222
IIN	0.0659	0.0485	0.0328	0.0323	0.0469	0.0083	0.0387	0.0932	0.0989	0.1163	0.0582
IEM	0.0471	0.0291	0.0328	0.0323	0.0469	0.0095	0.0129	0.0311	0.0330	0.1163	0.0391
IEX	0.0659	0.0291	0.0328	0.0323	0.0156	0.0133	0.0129	0.0311	0.0330	0.0698	0.0336
RMI	0.0412	0.0208	0.0263	0.0323	0.0469	0.0133	0.0077	0.0062	0.0110	0.0233	0.0229
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The pairwise matrix for importance or ranking of impact indicators as required in AHP was prepared based on the questionnaire survey and focused group discussion with the beneficiaries and also with experts working in the field of watershed development and management. The pairwise matrix for importance of impact indicators represents the importance of indicator over others as per the intensity of importance given by Saaty. The normalized pairwise matrix is prepared by dividing the matrix value by the sum of all values and the average value of the normalized pairwise matrix values ~~is~~are taken as the criteria weight. Normalized pairwise matrix with criteria weights is given in Table 2.

The criteria weights obtained by AHP tool were assigned to respective indicators to determine WPBI. The values of WPBI obtained are as per Table 3. The WPBI values for each project are shown in Table 4 along with the indicators having lower values and the corresponding status of implementation.

Statistical analysis and regression for WPBI

The regression analysis was carried out to develop the relationship of WPBI with the impact indicators by fitting a

Table 3: Values of WPBI for watershed projects.

Watershed Project	WPBI	Watershed Project	WPBI
Rellavada	6.6	Sunsar	6.68
Kadvadi	4.45	Raheda	7.19
Valuna	7.43	Ravol	7.06
Modarsumba	8.49	Dotad	8.27
Shika Kampa	5.98	Finchod	7.58
Dahegamda	6.67	Molli	6.04
Unchi Dhanal	5.99	Parsoda	6.68
Limda	7.11	Vankaneda	6.73
Dhansor	7.09	Ajwas	7.12
		Dhemada	7.48

Table 4: Relative Importance of WPBI with Impact Indicators.

Watershed	WPBI	Indicators having lower values	Status after implementation
Rellavada	6.6	CCI and IEX	Change in cropping intensity and increase in the capacity of saving and expenditure is not achieved well
Kadvadi	4.45	RSE, IGWT, CCI,	Reduction in soil erosion, increase in the ground water table, change in cropping intensity, increase in livestock,
		ILS, IEM and IEX	Increase in employment and increase in the capacity of saving and expenditure is not achieved well
Valuna	7.43	RSE and BCR	Reduction in soil erosion and the benefit-cost ratio is not achieved well
Modarsumba	8.49	CCI and BCR	change in cropping intensity and the benefit-cost ratio is not achieved well
Shika Kampa	5.98	RSE and CCI	Reduction in soil erosion and change in cropping intensity is not achieved well
Dahegamda	6.67	IGWT, CCI and IEM	Increase in the ground water table, change in cropping intensity and increase employment are not achieved well
Unchi Dhanal	5.99	RSE, IGWT, CCI and IEM	Reduction in soil erosion, increase in the ground water table, change in cropping intensity and increase in employment are not achieved well
Limda	7.11	CCI, ILS, BCR and IEM	Change in cropping intensity, increase in livestock, increase in employment and the benefit-cost ratio is not achieved well
Dhansor	7.09	CCI and IEM	Change in cropping intensity and increase in employment is not achieved well
Sunsar	6.68	RSE, CCI and IEM	Reduction in soil erosion, change in cropping intensity and increase in employment are not achieved well
Raheda	7.19	CCI and IEM	Change in cropping intensity and increase in employment is not achieved well
Ravol	7.06	CCI, BCR and IEM	Reduction in soil erosion, increase in the ground water table, change in cropping intensity, increase in livestock, increase in employment and increase in the capacity of saving and expenditure is not achieved well
Dotad	8.27	CCI and IEM	Change in cropping intensity and increase in employment is not achieved well
Finchod	7.58	CCI and IEM	Change in cropping intensity and increase in employment is not achieved well
Molli	6.04	IGWT, CCI, ILS,	Reduction in soil erosion, increase in ground water table, change in cropping intensity, increase in livestock, increase BCR, IEM and IEX in employment and increase in the capacity of saving and expenditure is not achieved well
Parsoda	6.68	IGWT, CCI, BCR	Increase in ground water table, change in cropping intensity, benefit cost ratio and IEM and increase in employment is not achieved well
Vankaneda	6.73	CCI, ILS and IEM	Change in cropping intensity, increase in livestock and increase in employment is not achieved well
Ajwas	7.12	CCI	Change in cropping intensity is not achieved well
Dhemada	7.48	CCI	Change in cropping intensity is not achieved well

Table 5: Model summary.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.993[a]	0.987	0.97	0.1549

a. Predictors: (Constant), RMI, IIN, CCI, CCP, RSE, IGWT, BCR, IEM, IEX, ILS.

Table 6: Annova.

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	14.205	10	1.4205	59.179	0.000[b]
	Residual	0.192	8	0.024		
	Total	14.397	18			

a. Dependent Variable: WPBI.

b. Predictors: (Constant), RMI, IIN, CCI, CCP, RSE, IGWT, BCR, IEM, IEX, ILS.

Table 7: Coefficients for indicator variables.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.3306	0.8967		1.4839	0.1761
	RSE	0.0255	0.0022	0.7772	11.4258	0.0000
	IGWT	0.0408	0.0118	0.3258	3.4526	0.0087
	CCP	0.0045	0.0062	0.0507	0.7228	0.4904
	CCI	0.0199	0.0046	0.2232	4.2903	0.0027
	ILS	0.0054	0.0041	0.2092	1.3152	0.2249
	BCR	0.0650	0.0325	0.1326	2.0012	0.0804
	IIN	0.0018	0.0026	0.0898	0.6652	0.5246
	IEM	-0.0015	0.0056	-0.0205	-0.2687	0.7950
	IEX	0.0077	0.0041	0.1898	1.9037	0.0934
	RMI	0.0039	0.0070	0.0386	0.5489	0.5981

a. Dependent variable: WPBI.

linear WPBI function with WPBI as the dependent variable and all other indicators as independent variables. The function applied to a watershed development project is to examine the factors influencing the WPBI of the respondent model is given below as per equation.

$$Y= \alpha+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6+\beta_7X_7+\beta_8X_8+\beta_9X_9+\beta_{10}X_{10} \quad ....(2)$$

Where,

Y= WPBI, (a-Constant (Intercept).

X1 to X10= Impact indicators as per equation (1), b_1 to b_{10}- Co-efficients.

As shown in Table 5, the coefficient of multiple determination (R^2) is significant with a value of 0.986, indicating the variables included in the WPBI function that explain 98.6 percent of the variation in the WPBI of the watershed in the sample. As shown in Table 6, the F-value of regression is 59.179 and significant value is nearer to 0 (zero) which indicates the regression model to be significant. As per Table 7, the intercept is positive and significant. The standardized beta co-efficient of RSE of the project is positive and statistically significant with a value of 0.777. Similarly, the standardized beta coefficients of all other indicators are statistically significant.

Based on regression, the following relationship is derived.

WPBI = 1.33060+0.02553 (RSE)+0.04080 (IGWT)+0.00450 (CCP)+0.01989 (CCI)+0.00542 (ILS)+0.06495 (BCR)+0.00175 (IIN)-0.00151 (IEM)+0.00772 (IEX)+0.00386 (RMI).

CONCLUSION

It is concluded that the overall watershed management practices in the study area have positive and effective changes in various parameters *i.e.*, agricultural crop production, crop productivity, reduction in soil erosion, land use, water resources, migration and capacity for saving and expenditure and livestock. The results of the study suggested that suitable steps needed to be taken for rational use of cultivated land, wasteland, forests and other common property resources by the farmers especially where the values of WPBI have very low score. An appreciable change in the land use pattern of the watershed area was recorded due to conservation soil and ground water. Improvement in socio-economic conditions and social and institutional participation was not much effective in watersheds having low score values of IEM, IEX and RMI. The majority of soil and moisture conservation works are in fairly good condition.

However, there is no provision for maintenance for these works in project guidelines. Opportunities for wage and self-employment considerably increased reducing the migration ratio of people and duration.

Conflict of interest: None.

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