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Impact of Watershed Management on Stream Flow and Build-up Water Storage in Parasai-Sindh Watershed of SAT Region, India

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Authors' contributions

This work was carried out in collaboration among all authors. This work was doctoral research work of author RK. Material preparation, data collection and analysis were performed by authors BS and PK. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study of runoff and base flow estimates and their impact on groundwater status in the semi-arid region of India is typically limited. We are focused on runoff and base flow in the Parasai-Sindh watershed, and impact of rain water harvesting structure on harvesting of stream flow and change ground water status.

Place and Duration of Study: The study site is located in Jhansi district (Bundelkhand region) of Uttar Pradesh and started from 2012 and completed at end of 2013.

Methodology: Total six rainwater harvesting structure (RHS) or checkdams were constructed on the drainage line from ridge to final outlet of watershed. Daily rainfall data was observed with automatic rain gauge during the study period. For discharge estimation, the runoff gauging station was installed at the outlet of watershed. The runoff and base flow of watershed were estimated by

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subtracting barometric pressure from the stage recoded by Baro and Diver install at outlet to get actual stage of runoff passing over it. The water pressure head of 200 randomly selected open wells were monitored on monthly interval.
Results: The geological area of watershed is 12.46 km^2 and it's main stream is found to be of 4^{th} order. The results indicate that out of 49.2 mm rainfall event, runoff and base flow at outlet of watershed were found as 20.98% and 4.19%, respectively. Whereas, runoff and base flow were recorded 14.12% and 11.18%, respectively against 86.2 mm rainfall. Total runoff and base flow produced from outlet was recorded as 16 and 7%, respectively. The water head pressure of open wells was improved 92.45% after the rainy season as compared to before the rainy season.
Conclusion: The findings of the study are useful and show relationship between rainfall: runoff and estimation of base flow separation from the total discharge at the outlet of watershed. The estimation of volume of runoff which was harvested as surface runoff during rainy season and it's indirectly effected groundwater recharging through construction of RHS in ephemeral drain of Bundelkhand region.

Keywords: Rainfall; runoff; base flow; water harvesting; watershed management.

1. INTRODUCTION

In India, the half of the total precipitation is occurs within a period of 15 days which induced more than 90% of the annual runoff during monsoon period. Runoff is the one of most important hydrological input data in water resource management. However, Base flow is water that sustains a stream after the precipitation occurred and it can be contributed in groundwater or unsaturated soil pool [1,2]. While, the study on runoff - base flow estimation and its relationship with rainfall are very limited particularly in developing country, especially under meso-scale watershed.

India is implemented large-scale watershed management programs [3] and invested US$ 14 billion since 1990 by Government of India along with several international donor agencies [4], for helping to improving degraded land, reduce water scarcity, food insecurity and develop rural livelihoods [5,6]. However, very limited study has been done on harvesting of runoff through rainwater harvesting interventions, water balance, upstream and downstream water balance, groundwater dynamics, change land use and income [7], with the exception of a few agro-hydrological studies at watershed level [8].

The dry land agriculture is uncertain due to low and unpredictable rainfall, high sloppy land and short crop growing period in Semi Arid tropical region of India. Agricultural production will improve in these areas with adoption of soil and water conservation practices, improve soil health and water holding capacity and use of harvested rainwater as supplemental irrigation in critical growth stages [9]. In India, dry land agriculture covers approximate 66% of the total cultivated area and it produces almost half of the total agricultural production [10,11]. In arid region, the harvested and stored rainwater is one of the major assets for crop survival by application of life saving irrigations in the dry period [12]. It is a widely used practice, which deals with various engineering approaches like as collection of surface runoff, storage, treatment and distribution [13]. Reduction of surface runoff can be reduced by constructing suitable in- and ex-situ rainwater harvesting structures, which automatically improve other natural resources like soil and vegetation. Harvested rainwater check infiltration and increase soil water content and indirectly improve groundwater status. Series of rainwater harvesting structures enhance water conservation at least 5-8 times than harvested rain water depending upon rainfall dynamic, terrain, soil type, etc [12]. The aim of study was analyzed (a) geomorphology of watershed for identification of suitable site for construction rainwater harvesting structures, (b) the impact of rainwater harvesting structures on landscape hydrology, specifically on runoff, base flow and groundwater recharge.

2. METHODOLOGY

2.1 Description of Site

The Parasai-Sindh watershed located in Jhansi district (Bundelkhand region) of Uttar Pradesh was selected for the study purpose from 2012. Its geographical area is 1246 ha, comprising three villages namely Parasai, Chhatpur and Bachhauni located at 25º 23' 47.6" -25° 27' 05.1" N and 78° 20' 06.5" - 78° 22' 33.0" E, and about

270-315 m above mean sea level (msl) (Fig. 1). It comes under agro-climatic zone of Central Plateau Hill Region representing a transitional zone of tropical sub-humid to semi-arid and comes under hot moist semi-arid ecological sub-region. The annual average rainfall is 877 mm (standard deviation, σ = 251 mm), out of this, 85 % falling from June to September [14] whereas, mean potential evapo-transpiration ranges from 1329 to 1532 mm. Mean annual temperature ranges from 24 to 25°C. The mean summer (April-June) and winter temperature (December-February) temperature are 34 and 16 °C, respectively. The aquifers are either unconfined or perched, having poor storage capacity (porosity of 0.01-0.05). These aquifers were derived primarily from weathering and developed in between two different layer system (i) unconsolidated fractured layers within 10-15 m, (ii) relatively impermeable basement starting from 15-20 m depth [15]. Soil profile depth in the watershed is very low and comes under Alfisols and Entisols of soil order (10-50 cm soil depth), coarse gravelly, light textured with low water-holding capacity (80-120 mm/m), with low organic carbon (< 1%) [16]. These soils are further classified according to their texture and color into four distinct series namely *Rakar* and *Parwa* in red soils and *Kabar* and *Mar* in black soils [17].

2.2 Estimation of Runoff and Base Flow

In watershed development, a number of RHS or checkdams were constructed on the drainage line from ridge to final outlet of watershed. For the selection of suitable site, the digital elevation model of watershed was prepared by using ASTER 30 m DEM of satellite imagery and it was used for topographic information, flow pattern, flood risk areas identification and to determine accessibility with the help of G.I.S. software Arc GIS 10. Out of six RHS, the gauging station of flow discharge was installed at the outlet of watershed. The automatic pressure recorded drive was placed at bottom of the sitting well which was constructed at upstream of check dam. The actual flow discharge passing over rectangular weir of checkdam, the barometric pressure head was subtracted from the stage recoded by Divers at 10 minute interval. The discharge corresponding to the depth of flow taken at an interval of 10 min was calculated from the discharge-head relationship [18,19]. This method was based on the continuity and Bernoulli's equations. Discharge over the crest was calculated by equation such as:

$$Q = C_d \left[\frac{2}{3} \left(\frac{2}{3} g \right)^{1/2} \right] B\, h^{3/2}$$

Where, Q is flow discharge (m^3s^{-1}); g- gravitational acceleration (ms^{-2}); C_d is discharge coefficient; B - the weir's breadth which spans the full channel width; and h - overflow head upstream of the weir (m).

In this study, flow received at watershed outlet within 12 hours (hr) of the rainfall event was referred as runoff and flow received after 12 hr was considered as base flow. The time of concentration (T_c) in Parasai-Sindh watershed at outlet (gauging station) was estimated as 1.2 hour. Longest path of the Parasai-Sindh watershed is 4.5 km and average velocity of runoff water is 3.75 km hr^{-1} as defined by Kirpich [20]. Thus, considering 12 hour as base time indeed is sufficient for partitioning water yield into runoff and base flow at any location in the study area. Singh *et al*. also reported similar that flow received at watershed outlet within 12 hours of the rainfall event was referred as runoff and flow received after 12 hours was considered as base flow for Garhkundar-Dabar watershed of Bundelkhand region in Central India [14].

2.3 Estimation of Rain Water Harvesting through RHS

The six RHS were constructed in 2012 in different ephemerals drains of watershed. Out of six RHS, one is the traditional rain water harvesting system which is known as *Haveli* checkdam. It is very popular in Bundelkhand region and located at upstream of watershed. It was rejuvenated because it was not harvesting surface water. The volume of harvested water storage capacities of the RHS are estimated by conducting 30m grid topographic survey of the stream channel at the height of the crest. The estimation of change of ground water, 200 open wells of Parasai-Sindh watershed were randomly selected and monitored for water pressure head on monthly interval by using the following formula.

$$\Delta W = \frac{\sum_n D_w - H_w}{n}$$

where, ΔW= average change in pressure head (m); D_w= depth of open well (m); H_w= height of water column in open well (m); n= total number of selected open wells

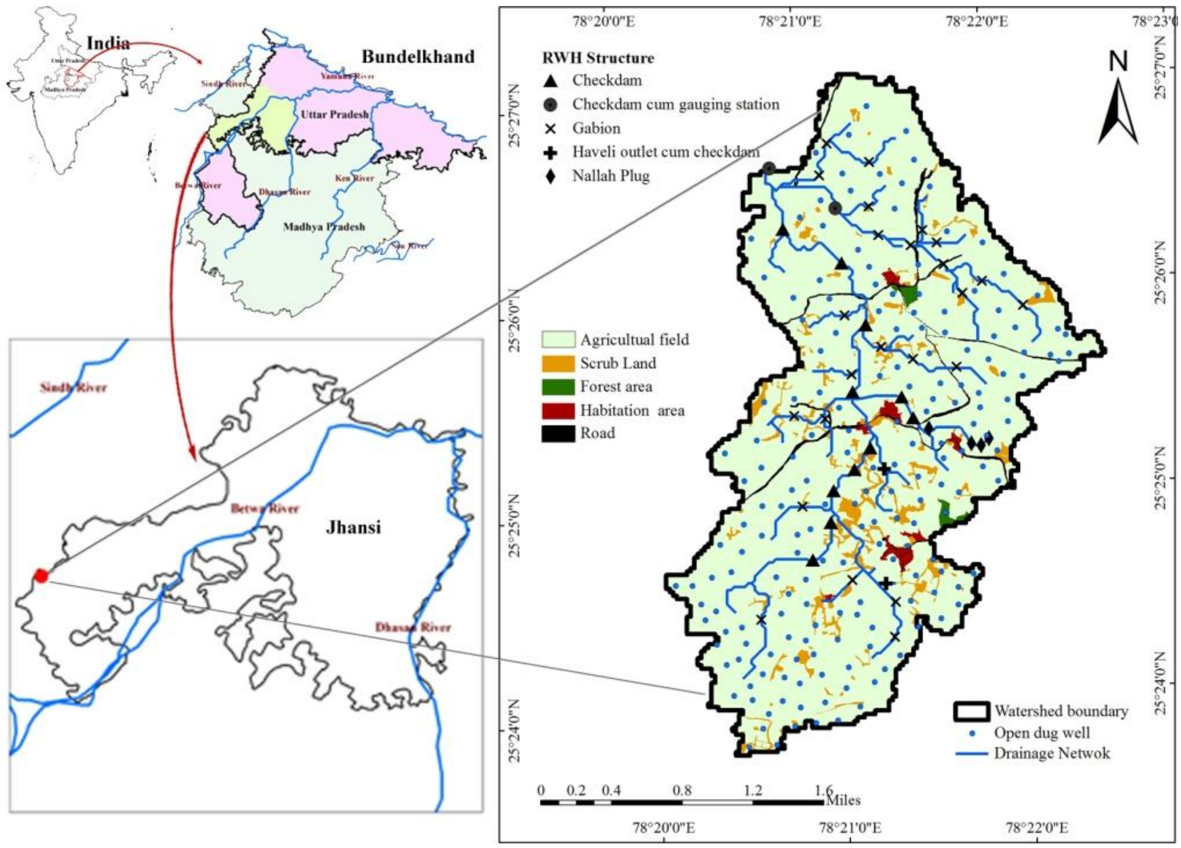

Fig. 1. Location map of Parasi-Sindh watershed

3. RESULTS AND DISCUSSION

3.1 Topographical Countenance

A DEM is a digital file of terrain elevations for ground positions. Outlet of the watershed was located at 270 m above msl, whereas land elevation varied from 270 to 315 m in the watershed. The maximum area, 329.02 ha of the watershed falls under 290-295 m elevation followed by area of 290.09 ha under 295-300 m (Fig. 2a). The term stream order is a measure of the position of a stream in the hierarchy of tributaries. Natural drainage system of the watershed was classified and the main stream was found as 4th order stream. Number of I, II, III and IV order streams were 31, 7, 2 and 1 respectively and their corresponding mean length of was 0.51, 0.72, 2.54, 0.99 km, respectively (Fig. 2c). It was also indicted that there was a negative correlation between frequencies of stream with stream order that means stream frequency is decrease if stream order is increase [21]. The total length of stream segments is highest in first order and decreases with increase stream order. This change may point toward flowing of streams from high elevation, landscape and land slopes [22]. The dominant slope category in the watershed were 5-10 per cent (45.83 %) followed by 3-5 and 10-15 (Fig. 2b). the higher watershed area comes under higher slope categories which means the flow of surface water is high and lost through runoff. Slopes of a region are vital parameters in deciding suitable land use, as the degree and direction of the slope decide the land use that it can support. Slope is also very important while determining the land irrigability and capability classification and has direct bearing on runoff [23].

3.2 Surface Runoff and Base Flow

During the study, the estimation of runoff and base flow separation were varied and dependent on watershed topographical situation and rainfall variability. The rainfall during rainy season (June-September) was recorded 1052 mm. Total stream flow was recorded 285.3.0 mm whereas runoff was recorded 197.5 mm which was 16% of total rainfall, rest stream flow was considered as

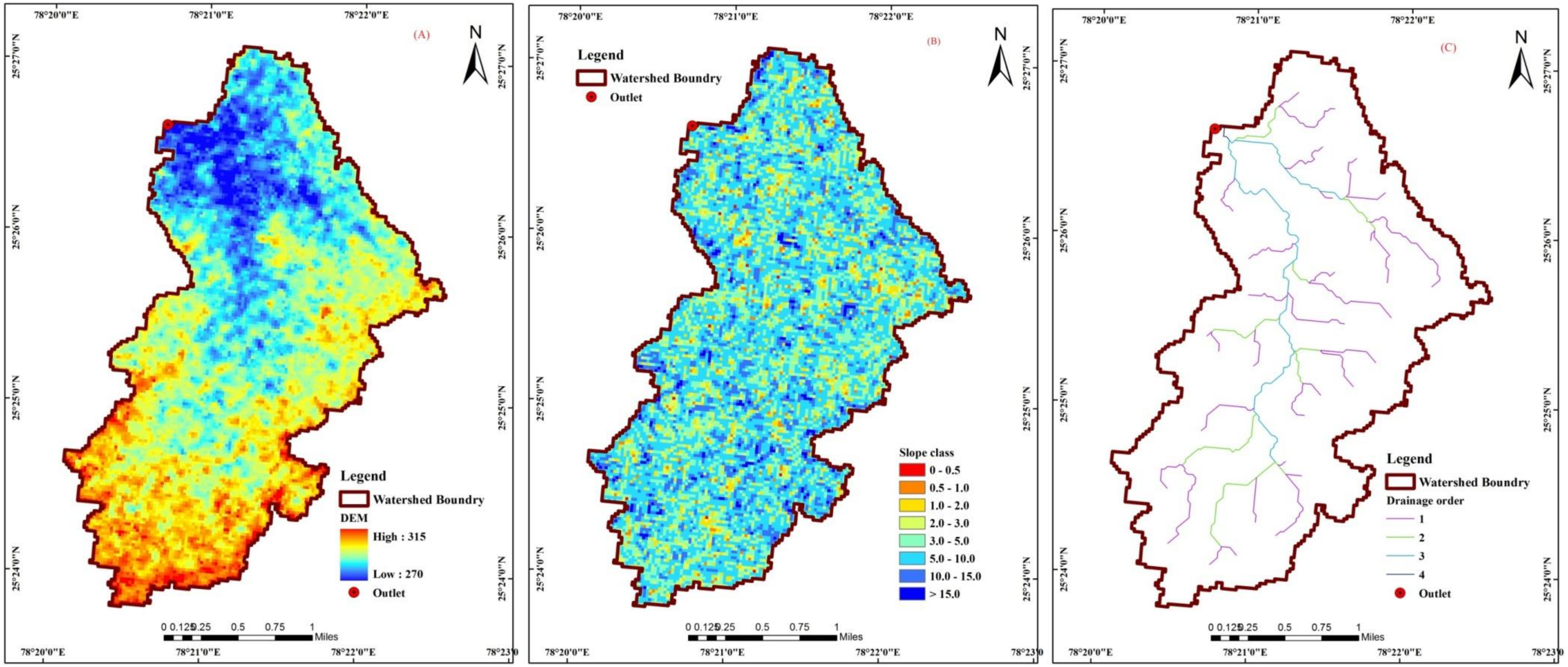

Fig. 2. Digital Elevation Model (a), slope (b) and drainage (c) maps of Parasai-Sindh watershed

base flow, respectively (Fig. 3a). Runoff coefficient changed with rainfall quantity and intervention density both on spatial and temporal scales [6]. Out of all event of rainfall, two event were selected and drawn the hydrograph for estimation of runoff and base flow. Runoff and base flow estimated at outlet of watershed for rainfall event-1 were found as 10.32 mm and 2.06 mm, respectively against 49.2 mm rainfall (Fig. 3b). Whereas, runoff and base flow of rainfall event-2 were recorded 12.17 mm and 9.64 mm, respectively, against 86.2 mm (Fig. 3c) rainfall. Peak discharge of event-1 and event-2 were observed at 2 hrs 20 min and 2 hrs after the occurrence of respective rainfall as the rainfall intensity was higher in case of event-2 as compared to event-1. However, magnitude of peak discharge was found higher in case of event-2 as compared to event-1. A long recession limb (lean flow) of event-2 continued even after 72 hours of the rainfall whereas outflow of event-1 reduced to zero after 40 hours of the rainfall. Number of water harvesting structures constructed at upstream of watershed have also impacted the hydrographs recorded at outlet. Singh et al. also reported similar storm flow and base flow in Garhkundar-Dabar watershed of Bundelkhand region Central India [14].

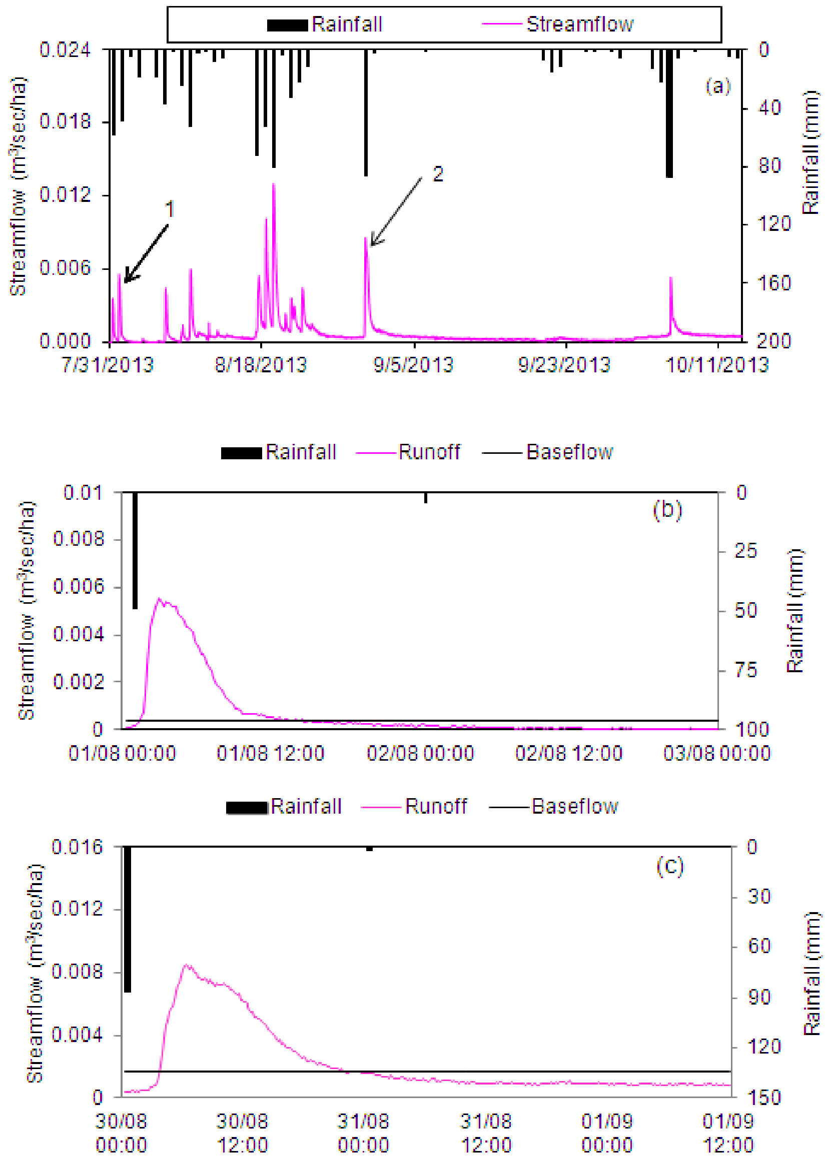

Fig. 3. Study of rainfall and discharge (a), runoff hydrograph and base flow of selected event 1 (b) and 2 (c) at outlet of watershed during rainy season, 2013

Table 1. Technical specification, Volume of harvested runoff and catchment area of different RHS under Parasai-Sindh Watershed

S. No.	Name of RHS	Crest length (m)	Heights of water drop (m)	Weir Height. (m)	Relief (m)	Length of Submergence (m)	Volume of harvested runoff (m^3)	Catchment area (ha)
1	CD 1 (*Haveli*)	5.00	1.10	0.65	25	500	73000	51.40
2	CD 2	6.00	1.35	1.02	24	-	7500	94.64
3	CD 3	6.00	1.50	0.90	27	310	2500	310
4	CD 4	6.00	1.30	1.10	30	350	2000	350
5	CD 5	6.00	1.13	1.50	34	485	4700	478
6	CD 6 (Outlet)	5.00	1.40	0.56	21	290	3000	1246

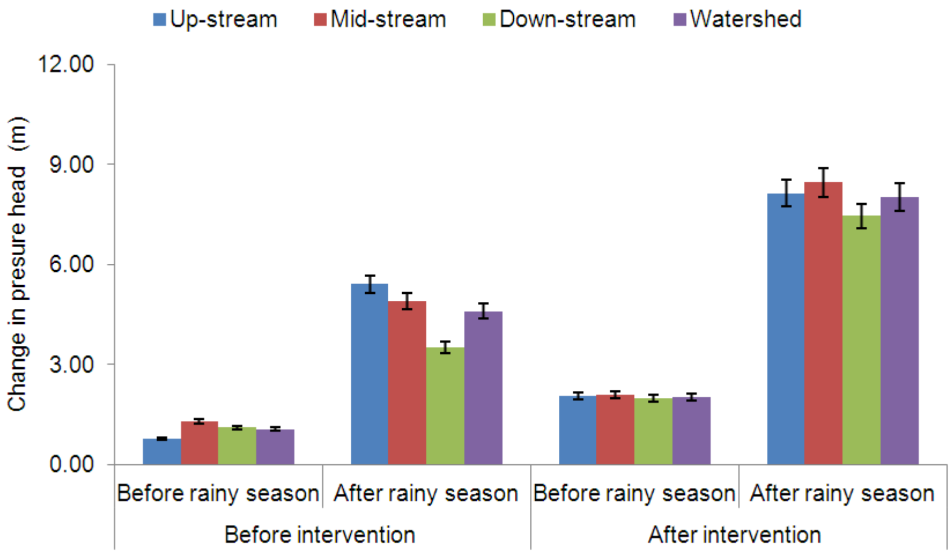

Fig. 4. Comparison of pressure head of open wells in between before and after intervention

3.3 Rainwater Harvesting and Change in Groundwater

Total rainwater stored through check dams except *Haveli* was 92700 m^3, out of these *Haveli* RHS was harvested 73000 m^3 runoff from 51.4 ha catchment area (Table 1). The change in ground water level of watershed was one of the major impacts of rainwater harvesting by construction of RHS in Parasai-Sindh watershed. The result revealed that the average depth of open wells was recorded 9.69 m. Average water pressure head was recorded 1.06 at starting of rainy season and 4.60 m at end of rainy season before implementation of RHS. Compared to pre-intervention, the open well water pressures of the up, middle, downstream and overall watersheds at the beginning of the rainy season after the construction of the RHS had increased by 1.27, 0.80, 0.87 and 0.98 m, respectively. Similarly, the water head pressure of open wells of up, mid, downstream and overall watershed was recorded higher by 50.46, 73.01, 112.25 and 74.35% respectively after the rainy season (Fig. 4). The difference in the average pressure head of groundwater could be attributed to the enhanced water availability through implementation of suitable RHS [24]. Singh et al. also reported that the integrated watershed development activities were recharged ground water and improved water level of open wells situated in Garhkundar-Dabar watershed of Bundelkhand region [14] and similar study done by Sharma et al. at Domagor-Pahuj Watershed [25].

4. CONCLUSION

The conclusion of the study was that the maximum area comes under higher slope category and suitable for lost of high amount of rain water through runoff. Out of total rainfall received during the study period, runoff and base flow were recorded 197.5 and 88.35 mm at outlet of watershed. Implementation of RHS in ephemeral streams at appropriate interval was one of the best options to check the stream flow and harvest the surface runoff. Total volume of harvested water through six RHS was 92700 m^3. Groundwater level of open wells was improved after development of water harvesting structure in watershed as compared before intervention. This study showed the rainfall and runoff estimation and impact RHS on surface water harvesting and build-up the ground water of rainfed region of India.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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