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Assessment of Hydrological Parameters for Efficient Management of Watersheds in Karnataka

C. Kumar, H. G. Shivananda Murthy, U. Sathishkumar, M. S. Shirahatti,
H. G. Ashoka and Basavaraj Bogi

Watershed Development Department, Government of Karnataka, Cauvery Bhavan, Bangaluru-560 009

Abstract

Integrated watershed management programme (IWMP) is one of the premier programme executing by Government of India (GOI) in all the states from last decade to mitigate the impacts of climate change in agriculture to augment the livelihood in rural areas. To understand the impacts, efficiency and management of soil and water conservation (SWC) structures under IWMP, Watershed Development Department (WDD), Karnataka, have developed a research strategy in characterize the diagnostic relationship correlating the rainfall to the surface runoff, soil and nutrient loss and potential recharge of pre and post treatment in twenty six representative watersheds in twenty six districts of Karnataka. The hydro-meteorological dynamicsreviles that the highest annual precipitation (n=4 years) of 3480 mm and at the lowest of 380 mm in Humid to arid regions. Combination of high temporal variability in rainfall and spatial heterogeneity of hydro-meteorological properties frequently causing the drought will impact on rainfed agriculture, ground water extractions for irrigation and their hydrological regime particularly in sub-humid to arid regions. High intensity rainfall causes floods, landslides, erosion and land degradation are experienced in some of the districts of Karnataka. Hydrological characteristics of the soil and water conservation structures in the study area inferred that a reduction of surface runoff, soil loss and improvement in potential recharge of the ground water regime will take place with a favourable rainfall year. In this context a detailed analysis of rainfall pattern, runoff, silt estimation, nutrient loss, ground water dynamics and the impacts of SWC measures have been summarized to improvise the efficient management.

Karnataka Watershed Development Department is the pioneer in the country in executing the integrated watershed management programme and SUJALA watershed management programme by the sustainable strategies for integrated development and to meet the potential climate change issues in the vast rainfed agricultural regions of Karnataka. The main objectives of the Watershed Development programmes is to restore the ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water with holistic approach (Common Guidelines-2008, GOI). The outcomes are to reduce the soil and nutrient loss, potential run-off, improving the water management, regeneration of natural vegetation, improving the soil moisture and recharging the ground water regime. This enables multi-cropping with the introduction of diverse agro-based activities, which help to increase income through enhanced agricultural production and improve sustainability of natural resources and livelihood, in the watershed areas.

Detail understanding of hydrological parameters, its processes, impacts of human interventions and natural ecosystem are the essential disciplines for the integrated watershed approach. By keeping these things in mind Model watershed studies are one of the best practices identified and implemented under IWMP in Karnataka to monitor and assess the facts and impacts of the diagnostic relationship of hydrological parameters *viz.*, rainfall, runoff, silt estimation, nutrient loss and ground water fluctuations both in pre and post SWC structures. The study was carried out by WDD in collaboration with SAU's using appropriate logistics in twenty six micro-watersheds (± 5 sq km each) in twenty six districts of Karnataka (Figure- I) from 2011.

Karnataka has ten agro-climatic zones comprises with highly diversified pattern in rainfall, lithology, soil type, GW regime, geomorphology, agriculture, forestry etc. Humid, transition or sub-humid and Semi-arid lands are characterized by a combination of high temporal variability in rainfall and spatial heterogeneity of hydro meteorological properties (Kumar *et al* 2014). As a consequence, presence of decadal variations in rainfall along with temporal variations will impact on groundwater extractions for irrigation requirements and their hydrological regime (Kumar *et al.*, 2014). The current study confirmed that the semi-arid regions of Karnataka is experiencing the frequent droughts and without discharging enough flow to the down streams due to the low rainfall, ground water exploitation and high evaporation. In many of the districts groundwater extraction has exceeded annual recharge and water tables have gone down (Batchelor *et al.*, 2000). In-situ SWC structures were implemented in the studied watershed during 2013 through IWMP, groundwater storage as eventually improved in 12 watersheds.

The literature reveals that in most of the developed watersheds with concerted efforts to manage rainwater, the ground water availability is improved not only in the watershed, but the downstream areas also benefitted with increased groundwater recharge (Wani *et al.*, 2003, Sreedevi *et al.*, 2006, Pathak *et al.*, 2007). Traditionally surface water tanks were built several decades ago to reduce the crop failures and to prevent water loss from the runoff (Kumar *et al.*, 2012). The hydrological monitoring and assessment studies agreed that an effective soil conservation measure with a regular water conservation performance is fairly acceptable in humid to semi-arid region. It is also presumed that even in the drought region good rainfall events in subsequent years could able to improve soil moisture, groundwater regime and prevent the fertile soil and nutrient loss.

MATERIAL AND METHODS

Instrumentation: Implementing the hydrological monitoring and assessment programme in twenty six districts across the state at a time was one of the great task and considerably achieved, eventhough, few of

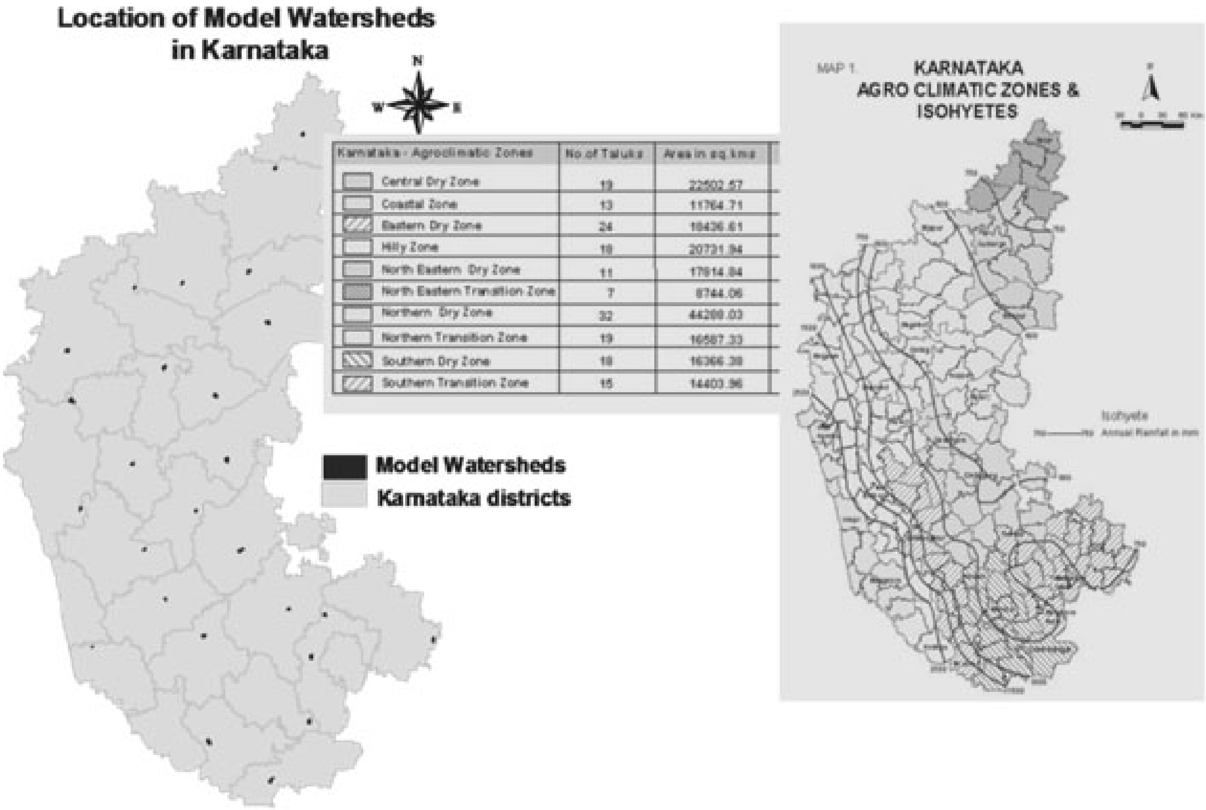

Fig. 1 : Distribution of IWMP model watershed's in different agro-climatics zones in Karnataka

the stations have the data gaps due to the damage of equipments also with other logistics. Model watersheds have been equipped by reasonable cost equipments. To measure the intensity and the quantity of the rainfall, one rain gauge station was established in each watershed. A broad crested weir was built at the outlet of the watershed to avoid the gully erosion and maintaining the uniformity of the stream course for discharge measurement and also to collect the sediment samples. Stilling well was built along with the weir for installing the stage level recorder to avoid damage from the debris and water current. Stage level recorder is operated by weight and float method with the support of pulley, which is used to measure the water stages (height) in the stream, in turn the stages have been converted into discharges. Current meters are running water velocity measuring device, the measurements were used to take across the stream. Automatic water sampler was installed at the outlet in three watersheds (Ramnagar, Bagalkot and Raichur) which consists of sampling pump, a set of sampling bottles with automated oscillate feeder pipe, monitor with display to program the sampling interval and the power supply is done through solar panel connected to 12 V battery. Stream water is pumped during the stream event and stored in the sampling bottles with regular intervals provided by user program and the samples have been used for silt and nutrient analysis. Water level indicator is used to measure the groundwater level in observatory wells (agriculture, abandon and drinking water wells) fortnightly and monthly to understand the ground water fluctuation.

Results and Discussion

Rainfall: Karnataka can be divided into four regions based on physiographic features: 1) the coastal region, 2) Malnad or the hilly region, 3) the northern plateau, and 4) the southern plateau. The climate varies from arid to semi-arid in the plateaus and sub-humid to humid tropical in Malnad and humid tropical monsoon climate in the coastal region. The monsoon originates in the Indian Ocean and reaches the southern part of the Kerala state in the south-west coast of India by the end of May (Kumar *et al.*, 2014). The rainfall pattern is bimodal, as it is affected by both the south west Monsoon (June - September) and the North east Monsoon (October - December) (Ruiz *et al*., 2010; Gunnell and Bourgeon, 1997). The average annual rainfall received in the state is 80 per cent in the south-west monsoon period, 12 per cent in the post-monsoon period, 7 per cent, in summer, and only 1 per cent is in winter. The north-eastern monsoon, mainly between October and December, accounts for about 30 per cent of the annual rainfall in the eastern part of south interior Karnataka (Anon. 2011).

The rainfall of the model watersheds shows that (Table I) (Fig. 2) the highest average rainfall (4 years) has been observed in Dakshina Kannada (3480 mm) followed by Uttara Kannada (UK) (2972 mm), Shivamogga (1260 mm) and Dharwad (1018 mm). The lowest average Rainfall was observed in Chamarajanagar (380 mm), Bagalkot (407 mm), Bellary (453 mm), Gadag (509 mm), Bijapur (530 mm), Belgaum (553 mm), Koppal (561 mm), Raichur (568 mm), Kolar (574 mm) and Chickballapur (586 mm) in the order.The Rainfall pattern shows that there is more rainfall during 2013 and 2014 compare to 2011 and 2012 in Chamarajanagar, Bagalkot, Bellary, Gadag, Bijapur, Koppal, Raichur and Chitradurga. Bidar and Kolar was the lowest rainfall district during 2014. There was drastic variability of rainfall pattern in Chamarajnagar (246, 457 and 437 mm), Doddaballapur (882, 490, 548, 673 mm), Bagalkot (295, 269, 351 and 713 mm), Kolar (735, 705, 465, 392 mm) and Chitradurga (309, 610 and 852 mm). In semi-arid and dry sub-humid agro-ecosystems rainfall variability generates dry spell (short periods of water stress during critical growth stages) almost every rainy season (Barron *et al*., 2003; Rao *et al*., 2006; Singh and Ranade, 2009).

There was a lot of uncertainty in daily, monthly and annual rainfall pattern every year in the northern plateau of black soil regions. The high range of contrast (Table II) (Fig. 3) in rainfall every year indicating difficult to predict the choice of crop planning and it leads to crop failures both by water deficit and also by floods. The traditional practice of farming in the watershed looks good probability for average rainfall years, but, not for severe drought. Due to the high intensity rainfall excess water from the flood is not been utilized by the farmers and not even can prevent

TABLE I

Annual rainfall in model watersheds

District, Taluk GP	Watershed Area (ha)	Annual Rainfall (mm)				Average of 3-4 yrs. (2011-14)
		2011	2012	2013	2014	
Chamarjnagar, Chamarajnagar, Udigala	573	_	246	457	436	380
Bagalkot, Badami, Neerabudihal	554.5	295	269	351	713	407
Bellary, Kudligi, Badeladuku	750	456	410	531	415	453
Gadag, Ron, Kotbal	966.4	426	429	564	615	509
Bijapur, B.Bagewadi, Mannur	539	548	332	612	628	530
Belgaum, Bailhongal	909.6	619	409	406	778	553
Koppal, Koppal, Hasagal	513	474	507	595	670	561
Raichur, Manvi, Hirehanigi	481.5	452	438	685	698	568
Kolar, Mulbagal, Gummakal	364.6	735	705	465	392	574
Chikkaballapur, Gowribidnr, Thondebavi	583.4	778	495	524	547	586
Chitradurga, Hiriyur, Metikurke	1020.9	_	309	610	852	590
Bangalore Rural, Dodbalpur, Bakthrhalli/kankenli	456.3	882	490	548	673	648
Tumkur, Tumkur, Bellavi, Thimmarajanahalli	509.5	_	670	614	664	649
Mysore, Hunsur, DoddaHejjur	612.3	937	409	642	629	654
Mandya, Malavalli, Byadarahalli	514.5	840	423	689	755	677
Bidar, Humnabadh,Tthalamadagi	490.1	714	794	891	398	699
Hassan, Arasikere	782	_	609	870	620	700
Haveri, Haveri, Karjagi	526	750	530	701	968	737
Chikkamagalur, Tarikere	116	_	1407	683	1022	778
Ramanagar, Magadi, Belagumba	616.1	1133	469	772	786	790
Gulbarga	495	_	_	720	921	821
Davanagere,Davanagere	48.4	1480	560	793	636	867
Dharwad, Dharwad, Benachi	588.5	1122	716	1159	1074	1018
Shimogga, Shimogga	490	729.4	1708	962	1640	1260
U. Kannada, Siddapur, Sirsi	478.2	2700	3230	2595	3363	2972
D. Kannada Mudibidre	30	3766	2748	3568	3838	3480

Installation was not completed

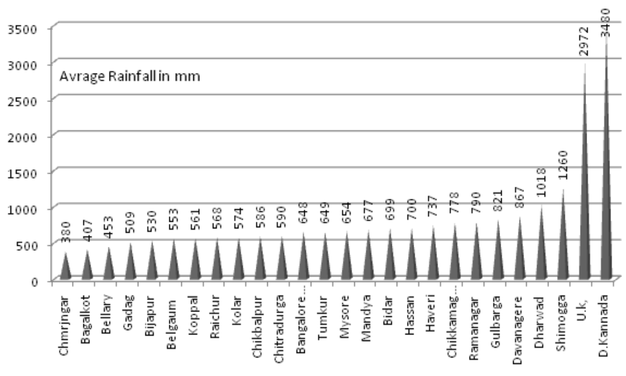

Fig. 2: *Average annual rainfall in model watersheds*

TABLE II

Rainfall of Mannur watershed, Bijapur district

	Rainfall in mm			
	2011	2012	2013	2014
January				84.1
February				172.6
March			5.6	49.7
April	84.1	26.8	40.5	89.7
May	172.6	0.13	83.7	113.3
June	49.7	6.5	119.1	21.1
July	89.7	83.9	99.7	17.7
August	113.3	122.15	69.0	
September	21.1	75.4	117.8	
October	17.7	16.6	76.4	
November				
December				
Total	548.2	331.4	611.8	548.2

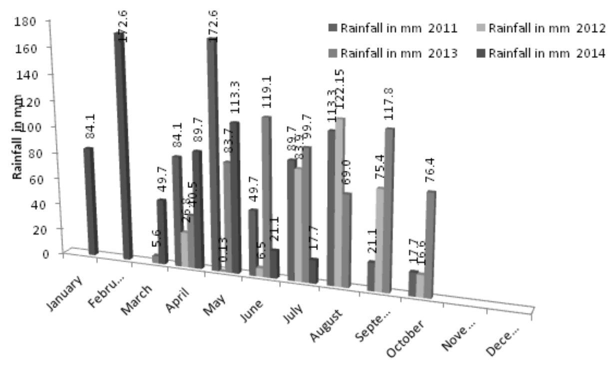

Fig. 3 : Monthly rainfall of Mannur micro watershed Bijapur from 2011-2014

the standing crops. To mitigate the drought and flood with respect to failure of the crops in alternative year, SWC structures are ideal to preserve the flashes of high rainfall and also to prevent the soil loss in this region.

Runoff : The precipitation reaching the land surface starts infiltrating into the soil. Runoff occurs only when the rate of precipitation, *i.e.*, its intensity, exceeds the rate of infiltration (Tideman, 2002). Runoff events were nil to low during study period (Table III) in Chitradurga, Kolar, Chamarajanagar, Mandya, Davanagere and Tumkur watersheds. About 11 semi-arid districts *viz.*, Chitradurga, Kolar,

TABLE III

The average runoff of the rainfall and total runoff events

District	Average runoff of the rainfall in 4 yrs. (%)	Runoff events				Total runoff events in 4 years
		2011	2012	2013	2014	
Chitradurga	0		0	0	0	0
Kolar	0		0	0	0	0
Chamarajanagar	0		0	0	0	0
Mandya	0		0	1	0	1
Davanagere	0		0	2	0	2
Tumkur	0.3		0	2	0	2
Belgaum	5.37		0	1	1	2
Mysore			0	6	0	6
Gulbarga	1.7			3	3	6
Hassan	0.3		2	2	3	7
Bellary	3.7	4	3	4	0	11
Chickballapur	0.4	5	7	0	1	13
Koppal	4.3	2	2	3	3	10
Raichur	3.3	3	2	4	3	12
Bidar	3.4	5	5	4	0	14
Bijapur	3.8	8	2	6	1	17
Shivamogga		12			11	23
Bagalkot	0.32	0	1	0	11	12
Gadag	0.6	0	0	5	9	14
Ramanagar	0.4		4	6	4	14
Bangalore rural	2.2		8	5	8	21
Dharwad	3	21	0	11	19	51
Chickamagalur		81			124	205
D. Kannada	52		102	68	92	262
U. Kannada	53	64	107	100	107	378

Chamarajanagar, Mandya, Davangere, Tumkur, Hassan, Chickballapur, Bagalkot, Gadag and Ramanagar have less than one per cent of average runoff in four years, due to the low rainfall and low intensity of rainfall, groundwater exploration, high recharge and more evaporation. The average runoff was more than one per cent and less than six per cent in Gulbarga, Doddaballapur, Belgaum, Bellary, Koppal, Raichur, Bidar, Bijapur and Dharwad district is due to moderately good rainfall. The highest runoff in the state is in Western Ghats mainly in Uttara Kannada and Dakshina Kannada watersheds which is about 50 per cent of the annual rainfall and it includes base flow.

The runoff estimation was made based on the pre treatment monitoring from 2011 to 2013 and impact on post treatment in 2014. The Impact of the treatment was significant in reduction of runoff loss (Table IV) in Belguam followed by Bellary and Bijapur (> 100%). Similarly, in Bidar - 57 per cent, Utttara Kannada- 41 per cent, Dharwad - 40 per cent, Koppal - 26 per cent and Tumkur - 5 per cent. The reduction of runoff of the rainfall was mainly due to the watershed treatment. The estimated runoff in Kolar, Mandya, Chamarajanagar, Chitradurga and Davanagere model watersheds remains 0 per cent due to low rainfall, low rainfall intensity and annual rainfall variability.

During 2014, there was high rainfall and more runoff compare to pre treatment in Hassan - 2 per cent, Gulbarga - 6 per cent, Chickballapur - 6 per cent, Gadag - 9 per cent, Doddaballapur - 16 per cent, Bagalkot - 18 per cent and Raichur - 34 per cent. Therefore, the runoff is mainly dependent on rainfall, rainfall intensity, conservation structures etc. but, conservation structures will withhold only limited

TABLE IV

Estimated runoff after the treatment

District	Average Runoff pre-treatment (2011-13)	Runoff 2014	Average Runoff of the total rainfall in % (2011-13)	Runoff % 2014	Estimated Runoff after the treatment in %	Remarks
Belgaum	478	778	9.0	0.0	188	Reduction
Bellary	466	415	5.0	0.0	107	Reduction
Bijapur	497	628	5.1	0.0	103	Reduction
Bidar	800	398	4.6	0.0	57	Reduction
Uttara Kannada	2842	3363	54.0	50.3	41	Reduction
Dharwad	999	1074	9.4	5.8	40	Reduction
Koppal	525	670	4.4	3.9	26	Reduction
Tumkur	642	664	0.3	0.0	5	Reduction
Kolar	635	392	0.0	0.0	0	No Runoff
Mandya	651	755	0.0	0.0	0	No Runoff
Chamrajanagar	351	436	0.0	0.0	0	No Runoff
Chitradurga	460	852	0.0	0.0	0	No Runoff
Hassan	739	620	0.2	0.3	-2	Surplus
Gulbarga	720	921	2.7	4.0	-6	Surplus
Chickballpur	599	547	0.2	0.6	-6	Surplus
Gadag	473	615	0.4	1.1	-9	Surplus
Bangalore Rural	640	673	1.4	2.5	-16	Surplus
Bagalkot	305	713	0.0	1.3	-18	Surplus
Raichur	525	698	2.5	5.7	-34	Surplus

amount of rain water remaining surplus water will goes as runoff.

Silt loss / sediment loss (t): The watershed is the object of an integrated study including soil dynamics and erosion process (Barbiero *et al.*, 2007). The run-off water discharged from a watershed is usually laden with sediments. The sediments are the end product of soil erosion, entrainment and transportation that ultimately get deposited on channel beds and dugout storage ponds. Sediment load could be broadly classified into suspended load and bed load, 25 per cent to 15 per cent of this load is considered as bed load and 80 - 90 per cent will be the suspended load. The sediment concentration is not homogenous in the entire cross-section and the concentration varies with various stage of flow.

Silt load have been analyzed with standard procedure before taking up the watershed treatment and after the treatment, highlights of the results reveals that highest silt loss (Table V) is in Hassan 1384 t (1.8 t / h) during pre treatment and 1118 t (1.4 t / h) is in post treatment. Uttara Kannnada, Bellary, Raichur, Koppal and Gulbarga has more silt loss before the

TABLE V

Silt loss reduction assessment

District	Soil type	Average rainfall 2011 to 13	Rainfall 2014	Total silt loss in entire watershed (t)		Total silt loss per hectare (t)		Total reduction of Silt loss (t) after the treatment during 2014		Reduction of Silt loss after the treatment in %
				Pre treat-ment	Post treat-ment	Pre treat-ment	Post treat-ment	For entire WS	Post treat-ment	
Bellary	Sandy loam	466	415	1114	0.0	1.5	0.0	1114	1.5	239.2
Tumkur	Red	642	664	394.2	0.0	0.8	0.0	394.2	0.8	61.4
Bidar	Laterite	800	398	392	0	0.8	0.0	392	0.8	49.0
Gulbarga	Clay loam	720	921	745	506	1.0	1.0	240	0.0	48.6
Koppal	Sandy loam	525	670	662	540	1.3	1.1	122	0.2	45.4
Belgaum	Black	478	778	198	0	0.2	0.0	198	0.2	41.4
Raichur	Deep black	525	698	650	690	1.4	1.4	-40	-0.1	24.9
Bijapur	Medium black	497	628	118	0	0.2	0.0	118	0.2	23.8
Uttara Kannada	Medium black	2842	3363	797	261	1.5	0.6	536	1.0	20.3
Dharwad	Medium black	999	1074	198	7	0.3	0.1	191	0.2	19.2
C. B. pur	Sahllow	340	547	133	118	0.2	0.2	15	0.0	17.6
Hassan	Red	739	620	1384	1118	1.8	1.4	266	0.3	1.8
Kolar	Red	390	392	0	0	0.0	0.0	0	0.0	0.0
Mandya	Red	371	755	0	0	0.0	0.0	0	0.0	0.0
Mysore	Red	350	629	0	0	0.0	0.0	0	0.0	0.0
C. R. Nagar	Shallow red	234	436	0	0	0.0	0.0	0	0.0	0.0
Chitradurga	Shallow red	306	852	0	0	0.0	0.0	0	0.0	0.0

treatment (Average of 3 years 1.5, 1.5, 1.4, 1.3,1.0 t / h). An average of 0.8 to 0.2 t/h has been observed in Bidar, Tumkur, Dharwad, Doddaballapur, Chickballapur, Belgaum and Bijapur. Kolar, Mandya, Chamarajanagar and Chitradurga remain no runoff and no silt loss.

After the watershed treatment programme there is great reduction of silt loss in Bellary - 239 per cent, Tumkur - 61.4 per cent, Bidar - 49 per cent, Gulbarga - 48.6 per cent, Koppal - 45.4 per cent, Belgaum - 41.4 per cent, Raichur - 24.9 per cent, Bijapur - 23.8 per cent, Uttara Kannada - 20.3 per cent, Dharwad -19.2 per cent, Chickballapur - 17.6 per cent Hassan- 1.8 per cent. Koppal and Bellary watersheds are having Sandy loam soils there was an intensive silt loss before the treatment and drastically reduced after the treatment. Tumkur Model watershed has two runoff events during 2013 caused net loss of 788.3 t in 509.6 ha. Except this event, there was no runoff event or silt loss observed in 4 years. Due to the high rainfall in 2014, Gadag, Doddaballapur, Chikkamagalur and Bagalkot districts having more silt loss (Table VI) than the pre treatment. Indeed there are many factors governing the silt loss, mainly by rainfall intensity, runoff coefficient (slope, land use and land cover) and treatment (*viz.,* bunds, check dams, tanks etc.,).

Nutrient loss: The silt is granular material of size between sand and clay which occurs as sediment load that mixed in suspension with running water in the stream. During the process of runoff, silt as a suspended load along with attached nutrient load (nitrogen, phosphorous and Potassium (N,P,K) and other micro nutrients) gets carried away depending upon specific energy of flow. From the perspective of silt-nutrient losses in watersheds, the relevant hydrological monitoring studies (2011-2014) on rainfall-runoff relations and silt load losses along with nutrient value across 26 districts of Karnataka could be categorized into black soil (10 No), red soils (13 No) and laterite soils (2 No) and red clay soil (1 No). The silt along with nutrient load that gets transported beyond the "out let" could be termed as "loss" relatively with respect to micro watershed area which contribute silt load at varied degree. During the four years (2011-2014) of monitoring, the data obtained could be distinguished into "pre- implementation period (2011-2013)" and post-implementation period (2014)" for the purpose of interpretation on effectiveness of soil and water conservation measures / structures undertaken in these identified micro-watersheds. During pre-implementation period, commensurating with silt load, nitrogen (N) nutrient has been lost in the range of 3.2 to 30 kg / ha annually, whereas, potassium (K) varied in the range of 0.5 to 14 kg / ha annually (Table VII). During post-implementation period (2013-2014), "N and K" losses have varied in the range of 0.3 to 25.0 kg / ha / year and 0.2 to 13 kg / ha / year, respectively. In both the cases, range of values are

TABLE VI

Increased silt loss after the SWC structure

District	Soil type	Average rainfall 2011 to 13	Rainfall 2014	Total Silt loss in entire watershed (t)		Total silt loss per hectare (t)		Total reduction of Silt loss (t) after the treatment during 2014		Increased Silt loss after treatment
				Pre treat-ment	Post treat-ment	Pre treat-ment	Post treat-ment	For entire WS	per ha	
Bellary	Sandy loam	466	415	1114	0.0	1.5	0.0	1114	1.5	239.2
Gadag	Black	473	615	252	362	0	0.4	110	0.3	5.7
Bang Rural	Shallow red	519	673	150	303	0.3	0.6	153	0.3	16.2
Chikmaglur	Red & Black	697	1022	0	246	0	0	246	0	24
Bagalkot	Black	305	713	0	188	0	0.3	188	0.3	26.4

TABLE VII

Nutrient loss assessment

District	Total NPK loss (Kg/ha/year)														
	2011			2012			2013			2014			Total Reduction after treatment		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Tumkur				0.0	0.0	0.0	1.2	0.1	0.2	0.0	0.0	0.0	0.6	0.0	0.1
Bagalkot	–	–	–	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6	0.3	0.9	0.6	0.3
Bidar	7.0	1.6	9.4	8.4	2.1	9.3	6.5	1.7	5.2	0.0	0.0	0.0	7.3	1.8	8.0
Bellary	6.9	1.4	6.8	3.2	0.8	4.3	2.8	0.5	3.4	0.0	0.0	0.0	4.3	0.9	4.8
Gulbarga							12.0	1.1	9.5	8.0	0.6	5.3	4.0	0.5	4.2
Raichur	30.0	5.6	14.0	28.0	3.6	9.1	35.0	2.8	12.3	25.0	1.9	13.0	6.0	2.1	-1.2
Koppal	8.7	1.2	7.3	9.8	1.1	7.4	4.0	0.7	5.7	3.5	0.5	5.1	4.0	0.5	1.7
Bijapur	3.2	1.0	0.5	0.1	0.0	0.1	2.2	0.3	0.8	0.0	0.0	0.0	0.5	0.4	1.8
Bangalore Rural	–	–	–	4.8	0.1	0.1	4.1	0.0	0.1	4.8	0.0	0.1	-0.3	0.0	2.4
Dharwad	2.2	0.0	1.8	0.0	0.0	0.0	0.4	0.0	0.4	1.1	0.6	0.6	-0.6	0.0	2.2
Hassan	–	–	–	1.8	0.6	0.6	1.8	0.6	0.6	1.3	0.7	0.5	0.5	-0.6	1.4
Belgaum	1.0	0.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4
Chickballpur	–	–	–	1.8	0.6	0.5	0.0	0.0	0.0	1.1	0.5	0.3	0.2	0.2	0.0
Ramanagar				1.6	0.2	0.5	1.5	0.2	0.3						
Gadag	–	–	–	–	–	–	0.3	0.0	0.3	1.0	0.6	0.2	-0.9	-0.6	-0.1
Uttara Kannada	1.6	0.0	1.7	14.8	0.0	6.4	9.0	0.0	1.5	13.3	1.5	1.1	-4.8	-1.5	2.1

indicative of wider possibility of losses in each watershed depending upon prevailing nutrient application practice that being followed coupled with conservation measures imposed. In both the cases wider range of values are possible as intensive runoff events especially in north-eastern Karnataka do occur in the months of August and September. In the wake of the farmers' practice of applying fertiliser by broad casting instead on recommended band method of application and prevailing scanty vegetation would possibly promote accelerated nutrient loss along with silt load along the runoff volume. The relatively very less soluble phosphorous (P) has shown that its losses in pre implementation period (1.0 to 9.3.6 kg / ha / year) reduced consistently during post-implementation (0.6 to 1.9 kg / ha / year) period which highlights effectiveness of soil and water conservation measures. The higher side of values are occasional and possibly do happen because of one or more aforesaid reasons which compound the nutrient loss rate along with silt loss. The prevailing nutrient loss loads, in a way, under aforesaid situations would lead to decide as "nominal" looking into the practices of fertilizer application and soil conservation during high intensive rainfall events. Further, nitrogen and potash are highly soluble and gets leached along runoff at more ease than phosphorous. The nutrient uptake by the crop has also contributes in limiting the nutrient use efficiency in a given cropping situation. The application of DAP or complex fertilizers are need to be applied in split doses to reduce the losses by erosion or volatalization.

In case of red soils (with variants including sandy loam and loam) "N" losses during pre implementation period ranged 1.0 to 8.7 kg ha / year which reduced to the range of 1.1 to 3.5 kg / ha / year during post-implementation period. Similarly, "K" values were observed to be in the range of 0.1 to 7.3 and 0.1 to 5.1 kg / ha / year respectively. In case of "P" varied from the range of 0.6 to 1.4 kg / ha / year reduced to a range of nil to 0.5 kg / ha / year. It is evident that clay soils are rich in nutrient status as compared to shallow red loamy soils. The losses of nutrient are also high in clay soils as compared to loamy soils. The red loamy soils by the virtue of having property of higher drainable porosity, nutrient gets settled down in deeper soil profile as compared to black clay soils which on the contrary have less infiltration rate and less drainable porosity. Hence, it would be also a good practice if soil is tested for its fertility status and fertilizers are applied on need base. Further, while designing effective, economic and efficient conservation / harvesting measures, the data on rainfall pattern over previous years, its intensity, probability of 1-day, 2-day and 3-day rainfall of the area need to be taken into account invariably. In semi arid regions there is almost negligible amount of nutrient loss were observed and nutrient loss is nil after the SWC in Bellary, Bidar, Bijapur , Belgaum and Tumkur.

Ground water : In the hard rock areas like peninsular India, groundwater is mostly confined to fractured zones as well as master joint systems. The occurrence of groundwater is governed by climate, geology, structures and geomorphology. Variability of topography, soil and geologic framework within the flow system may cause different controls to operate in different regions (Sekhar *et al*., 2004). Ground water levels rise and fall in response to many different phenomena. Changes in water levels occur over different time scales. Long-term fluctuations over periods of decades, can be attributed to naturally occurring changes in climate and to anthropogenic activities (e.g., changes in land usage, pumping, irrigation and induced infiltration). Seasonal fluctuations in ground water levels are common in many areas due to the seasonality of precipitation, evapotranspiration and irrigation. Short-term water-table fluctuations occur in response to rainfall, pumping, barometric-pressure fluctuations or other phenomena. Water table fluctuations (WTF) method is based on the principle that increases in groundwater levels is due to recharge water arriving at the water table (Sowmya *et al*., 2008). This method is most applicable over short time periods in regions having shallow water tables that display sharp raises and declines following rainfall events (Coes *et al.*, 2007). Analysis of water level fluctuations can, however, also be useful for determining the magnitude of long term changes in recharge caused by climate, land use changes and watershed treatment.

Ground water fluctuations were measured in all model watersheds (Fig. 4) over a period of four years before and after treating the watershed. The study reveals that there are few shallow wells or open wells

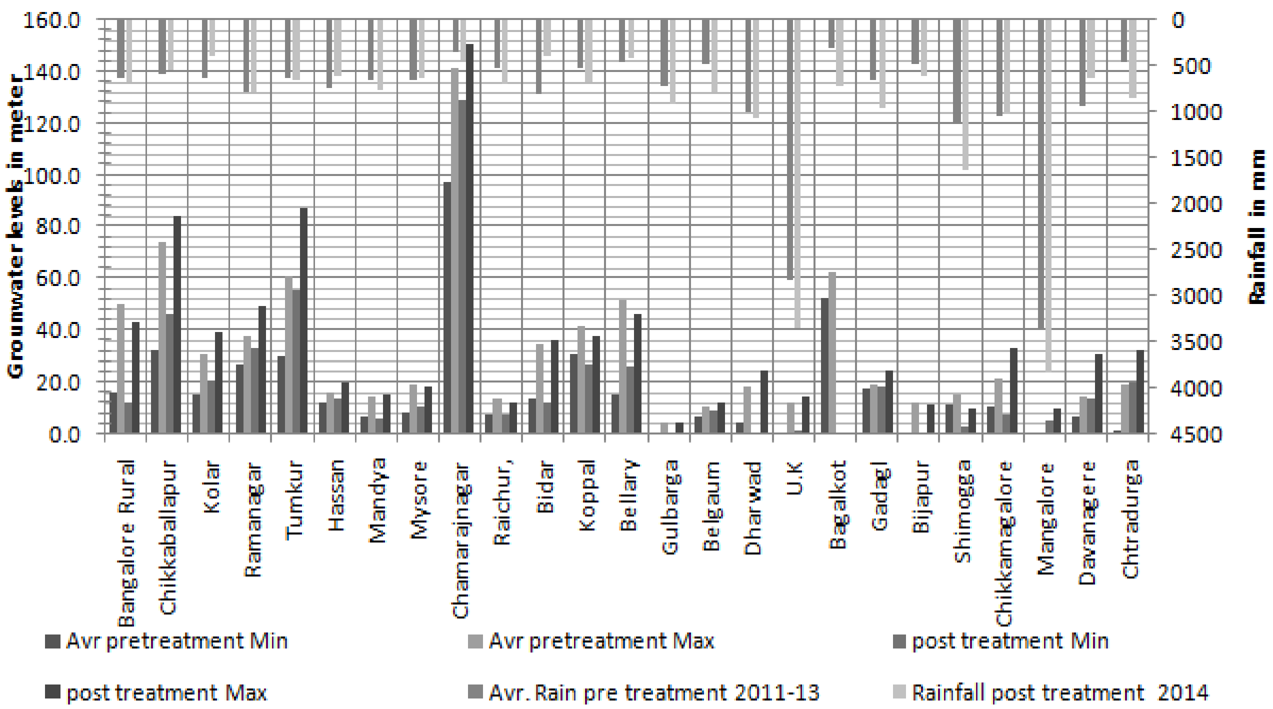

Fig. 4 : Assessment of ground water levels

having a water table of less than one meter during monsoon and it goes up to 7 meters below ground level during summer in Uttara Kannada, Dakshina Kannada, Bijapur, Dharwad and Shimogga watersheds. The shallow water tables in the shallow wells majority of them are located in the valleys, thick vadose zones, black soils and high rainfall regions. Water table fluctuation (Δh) between pre and post monsoon seasons are highly variable in space (Marechal *et al*., 2009). Some of the wells remain as shallow water table during summer due to the potential recharge. The second category of the shallow wells fluctuates from three meters (monsoon) up to twelve meters (summer) due to moderate recharge, moderate rainfall and moderate slope regions example in Raichur, Bidar, Koppal, Doddaballapur, Ramanagar, Chickmagalur watersheds. Most of the shallow wells in semi-arid regions are abandoned and polluted in semi-arid region. The impact of Watershed treatment shows that there was immediate recharge both in shallow wells and deep wells which are close to the stream or in the valley, as the gradient increases away from the stream water needs to be saturated and takes few days of time lapse to recharge neighbouring wells. The high rate of evapotranspiration induces low recharge rate to the aquifer. Consequently, the water table is deep and disconnected from the stream (marechel *et al*., 2011). Ground water flows from recharge areas, which are associated with high ground water levels, to discharge areas, which are associated with low groundwater levels. A local flow system develops between a topographic high (recharge area) and an adjacent topographic low (discharge area). An intermediate flow system consists of several topographic lows intervening between recharge and discharge areas. A regional flow system has its recharge area at the highest part of the ground water basin and its discharge area at the lowest part of the basin (Marechal *et al*., 2011).

Due to the watershed SWC measures the ground water level has been improved during wet season (rainy season) and also in dry season (Table VIII) (Fig. 5) in 12 districts *viz*., Gulbarga (0.4 m), Bijapur (0.9 m), Shivamogga (8 m), Raichur (2 m), Mandya (1 m), Dharwad (4m), Mysore (2 m), Chickmagalur (3 m), Bidar (2 m), Bangalore rural (3 m), Koppal (3 m) and Bellary (5 m). However, it is important to understand the impacts of SWC and it is recommended to monitor ground water levels (GWL) another 3 more years to know the further improvements in ground water

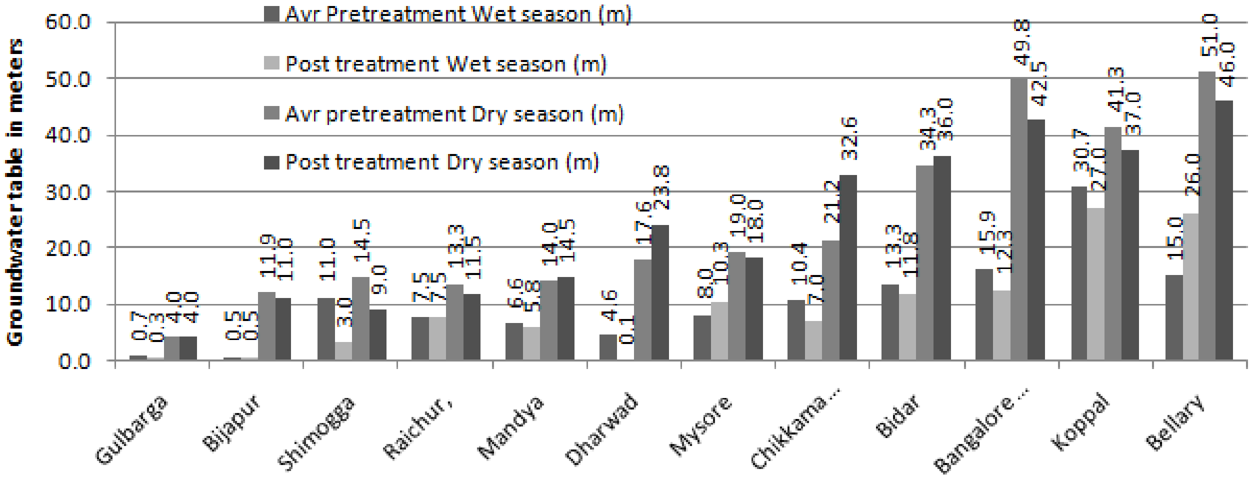

Fig. 5 : Improved ground water table after treatment

recharge, sustainable and stabilized ground water storage of the post treatment.

A classical treatment of watersheds programme have not shown any impact in improving the GWL in 10 districts (Fig. 6) (Table IX) due to low rainfall, GW exploitation etc., which are Gadag, Davanagere, Uttara Kannada, Belguam, Kolar, Hassan, Ramanagar, Chickballapur, Tumkur and Chamarajnagar Districts.

Ground water table fluctuation in deep / tube wells in model watersheds across the state indicated a lot of variability. Majority of the water table fluctuates ranging from 6 meters to 40 meters in Raichur, Koppal,

TABLE VIII

Improved ground water table after treatment

District	Avrage Pretreatment Wet season (m)	Post treatment Wet season (m)	Total GWL rise b/n pre and post treatment (m) wet season	Avr. GWL pretreatment Dry season	Post treatment Dry season (m)	GWL rise b/n pre and post treatment (m) Dry season
Gulbarga	0.7	0.3	0.4	4.0	4.0	0.0
Bijapur	0.5	0.5	0.0	11.9	11.0	0.9
Shivamogga	11.0	3.0	8.0	14.5	9.0	5.5
Raichur,	7.5	7.5	0.0	13.3	11.5	1.8
Mandya	6.6	5.8	0.8	14.0	14.5	-0.6
Dharwad	4.6	0.1	4.5	17.6	23.8	-6.2
Mysore	8.0	10.3	-2.3	19.0	18.0	1.0
Chickmagalore	10.4	7.0	3.4	21.2	32.6	-11.4
Bidar	13.3	11.8	1.5	34.3	36.0	-1.7
Bangalore Rural	15.9	12.3	3.6	49.8	42.5	7.3
Koppal	30.7	27.0	3.7	41.3	37.0	4.3
Bellary	15.0	26.0	-11.0	51.0	46.0	5.0

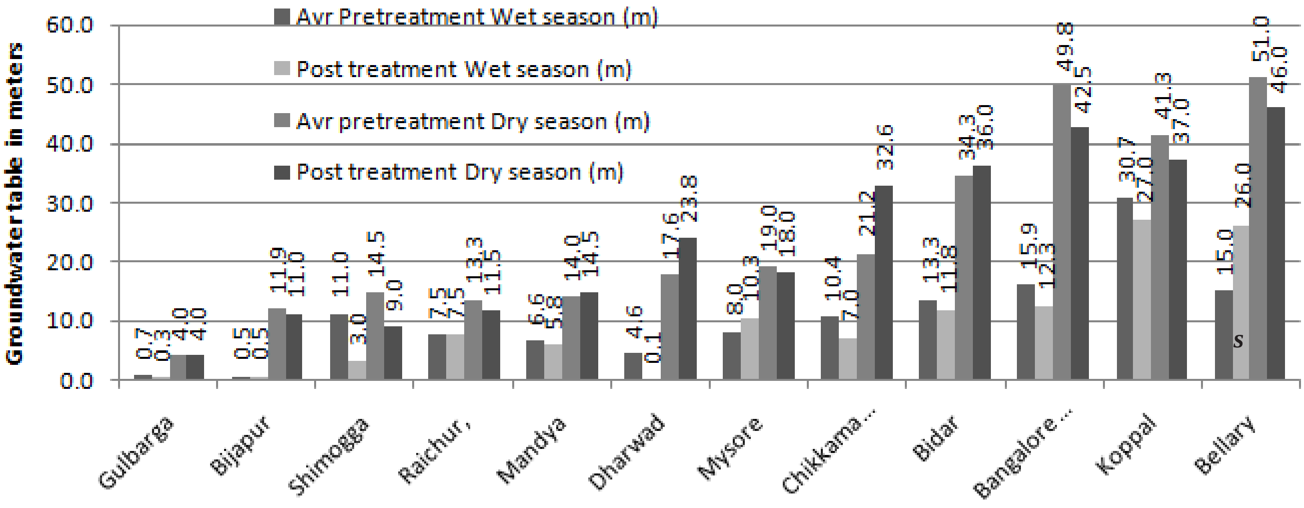

Fig. 6 : No impact on ground water levels

TABLE IX

No impact on groundwater levels

District	Average Pretreatment wet season	Post treatment wet season	Average pretreatment dry season	Post treatment dry season
Gadag	17.3	17.9	18.4	23.7
Davanagere	6.9	13.3	14.3	30.0
Uttara Kannada	0.8	1.0	12.0	13.6
Belgaum	6.5	9.2	9.7	11.4
Kolar	15.4	20.3	30.5	38.7
Hassan	12.0	13.1	15.3	19.3
Ramanagar	26.5	33.1	37.7	49.0
Chickballapur	32.6	46.4	74.0	83.8
Tumkur	29.8	55.2	60.3	87.0
Chamarajnagar	97.5	129.0	141.7	151.0

Bidar, Dharwad, Mandya, Mysore, Tumkur, Ramanagar, Hassan Davanagere, Chamarajanagar and in Shivamogga watersheds. This kind of water table fluctuations are expected due to the moderate to low rainfall regions, low specific yield, hard rock terrain, wells are away from the streams and intensive ground water agriculture or over exploited regions. The typical characteristics of these regions are often failure of wells, farmers deepening the wells or going to drill as many number as possible. In practice, drilling deeper than the bottom of the weathered-fractured layer does not increase the probability of improving the well yield (Maréchal *et al.*, 2004). As a general rule, fractures near the bedrock surface are most numerous and have the largest openings, so that the yield of most wells is not increased by drilling to depths greater than the bottom of this active zone (Maréchal *et al.*, 2010). To mitigate these situations in the above said districts the ideal practices needed to be applied are adopting rainfed crops than cash / commercial / irrigated crops, avoid drilling deep wells, watershed management practices and avoiding over exploitation of ground water during summer are the best practices to be adopted for these regions for sustainable ground water utilization. Ground water management are the ideal practice needs to be followed or otherwise there may not be any more ground water to pump in next 10 -15 years in these regions.

Most highest ground water fluctuation is observed from 20 meters to 89 meters in Chickballapur (20-89.1m), Bangalore rural (18.9-67.5 m) and Tumkur (25- 80 m). These changes are due to over exploitation, low specific yield, low rainfall and low fracture network. These zones are more dangerous and vulnerable situation for the interest of farmer is concerned. In economics and business management, it is well known as the sunk cost fallacy: increasing the resources available to an unsuccessful venture in the hope of recovering past losses (Maréchal *et al.*, 2010). In India, the cost of dry deep wells has become unaffordable for most of the farmers. The rate of farmer suicides has reached high levels as they cannot reimburse loans undertaken for increased expenses, among which are well drilling costs (Sainath, 2004). In this region formers should avoid ground water dependent long term plantation, avoid ground water irrigation, and avoid drilling wells. The uniqueness of this region is shallow to deep red soils with lot of moisture holding capacity for longer time, dry land horticulture plantation, and timber bearing plantation, rainfed crops, xerophytes plantations and other industries *viz.*, brick, quarry or crusher, livestock development etc., could be adapted to generate the income.

Frequent rainfall variability and spatial heterogeneity is the basic phenomenon cause the stress of current agricultural practices. Aggressive usage of ground water, improper watershed management and adapting agro-hydrological smart agriculture needs to be examined and implemented with efficient cutting edge approach. The best recommendations for high rainfall regions are water logging management, manure and pest management, prevention measures for land slides and soil erosion, major irrigation projects for irrigation and ground water recharge to semi-arid regions through canal supply, afforestation, desiltation of tanks and reservoirs, use of surface water for fisheries, power projects etc. In agricultural perspective point of view adopting suitable commercial crops *viz.*, betel, areca, pepper, cocoa, banana, coconut, rubber, vanilla, paddy, silver oak, teak etc., are ideal.

Moderate to lowest average rainfall districts are more vulnerable to water it is important to adapt watershed management practices, practice of rainfed and canal agriculture than ground water irrigation, adopting more efficient irrigation system such as micro irrigation (drip or sprinkler etc.,) rejuvenating existing infrastructure (SWC), desiltation and rehabilitation of tanks and reservoirs, promoting local tank management, capacity building and public awareness related to water resources management, promoting agro-forestry, diversification of income and livelihood opportunities *viz.*, livestock diversification, enhanced access to developmental programmes such as IWMP, MGNREGA etc., Financial compensation through crop insurance, providing opportunities to rural households to diversify sustainable means of livelihood through promoting non-farm-based income opportunities are the ideal suit based on the aptness.

Watershed post treatment studies shows that there was drastic reduction of runoff, silt and nutrient loss and increased ground water levels in aforesaid watersheds. Some watersheds in semi-arid regions have no impact in the study period because of the heterogeneity of Hydro-meteorological parameters and it is presumed that good rainfall events in upcoming years could able to improve soil moisture, ground water regime and prevent the fertile soil and nutrients losses. Model watershed studies have been extended for three more years to understand the improvised soil moisture and elongated sustainable ground water performance and also to assess the non impacted watersheds.

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