Estimation of Runoff, Baseflow and ground water status in Parasai-Sindh watershed of SAT region, India

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Research Article

Keywords: Rainfall, runoff, baseflow, watershed management, Parasai-Sindh watershed

Posted Date: September 21st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-921289/v1

Abstract

A study of runoff and baseflow estimation and its impact ground water status are typically limited in semi-arid region of India. We are focused on runoff and baseflow in the Parasai-Sindh watershed, with the aim of analyzing the influence of watershed management on the response characteristics of discharge. The geological area watershed is 12.46 km2 and its main stream is found to be of 4th order. The runoff and baseflow of watershed were estimated by subtracting barometric pressure from the stage recoded by Baro and Diver install at outlet to get actual stage of runoff passing over it. The results indicate that out of 49.2 mm rainfall event, runoff and baseflow at outlet of watershed were found as 20.98% and 4.19%, respectively. Whereas, runoff and baseflow were recorded 14.12% and 11.18%, respectively against 86.2 mm rainfall. Total runoff and baseflow produced from outlet was recorded as 16 and 7%, respectively.

1 Introduction

In India, the half of the total precipitation is occur 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 (Lee et al., 2018; Foks et al., 2019). While, the study on runoff - baseflow 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 (Hope, 2007) and invested US$ 14 billion since 1990 by Government of India along with several international donor agencies (Mandal et al., 2020), for helping to improving degraded land, reduce water scarcity, food insecurity and develop rural livelihoods (Mondal et al., 2017; Garg et al., 2020). However, very limited study have been done on harvesting of runoff through rainwater harvesting interventions, water balance, upstream and downstream water balance, groundwater dynamics, change landsue and income (Glendenning et al., 2012), with the exception of a few agro-hydrological studies (Karlberg et al., 2015) at watershed level..

The dryland 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 this 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 (Keller et al., 2000). In India, dryland agriculture cover approximate 66% of the total cultivated area and it produces almost half of the total agricultural production (Rosegrant et al., 2002; Kumari et al., 2018). In arid region, the harvested and store rainwater is one of the major asset for crop survival by application of life saving irrigations in the dry period (Kumari et al., 2017). It is a widely used practice, which deals with various engineering approaches like as collection of surface runoff, storage, treatment and distribution (Tripathi et al., 2016). 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 (Kumari et al., 2017). 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, baseflow 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” -25º 27’ 05.1” N and 78º 20’ 06.5” - 78º 22’ 33.0” E, and about 270-315 m above mean sea level (Figure 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 (Singh et al., 2014a) whereas, mean potential evapotranspiration 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 total no. of households and the average land-holding per household are 417 and 3.12 ha, 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 into two layered system (i) unconsolidated fractured layers within 10-15 m, (ii) relatively impermeable basement starting from 15-20 m depth (GOI, 2000). Soil in the watershed is shallow and comes under Alfisols and Entisols soil order (10-50 cm soil depth), coarsegravelly, light textured with low water-holding capacity (80-120 mm/m), with low organiccarbon (< 1%) (Kumari et al., 2015). 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 (Kumari et al., 2020).

2.2 Construction of rainwater harvesting structure (RHS)

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. Six RHS were constructed in 2012 and technical specification given in table 1. Out of six RHS, one is traditional rainwater harvesting system (*Haveli*)which is popular in Bundelkhand and located at upstream of watershed. Catchment area of *haveli*is 80 ha and 73000 m^3 water storage volume. A total rainwaterstoredthrough check dams except *haveli* was 19700 m^3.

2.2 Estimation of Runoff and Baseflow

Out of six RHS, the runoff gauging station 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 runoff 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 (Bettez et al., 2001; Goodarzi et al., 2012). 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 of the rainfall event was referred as storm flow and flow received after 12 hours was considered as baseflow. The time of concentration (Tc) in Parasai-Sindh watershed at outlet (gauging station) was estimated as 1.2 hours. Longest path of the Parasai-Sindh watershed is 4.5 km and average velocity of runoff water 3.75 km h^{-1} as defined by Kirpich (1940). Thus, considering 12 hour as base time indeed is sufficient enough for partitioning water yield into storm flow and baseflow at any location in the study area. Singh et al., (2014a) also reported similar that flow received at watershed outlet within 12 hours of the rainfall event was referred as storm flow and flow received after 12 hours was considered as baseflow for Garhkundar-Dabar watershed of Bundelkhand region in Central India.

3 Result 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 mean sea level (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 (Figure 2a).The dominant slope category in the watershed were 5-10 per cent (45.83 %) followed by 3-5 per cent (23.57 %) (Figure 2b). It was also noticed that slope of majority of agricultural land varied from 3-10 per cent. Slope 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 (Singh et al., 2014b). 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 4^{th} 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 (Figure 2c). It was also indicted that there was a negative correlation between frequency of stream with stream order that means stream frequency is decrease if stream order is increase (Pareta and Pareta, 2012). The total length of stream segments is highest infirst order and decreases with increase stream order. This change may point toward flowing ofstreams from high elevation, landscape and land slopes (Vittala et al., 2004).

3.2 Surface runoff and Baseflow

Runoff of catchment significantly affected with annual rainfall. The rainfall during monsoon (Jun-Sep) was recorded 1052 mm. Total outflow was recorded 285.3.0 mm whereas runoff was recorded 197.5 mm which was 16% of total rainfall, rest outflow was considered as baseflow, respectively (Figure 3a). Runoff coefficient changed with rainfall quantity and intervention density both on spatial and temporal scales (Garg et al., 2020). Out of all event of rainfall, two event were selected and drawn the hydrograph for estimation of runoff and baseflow. Runoff and baseflow 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 (Figure 3b). Whereas, runoff and baseflow of rainfall event-2 were12.17 mm and 9.64 mm, respectively, against 86.2 mm (Figure 3c) rainfall. Peak discharge of event-1 and event-2 were observed at 2 hrs 20 min and2 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., (2014b) also reported similar storm flow and baseflow in Garhkundar-Dabar watershed of Bundelkhand region, Central India.

3.3 Change in Groundwater status

The change in ground water level of watershed was one of the major impact of rainwater harvesting by construction of RHS in Parasai-Sindh watershed. For this purpose, 200 open wells of Parasai-Sindh watershed were randomly selected and monitored for water pressure head on monthly interval. The average depth of open wells was 9.69 m. Average water pressure head was recorded1.06 at starting of rainy season (May) and 4.60 m at end of rainy season (October) before implementation of RHS. After construction of RHS, The average water pressure head of open wells was recorded 2.04 and 8.02 m at starting of rainy season (May) and end of rainy season (October), respectively (Table 2). During monsoon season 2011-12, life-saving irrigation was given in 828 ha. However, irrigation was done in 979 ha (18.2 % higher than pre intervention scenario) during 2012-13 due to enhanced availability of water in the watershed. The difference in the average pressure head of groundwater could be attributed to theenhanced water availability through implementation of suitable RHS (Kumari el al. 2014). Singh et al., (2014) also reported that the Integrated watershed development activities were recharged groundwaterand improved water level of open wells situated in Garhkundar-Dabar watershed of Bundelkhand region and similar study done by Sharma et al., (2015) at Domagor-Pahuj Watershed.

4 Conclusion

The Parasi-Sindh watershed of 1246 ha in Jhansi was developed through construction of series of RHS including check dams and renovation of traditional RHS known as *Haveli* check dam. The major area of watershed comes under 5-10 per cent (45.83 %) slope category followed by 3-5 per cent (23.57 %). Implementation of RHS in ephemeral streams at appropriate interval wasbest option to improve the storage of rainwater and enhance groundwater. Total volume of harvested water through check dams was 92700 m^3. The runoff and baseflow were recorded 197.5and 88.35mm at outlet of watershed. Groundwater availability of watershed was improved with construction of check dam on ephemeral drain and harvesting of rainwater that lost through surface runoff. RHS have significant and quick impact on groundwater recharge in Bundelkhand region. The improved ground water and stored surface water in check dams maybe use a source of supplemental irrigation during critical stagesof major crop grown in watershed.

Declarations

Acknowledgments

We are thankful to Coca-colo foundation of India for financial supported and technically guidance given by ICRISAT, Hyderabad, India.

Conflict of Interest The authors declare no conflict of interest.

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Tables

Table 1 Technical specification of rainwater harvesting structures

S. No.	Name of RHS	Crest length (m)	Ht. of water drop (m)	Weir Ht. (m)	Relief	Length of Submergence (m)	Storage capacity (m3)	Catchment area (ha)
1	CD 1 (*Haveli*)	5	1.1	0.65	25	500	73000	51.4
2	CD 2	6	1.35	1.02	24	-	7500	94.64
3	CD 3	6	1.5	0.9	27	310	2500	310
4	CD 4	6	1.3	1.1	30	350	2000	350
5	CD 5	6	1.13	1.5	34	485	4700	478
6	CD 6	5	1.4	0.56	21	290	3000	15.85

Table 2 Comparisionof pressure head of open wells in between before and after intervention

Village	No of wells	Average depth of wells (m)	Change in presure head (m)			
			Before intervention		After intervention	
			May	October	May	October
Parasai	77	9.79	0.78	5.41	2.05	8.14
Chhatapur	56	9.95	1.29	4.89	2.09	8.46
Bachauni	67	9.37	1.12	3.51	1.99	7.45
Total/ Average	**200**	**9.69**	**1.06**	**4.60**	**2.04**	**8.02**

Figures

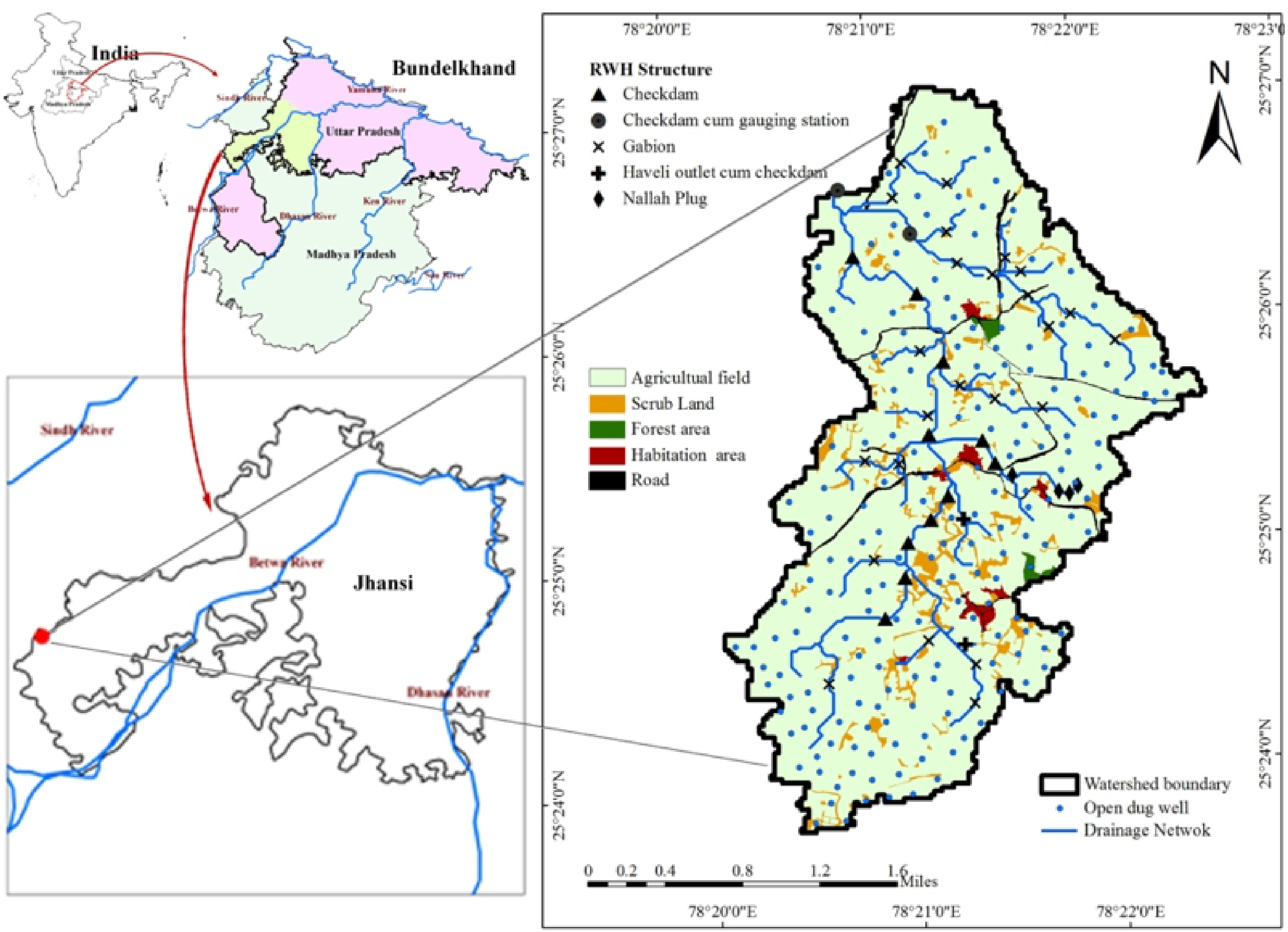

Figure 1

Location of study area Parasi-Sindh watershed, Jhansi.

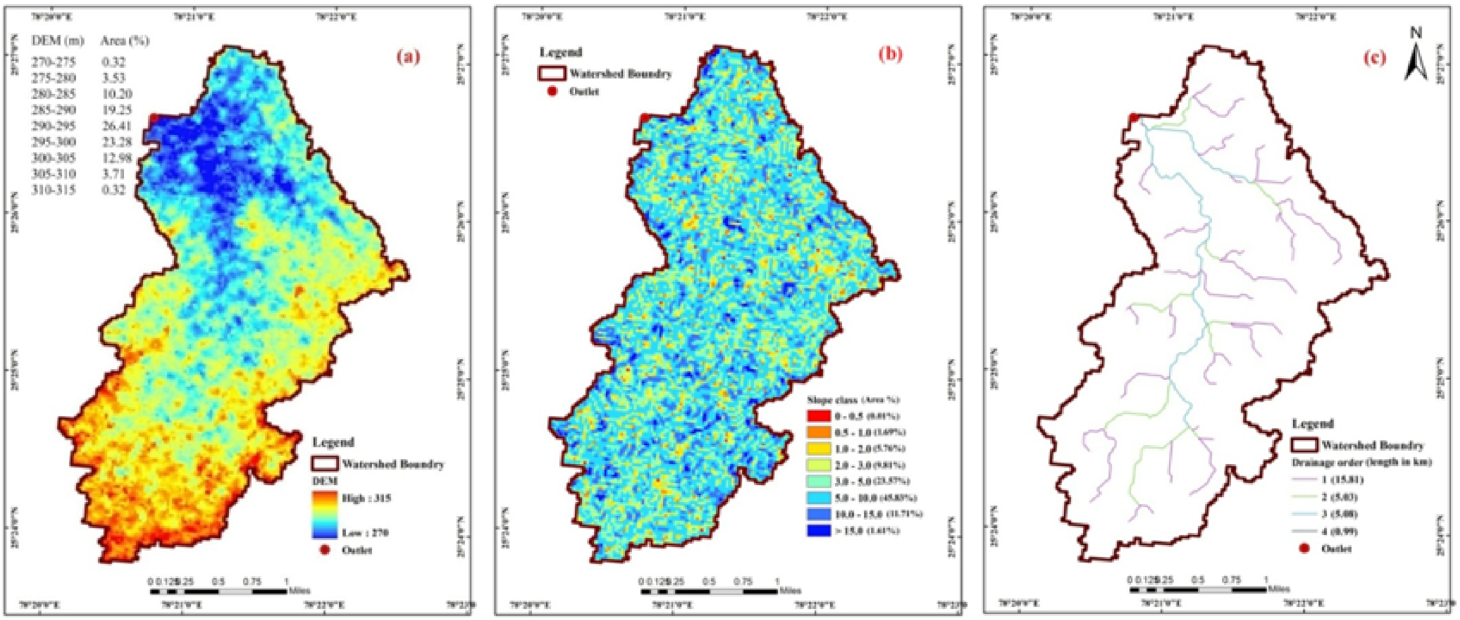

Figure 2

Digital Elevation Model (a), slope categories (b) and drainage network (c) of Parasai-Sindh watershed

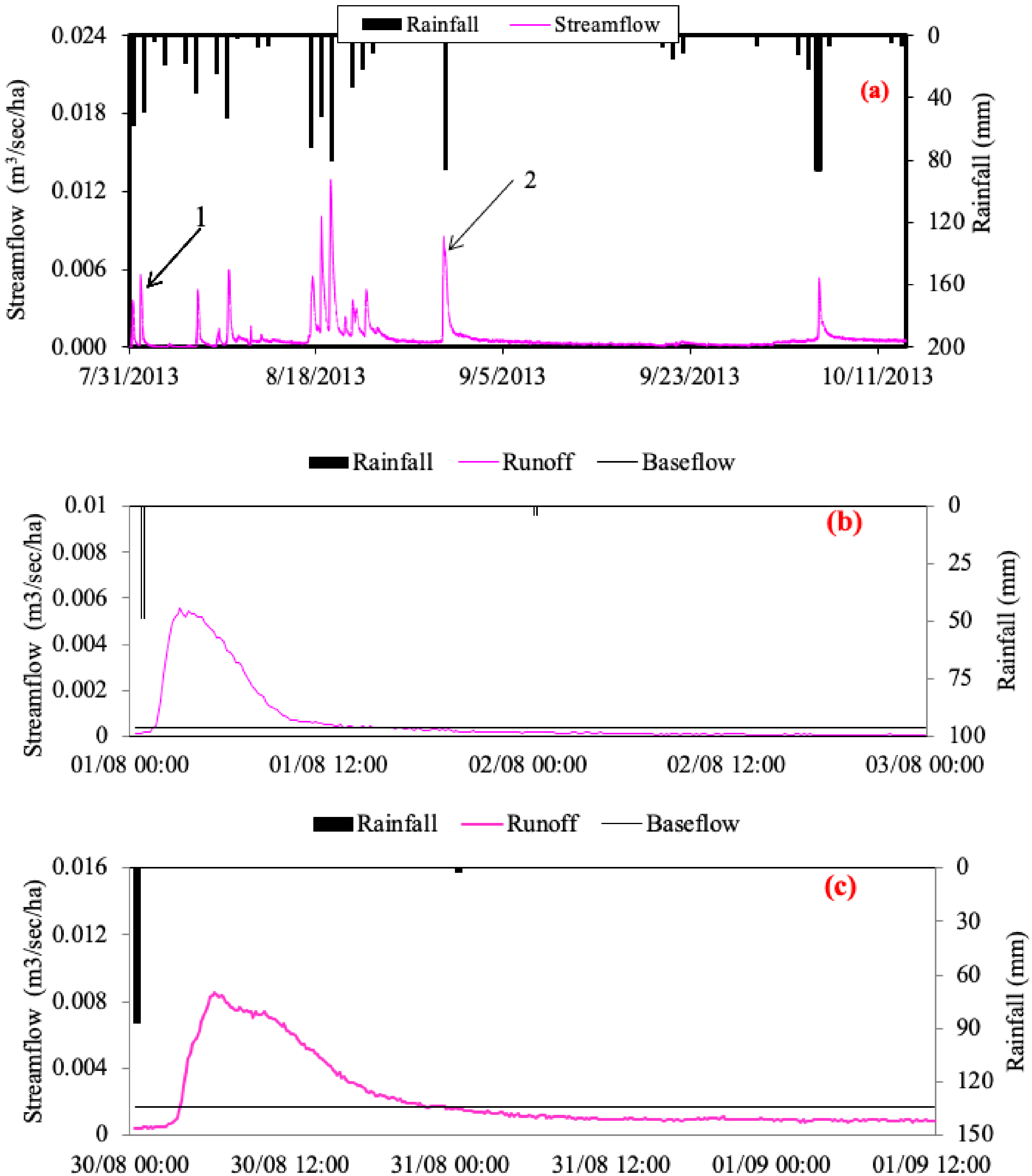

Figure 3

Study of rainfall and stormflow (a), runoff hydrograph and baseflow of selected event 1 (b) and 2 (c) at outlet of watershed during rainy season, 2013.