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Studies on mechanical, vegetative, and roof water harvesting: strategies to enhance recharge of spring and its discharge in Himalaya

Suresh Chandra Panday[a], Dinesh Chandra Mishra[a], Ram Prakash Yadav[a,*], Arunava Pattanayak[b]

[a]*Crop Production Division, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora – 263601, Uttarakhand, India, emails: rams34052@gmail.com (R.P. Yadav), sureshpanday39@yahoo.com (S.C. Panday), dcmishra15511@gmail.com (D.C. Mishra)*
[b]*ICAR-Indian Institute of Agricultural Biotechnology, Ranchi – 834010, Jharkhand, India, email: apatttanayak@gmail.com*

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ABSTRACT

The springs are a main source of water in Himalaya but these are drying mostly due to unplanned construction activities and deforestation. One of the springs of which discharge was reduced heavily selected for revival and to enhance discharge by harvesting rooftop water in trenches and planting of broad leaf species *Alnus nepalensis* on trench risers. These two methods enhanced average annual discharge by 118.9% and in 2019 (147.8%) compared to discharge (794.0 m^3/y) recorded in the year 2000 before the treatment inception. Similarly, lean period (October–June) average discharge enhanced by 117.8% and for 2018–19 it enhanced by 152.4% compared to discharge (500.7 m^3 y) recorded in the year 2000 before the treatment inception. The discharge to percent rainfall was lowest (1.8%) in year 2000 however, after treatment inception it ranged from 3.6% in year 2006 to 7.7% in year 2018. The correlation with rainfall was highly significant in different years of either daily, weekly, and monthly after treatment inception except initial year 2006 and 2007 of the treatments. Hence, it can be recommended that rooftop water and runoff harvested in trenches with broad leaves plantation can enhance discharge of water springs in hills.

Keywords: Hill water spring; Himalayan region; Recharging; Spring discharge

1. Introduction

Water is the basis of survival and essential components for functioning of cell a smallest unit of life to ecosystem. Sustainable water management is indispensable [1–3] that plays crucial role in the food production, and an essential parts of all the development activities. It is a fact that the mountain ecosystem receives more than sufficient rainfall (up to 3,050 mm), house of large amount of snow outside the pole and origin of several rivers and tributaries. Since 1871 to 2007 the extreme rainfall events of >500 mm (504–820 mm) has occurred 33 times with large variation of annual and monthly rainfall [4]. Himalayas considered "Water Towers" of Asia [5,6] and supports ~1.5×10^9 human population for their survival and economic activities [4]. The population of Himalaya is growing at 3.3% annually in last 50 y (1961–2011) [7]. Inspite of all these water reservoirs, mountains are facing wide spread scarcity in all the sector including domestic sector where water supply is not sufficient. Springs are the main water resources for 60% of residents of Indian Himalayan region [8] for drinking [9] and other household purposes in the habitat of the high lands [10–12].

The springs are point or place where ground water emerges on earth surface and flows out from earth profile. The human settlement developed around natural water resources, that is, water springs in sub-humid and humid areas of North-Western Himalayan regions. Almora town founded in 1,563 traditionally depends

* Corresponding author.

upon its *naulas* (natural springs) and *dharas* (seepages). The area has shallow aquifers that feed its springs [13]. The findings of a study revealed that ~50% population of Kumaun region is dependent on spring to meet their daily water requirements [14]. However, rapid increase in population, unplanned urbanization with extreme construction and the extension of agriculture from safe to steep slope are the factors contributed to poor utilization and damage of water resources particularly water springs.

Springs in the Himalayan region contribute to base flows of streams and rivers. The mountain people have used spring water most significantly, since ancient times to meet most of their basic needs. The demand of increasing population, upcoming technology, changes in rainfall patterns, and a poor legal policy framework for managing groundwater resources call for a specific paradigm on spring water management in the Himalaya to conserve these resources. The springs are drying up and/or becoming seasonal besides the difference in the volume of water flowing down in the rivers during dry and rainy season is commonly more than 1,000 times, resulting in too–little–and-too-much–water syndrome – a common feature of the desert country [15]. It is well-known feature of Himalayan region and known to every inhabitant of hills that perennial springs discharge is reducing day by day and are becoming seasonal and these seasonal springs are being get dried. The study of *Gaula* river catchment in lesser Himalaya with 40% of the villages revealed that the extent of spring discharge declined in the last 5–50 y ranged from 25% to 75%, and more than 2% of the springs completely dried up in the last 15–20 y [15]. The water resources has greatly dwindled over the years to such extent that ~60% population need travel 1–5 km to fetch 20 L water for house hold consumption [16]. Therefore, large working population migrated to plains that clearly highlight the grim situation of villages, which are going to face acute water shortage in future.

Over the last 150 y, the number of springs has declined from 360 to 60 in Almora region of Himalaya [13] and nearly 8,000 villages are currently facing acute water shortage even for their drinking purposes [17] in Himalaya. The factors such as human activities [18,15,19], increased rainfall intensity, reduction in winter rains [20], climate change and anthropogenic activities [21,22], besides, recharge area characteristics [23,24], deforestation, land use changes, intense grazing, reduced water retention capacity of catchments and declining rainfall [15,25] are responsible for drying and decrease of spring discharge. The spring hydrograph [12] are the only way to administrate and forecast spring by studying their temporal discharge variation.

Hence, the reviving and rejuvenation of springs is the need of the hour in order to ensure the supply of water and reduce water-carrying load of especially women and children in hills. The manipulation in recharging zone (catchment) characteristics and regulating weather are two potential factors to enhance discharge of hill spring. However, it is well-known fact that weather and climate is not under human control. Annual rainfall at 0.6 mm per/y and *kharif* rainfall at 1.15 mm per season are declining and rainy days of 25 mm decreasing, but higher rainfall rainy days of 50, 75, and 100 mm is increasing [26]. These changes also play role in reducing water discharge of hill springs. Therefore, change in catchment (recharging zone) characteristics to increase water infiltration and percolation in spring aquifer is only possible and reliable option to recharge the spring that can contribute to enhance spring discharge. The main purpose of artificial spring recharge technology is to store excess surface runoff for later uses and ensure the water availability during lean period (October–June). The water storage at surface of the earth is not feasible due to multiple (percolation, infiltration, and evaporation) losses of water. The injecting of water in subsurface aquifers and its storage in soil profile is a better option for augmenting and ensuring water availability. The recharging also required to reduce runoff, erosion, flooding and maintain base flow of small and large rivers originated from non-snow area such as *Kosi* and *Gaghar* in Indian Himalaya. Until now, the studies focussed the analysis based on annual rainfall and discharge, however, in our current study we have also analyzed the relationship between daily, weekly, and monthly discharge of spring with rainfall. The heavy construction activities on spring recharging/catchment zone resulted in reduced percolation/infiltration in soil profile and ultimately reduced discharge of the selected spring. Therefore, an experiment was conducted on one of the spring with the objectives (i) to enhance discharge by recharging through mechanical and (ii) vegetational measures in Indian mid Himalayas.

2. Material and methods

The spring is located at Hawalbagh experimental farm (29°36′N latitude and 79°40′E) of ICAR-Vivekanada Parvatiya Krishi Anusandhan Sansthan, Almora at an elevation of 1,250 m amsl. The selected spring is situated in north-west side and lower part of the experimental farm (Fig. 1). The Hawalbagh experimental farm covers ~80 ha area and falls in Almora district of the Uttarakhand. The discharge of this spring is greatly reduced due to heavy construction on its catchment. The constructed area covers approximately 9,739 m^2 area out of 32,000 m^2 catchment area which was constructed during 1977–1979, 1983–1988, 1998, 1999–2000, 2004, and 2003–2006 y. The construction damaged internal water channels, which carries water to spring. The construction has also reduced water infiltration in its recharging zone and increased the siltation in close proximity of the spring due to intense runoff generated by rooftop water and activities of rats. The experiment was conducted in order to rejuvenate spring and enhance its discharge.

2.1. Climate

The mean monthly average temperature varies from 9.4°C (January) to 25.2°C (July). The average annual rainfall is 991.3 mm that varied from 650.8 mm in 1974 to 1,496 mm in 1971 of which 72.2% is normally received during June–September [26,27]. The frequency of drought years is increasing, as out of 56 y, 30 y were drought years (based on deviation of rainfall from its standard deviation) and out of 30, 16 drought years occurred during 1964 to 2000 and out of 16, four were severe drought years [27,28].

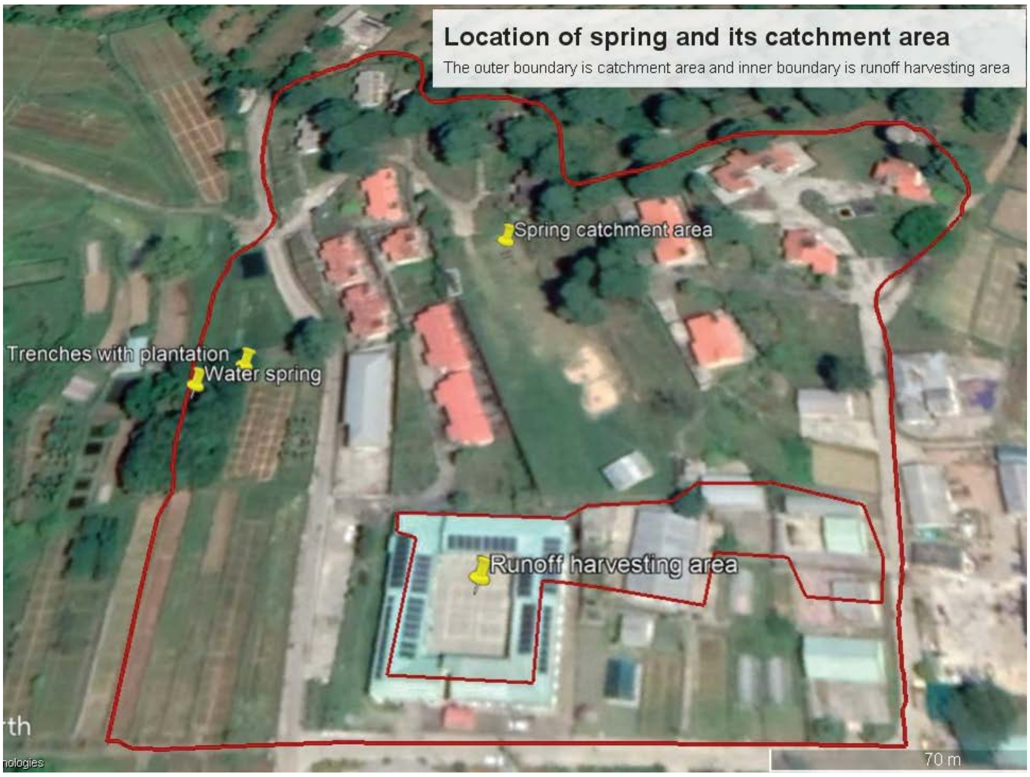


Fig. 1. Google location map of the spring and spring recharging zone.

However, after 2000 to 2019 the 14 y was drought years and out of them, five were severe [26,27].

2.2. Soils

The soils of the spring recharging catchment are formed under the cool and moist climate from rocks of biotite, schist, and phyllitic material [29]. These are shallow, gravelly, and impregnated with weathered fragments of stones and parent rock. The soils are brown to greyish-brown and dark gray in color, besides being generally non-calcareous and neutral to slightly acidic in reaction [29]. It is also presumed that the soils are influenced by river action during their formation as in all over farm round boulders are present in soil profile. This is indication that river was flowing in past period over the farm area.

2.3. Treatments

Two trenches of size 10 m × 2 m × 2 m was constructed in order to capture silt generated in upper part of catchment, avoid deposition of soil near by the spring and capture runoff generated from rooftop as well as field areas. In order to facilitate and enhance infiltration and percolation, the runoff generated from 3,200 m^2 area of the rooftop and 135 m^2 fields was diverted in these trenches. It was observed that trench captured total water during lean period but in rainy season, only 50% runoff water was retained in trenches and rest water flow out of the recharging zone. The analysis of water percolation and runoff generation revealed that the water percolated in the soil through trenches was around 27%–50% annually in different years and rest gone as runoff.

2.4. Vegetative measures

The *Alnus nepalensis* saplings of one year old were planted on trench risers in the year of 2006 to reduce evaporation of stored standing water in trenches. In addition, to increase the time of concentration of water to facilitate infiltration for longer period in aquifer recharging zone.

2.5. Data recording and analysis

The spring flow was measured manually by measuring amount of water coming out of the spring and the time taken for a measured amount of water. The spring discharge was recorded on weekly basis initially from 2006 to 2011; however, 2012 onwards daily discharge was measured. The weekly, monthly, seasonal, and annual discharge was estimated using recorded data. These data were compared with available monthly discharge data of year 2000 before the inception of treatments and the progressive data was compared. The rainfall data was collected from observatory located in Hawalbagh experimental farm and rainfall and discharge relationship was carried out to know the effect of rainfall and harvested water on the discharge. The methodology adopted for the low flow analysis is as per the procedure of Institute of Hydrology [30]. The correlation analysis between rainfall and water spring flow during different period, i.e., daily, weekly, monthly and annually was carried out to established relationship between rainfall and discharge.

3. Results and discussion

3.1. Annual discharge and annual rainfall relation

The comparative study was carried out of annual discharge recorded in the year 2000 before the inception of treatments (BTI) and after treatments inception (ATI) in 2006. The data revealed that annual discharge of water spring was 18.9%, 68.8%, 72.8%, 64.6%, 141.9%, 155.8%, 136.1%, 181.2%, 129.1%, 126.6%, 120.0%, 156.3%, 146.5%, and 147.7% higher during 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, and 2019, respectively, in comparison to annual discharge recorded during 2000 BTI (Table 1). Although annual rainfall was 39%, 19.6%, 25.8%, 26.7%, 9.4%, 29.3%, 16.3%, 21.5%, 44.4%, 25.7%, 27.5%, 41.8%, and 33.5% lower in 2006, 2007, 2008, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018 and 2019, respectively, in comparison to year 2000 BTI. However, rainfall was 14% higher only in one year, that is, 2010 in comparison to year 2000 BTI. The linear relationship of discharge with year was found significant and discharge increased 81.7 m^3/y (Fig. 2). The highest discharge (2,232.4 m^3) was recorded in the year 2013 followed by the year 2017 (2,035.0 m^3), 2011 (2,031.0 m^3), and lowest was in the year 2000 (794.0 m^3) followed by the 2009, 2006, and 2007 which ranged from 1,307 to 1,369 m^3. The linear relationship of annual rainfall with annual discharge computed by including data of 2000 BTI (Fig. 3A) and ATI (Fig. 3B) were revealed that correlation coefficient increased after excluding data of 2000. It revealed that treatments have positive effects on annual spring discharge. The percent annual rainfall to discharge study revealed that highest rainfall 7.7% was converted into discharge in year of 2018 followed by 2015, 2019, and lowest 1.8% was recorded BTI in year 2000 (Table 1).

The hydrological conditions viz., mean of the cumulative rainfall over a specific time-interval are transferred into the aquifers, by lowering or rising groundwater levels and by decreasing and increasing spring discharges [31,32] also studied the annual and monthly rainfall to predict the spring discharge in Italy. Similarly, rainfall and spring discharge relationship was studied in Petoyan Spring, Java, Indonesia and it was revealed that it is a reliable prediction [33]. The cumulative rainfall and cumulative spring flow have a power relationship besides water storage structures during monsoon months are conducive for spring discharge enhancement [10].

Table 1
Annual rainfall, discharge, and discharge of percent rainfall in different years

Year	Rainfall (mm)	Discharge (m^3)	Discharge of percent rainfall
*2000	1,201.3	794.0	1.8
2006	733	942.3	3.6
2007	966	1,337.4	3.8
2008	891	1,369.8	4.3
2009	880	1,307.0	4.1
2010	1,369.5	1,921.0	3.9
2011	1,088	2,031.0	5.2
2012	849.4	1,874.7	6.1
2013	1,005.2	2,232.4	6.1
2014	943.3	1,819.2	5.3
2015	667.9	1,799.6	7.5
2016	892.8	1,746.7	5.4
2017	871.2	2,035.0	6.5
2018	699.7	1,957.4	7.7
2019	810.8	1,967.8	6.7

*Control (data without any treatment)

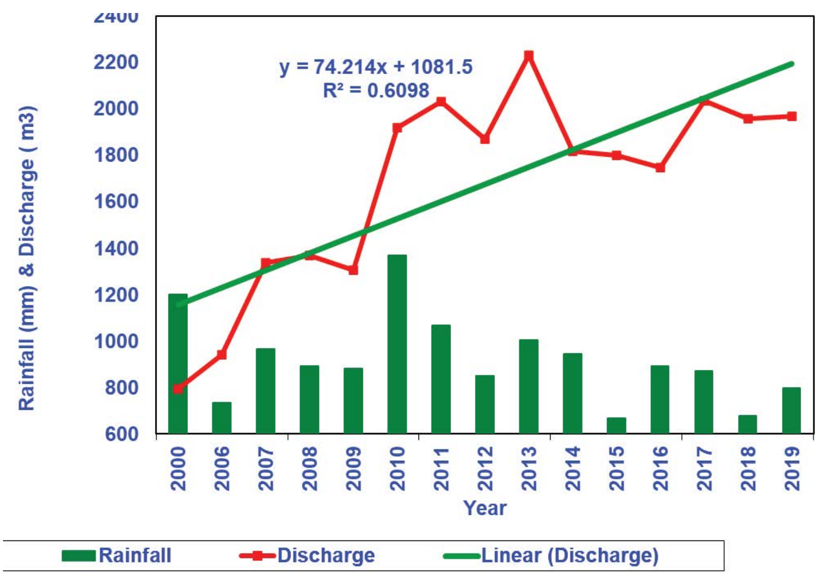
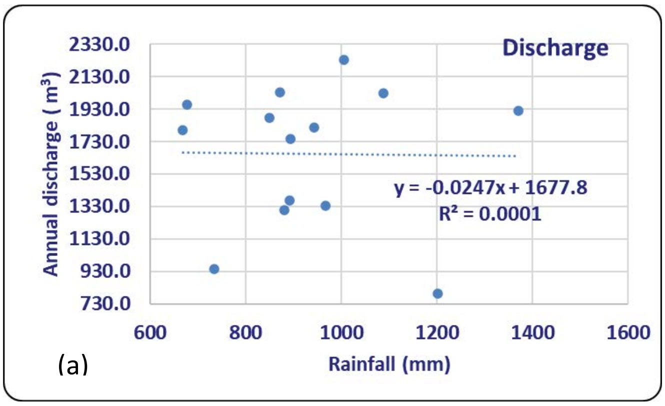


Fig. 2. Rainfall and discharge of spring before treatment and after treatment.



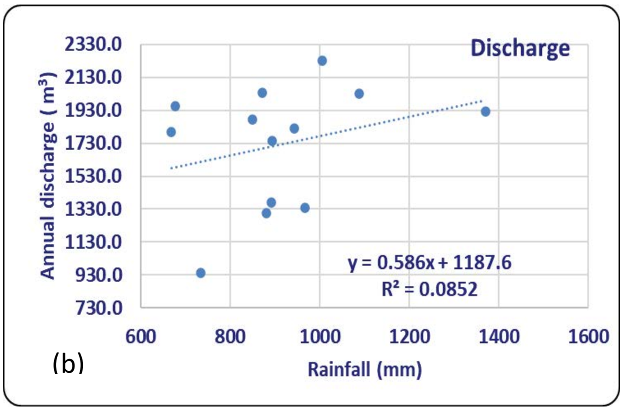


Fig. 3. Annual rainfall and discharge relationship of the spring (A) included data before the treatment inception and (B) after treatment inception.

3.2. Quinquennial (five yearly) discharge and rainfall relationship

The rainfall and the mean of quinquennial (2006–2010, 2011–2015, and 2015–2019) annual discharge revealed that the discharge increased by the 73.2%, 145.8%, and 140.1%, respectively, than the discharge recorded (794.0 m^3) in the year of 2000 BTI. Whereas, in same period rainfall was –19.4, –24.2, and –34.7% over the rainfall (1,201.3 mm) recorded in year 2000 BTI (Table 2).

3.3. Seasonal discharge relation with seasonal rainfall

The lowest rainfall during winter, summer, monsoon, and post-monsoon was recorded as 13.0 mm in 2016, 29.0 mm in 2013, 424.4 mm rainfall in 2015, and 0.0 mm in 2017, respectively (Table 3). However, lowest discharge (winter 167.5, summer 92.4, monsoon 334.8, and 199.4 m^3) was recorded in the year 2000 BTI (Table 3). It was revealed that despite good rainfall percolation of rainwater in recharging zone was very poor BTI. The highest rainfall (251.0 in 2014, 199.0 in 2007, 1,156.5 in 2010, and 106 mm in 2009), whereas highest discharge (556.8 in 2013, 438.3 in 2015, 1,047.7 in the 2017, and 386.6 m^3 in 2010) were in winter, summer, monsoon, and post-monsoon, respectively (Table 3). It was observed that not only the amount of rainfall but its distribution pattern also plays great role in discharge enhancement. The amount of rainfall in one day and same amount spread in more than 1 d will lead more percolation that will enhance discharge of water spring.

Table 2
Rainfall and monthly discharge of spring before and after treatment inception

Month	Monthly discharge (m^3)				Rainfall (mm)			
	BTI	ATI			BTI	ATI		
	Year							
	2000	2006–2010	2011–2015	2015–2019	2000	2006–2010	2011–2015	2015–2019
January	40.2	88.9	148.7	131.2	50.0	9.6	36.6	25.7
February	43.8	74.0	161.8	131.0	99.9	53.8	68.5	31.9
March	41.5	86.7	146.5	128.0	41.4	26.4	28.0	34.1
April	28.1	86.1	128.8	109.2	22.7	35.5	31.4	44.5
May	22.8	74.9	97.7	109.9	101.3	80.6	25.2	49.1
June	41.5	90.1	152.2	128.8	306.2	88.2	179.6	109.6
July	55.4	122.9	252.5	230.8	193.1	203.0	227.5	209.5
August	90.6	152.8	245.1	334.9	249.1	212.6	191.0	183.8
September	147.3	197.7	192.0	197.7	125.6	218.4	65.2	70.8
October	113.8	165.6	163.1	156.1	0.0	23.1	31.3	12.0
November	85.5	120.8	129.7	119.8	9.5	5.0	1.8	2.1
December	83.5	114.9	133.3	128.9	2.5	11.7	24.7	11.0
Total (annual)	794.0	1,375.5	1,951.4	1,906.4	1,201.3	967.9	910.8	784.0
Discharge (±, %) of rainfall (%) than year 2000	–	73.2	145.8	140.1	–	–19.4	–24.2	–34.7

BTI, Before treatment inception; ATI, After treatment inception

Table 3
Seasonal rainfall and discharge in different years during experimentation period

Year	Winter (December–February)		Summer (March–May)		Monsoon (June–September)		Post-monsoon (October–November)	
	Rainfall (mm)	Discharge (m^3)	Rainfall (mm)	Discharge (m^3)	Rainfall (mm)	Discharge (m^3)	Rainfall (mm)	Discharge (m^3)
2000	152.4	167.5	165.4	92.4	874	334.8	9.5	199.4
2006	23.5	193.5	161	137.4	543	409.5	5.5	201.9
2007	153.5	240.4	199	306.5	602.5	512.1	11	278.4
2008	23.5	285.8	111.5	215.3	748.5	589.5	7.5	279.3
2009	54	307.9	159.5	250.1	560.5	463.2	106	285.8
2010	121	361.5	81.5	329.7	1,156.5	843.2	10.5	386.6
2011	71	428.2	154	361.4	815.5	902	47.5	339.3
2012	46	421.1	58	327.9	736.7	815.6	8.7	310.2
2013	197.5	556.8	29	364	761.7	1,030.20	17	281.4
2014	251	426.2	61.5	373.2	578.3	717.8	52.5	301.8
2015	83.5	386.5	120.2	438.3	424.2	743.2	40	231.6
2016	13	258.2	119.8	264.8	756.5	944.9	3.5	278.8
2017	31	358.3	150.8	287.4	689.4	1,047.70	0	341.6
2018	19.5	383.9	126.1	388.2	531.7	885.5	22.5	299.8
2019	145.5	512.5	121.0	357.1	466.9	839.8	27.0	227.8
Mean	88.6	341.1	121.2	295.5	698.5	731.4	24.4	286.8
Lowest	13	167.5	29	92.4	424.2	334.8	0	199.4
Highest	251	556.8	199	438.3	1,156.5	1,047.70	106	386.6
SD	75	105.8	48.6	96.9	183.1	233.5	28.8	51.7

The seasonal rainfall was correlated with discharge of the same period and it was revealed that correlation coefficient was negative when the data of year 2000 BTI was included for calculating correlation. Similarly, correlation coefficient was improved when calculation was carried out excluding data of year 2000 BTI (Table 4). It was revealed that discharge and rainfall correlation coefficient was higher (0.89, –0.89, 0.45, 0.001, 0.08, and 0.3 per season per year) during ATI in comparison to (0.65, –0.62, 0.25, 0.0001, 0.002, and –0.17 per season per year) when data of 2000 BTI was included in winter, summer, monsoon, post-monsoon, annual, and lean period (October–June), respectively.

3.4. Lean period discharge

The trenching and plantation helped in increasing recharge of spring and increasing discharge as it is evident that winter rainfall was 5.0% and 6.0% higher in 2007 and 2015, however, discharge was 42% and 147% higher than the year 2000 BTI. Besides, in 2011, rainfall was lower (39%) nevertheless discharge was higher. During year, 2000, 2007, 2011, and 2015 almost similar amount of rainfall was received but discharge was higher (147%) in year 2011 in comparison to year 2000 BTI in winter season. It reveals clear-cut effect of trenches, water harvesting and vegetation on discharge. The lean period discharge (October–June) was increased tremendously ATI, however, it was gradually reduced towards June (Fig. 4). The highest mean discharge was recorded during 2011–2015 followed by 2015–2019 and 2006–2010. The lowest discharge was recorded during 2000 BTI (Fig. 4).

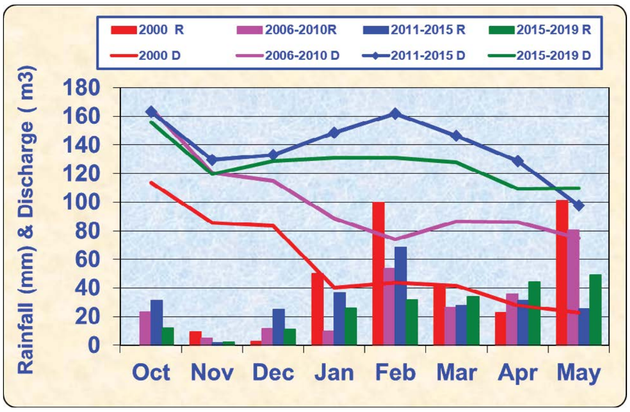


Fig. 4. Spring discharge (D) and rainfall (R) during lean period (October–June) before and after the treatment inception during different years.

3.5. Winter discharge and rainfall

Winter rain impact was positive and it was increased over the years. The discharge of the year 2000 was 167 m^3 with rainfall 152.4 mm, however, in the year 2007 discharge was 238.2 m^3 (42.6% higher) with rainfall 160.5 mm and in

Table 4
Annual, seasonal rainfall, and discharge linear relationship of different seasons over the years

Season/annual	Including year 2000 BTI			ATI from 2006		
	Slope	R^2	Significance level	Slope	R^2	Significance level
Winter	0.6546	0.1634	NS	0.8934	0.3502	5%
Summer	–0.893	0.2008	NS	–0.6214	0.1423	NS
Monsoon	0.2453	0.037	NS	0.4518	0.1523	NS
Post-monsoon	0.0567	0.001	NS	–0.0564	0.0013	NS
Annual	–0.0247	0.0001	NS	0.586	0.0852	NS
Lean period	–0.1744	0.0027	NS	0.5535	0.0323	NS

BTI, Before treatment inception; ATI, After treatment inception; NS, Non-significant.

the year 2015 discharge was 444.1 m^3 (164.2% higher) with rainfall 162.0 mm during winter season than the year 2000 BTI (Fig. 5). It is evident that rainfall was more or less similar in these years but impact was negligible in year 2000 BTI and it was increased slowly in initial year of treatment 2007 and impact was increased further at the time of full-grown plantation. Its effect was increased over the years with advancement in age of plantation as fully-grown vegetation helped in reducing evaporation, enhanced percolation and conserved the soil. Thus, the impact of water harvesting on discharge was visible and increased despite the low rainfall. This was the reason that correlation between winter rains and discharge was found significant at 5% level of significance (Table 5), however, in other season, impact was non-significant.

3.6. Monthly discharge and rainfall relations of different years

The lowest rainfall 0.0 mm was recorded for January in 2007, February in 2006, and March in 2010 (Table 5). In October month 0.0 mm rainfall was observed in the year of 2000, 2008, 2017, and 2018, for November in 2006, 2007, 2011, 2014, 2015, 2016, and 2017 and for December in the year of 2015, 2016, and 2018. The April month recorded 2.0 mm lowest rainfall in 2016, 3.4 mm in 2015 for May, 7.5 mm in 2009 for June, 96.5 mm in 2007 for July, 65.0 mm in 2014 for August, and 12.1 mm in 2015 for September. The highest rainfall was recorded for January (56.5 mm) in the year of 2014, for February (146.5 mm) in 2007, for March (76.5 mm) in 2007, for April (76.3 mm) in 2018, for May (112.5 mm) in 2006, and for June (342.5 mm) in 2013. Likewise, for July (394.9 mm) in 2014, for August

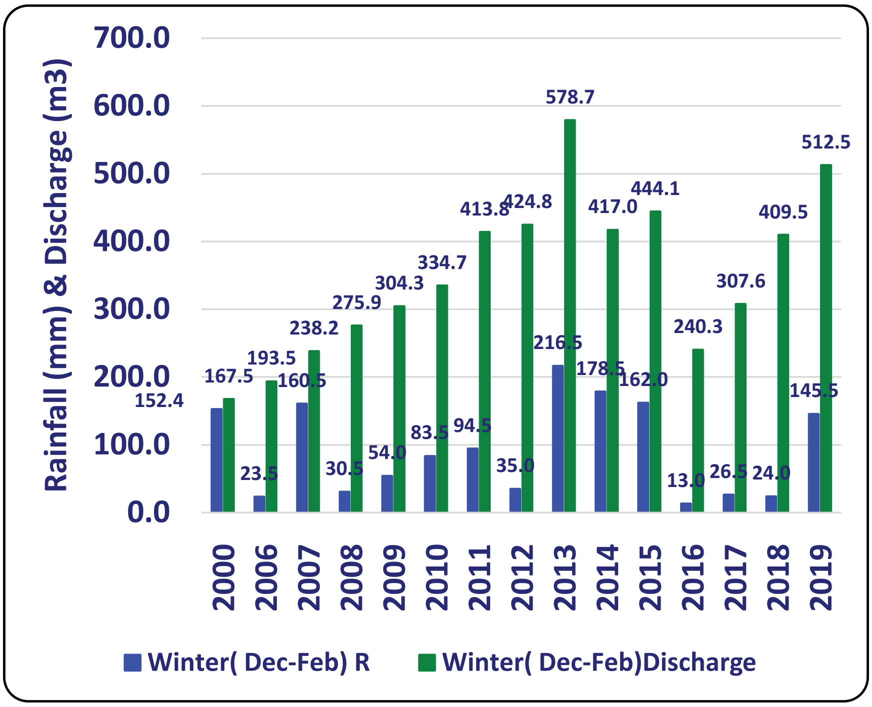


Fig. 5. Winter rainfall (R) and discharge over the years.

Table 5
Monthly rainfall (mm) in different years during experimentation period

Year	Monthly rainfall (mm)												Annual rainfall
	January	February	March	April	May	June	July	August	September	October	Number	December	
2000	50.0	99.9	41.4	22.7	101.3	306.2	193.1	249.1	125.6	0.0	9.5	2.5	1,201.3
2006	9.5	0.0	31.0	17.5	112.5	74.5	224.2	219.8	24.5	5.5	0.0	14.0	733.0
2007	0.0	146.5	76.5	73.0	49.5	100.5	96.5	204.0	201.5	11.0	0.0	7.0	966.0
2008	18.0	5.5	5.5	27.5	78.5	173.5	189.0	209.5	176.5	0.0	7.5	0.0	891.0
2009	4.0	50.0	19.0	46.5	94.0	7.5	137.5	189.5	226.0	93.5	12.5	0.0	880.0
2010	16.5	67.0	0.0	13.0	68.5	85.0	368.0	240.0	463.5	5.5	5.0	37.5	1,369.5
2011	7.0	50.0	17.5	49.5	87.0	258.5	124.0	374.5	58.5	47.5	0.0	14.0	1,088.0
2012	19.0	2.0	21.5	30.5	6.0	16.0	307.5	264.2	149.0	2.5	6.2	25.0	849.4
2013	54.5	137.0	15.5	8.0	5.5	342.5	192.2	158.5	68.5	14.0	3.0	6.0	1,005.2
2014	56.5	116.0	22.0	15.5	24.0	80.5	394.9	65.0	37.9	52.5	0.0	78.5	943.3
2015	46.0	37.5	63.3	53.5	3.4	200.5	118.8	92.8	12.1	40.0	0.0	0.0	667.9
2016	3.0	10.0	37.3	2.0	80.5	113.1	383.5	212.0	47.9	3.5	0.0	0.0	892.8
2017	25.0	1.5	28.7	20.3	101.8	100.7	287.4	149	152.3	0.0	0.0	4.5	871.2
2018	14.5	5.0	8.5	76.25	41.3	80.5	138.6	230.0	82.5	0.0	22.5	0.0	699.7
2019	40	105.45	32.45	70.3	18.25	53.4	119	235	59.25	16.5	10.5	50.5	810.8
Mean	24.2	55.6	28.0	35.1	58.1	132.9	218.3	206.2	125.7	19.5	5.1	16.0	924.6
Lowest	0.0	0.0	0.0	2.0	3.4	7.5	96.5	65.0	12.1	0.0	0.0	0.0	667.9
Highest	56.5	146.5	76.5	76.3	112.5	342.5	394.9	374.5	463.5	93.5	22.5	78.5	1,369.5
SD	19.9	53.1	20.7	24.7	39.2	101.9	104.3	73.2	114.9	27.2	6.5	23.0	186.8

Table 6
Monthly discharge (m^3) during different years of experimentation

Year	Monthly discharge (m^3)												Annual rainfall
	January	February	March	April	May	June	July	August	September	October	Number	December	
2000	40.2	43.8	41.5	28.1	22.8	41.5	55.4	90.6	147.3	113.8	85.5	83.5	794. 0
2006	59.8	33.3	46.2	39.4	51.8	56.2	117.6	112.7	123.1	124.1	77.8	100.4	942.3
2007	69.2	68.5	93.7	119.9	92.9	88.6	116.1	158.5	149.0	166.1	112.3	102.7	1,337.4
2008	94.6	78.6	81.2	74.9	59.1	86.4	122.8	165.2	215.1	154.0	125.3	112.5	1,369.8
2009	107.1	84.7	87.5	77.8	84.8	74.3	118.3	100.0	170.6	156.2	129.6	116.1	1,307.0
2010	113.8	104.8	125.0	118.8	85.9	145.2	139.9	227.7	330.5	227.7	159.0	142.8	1,921.0
2011	150.0	121.0	120.5	139.7	101.2	144.0	208.1	306.0	243.9	186.0	153.3	157.2	2,031.0
2012	143.1	124.4	114.5	108.4	105.0	81.8	222.0	297.1	214.7	154.7	155.5	153.5	1,874.7
2013	159.6	265.7	167.0	116.9	80.1	348.5	265.0	251.7	165.0	151.8	129.6	131.6	2,232.4
2014	136.2	149.2	165.9	112.6	94.8	87.3	293.2	179.7	157.7	179.1	122.7	140.8	1,819.2
2015	154.4	148.9	164.4	166.5	107.4	99.4	274.2	191.1	178.6	144.0	87.6	83.2	1,799.6
2016	80.4	76.7	99.1	76.3	89.4	153.2	275.6	328.3	187.8	169.5	109.3	101.1	1,746.7
2017	108.0	98.5	98.5	83.5	105.4	178	333.5	274.8	261.5	191.5	150.0	151.8	2,035.0
2018	129.3	128.4	117.5	115.8	154.9	118.9	131.0	420.3	215.1	146.0	153.8	126.1	1,957.4
2019	183.7	202.6	160.7	104.1	92.3	94.5	139.7	459.9	145.7	129.3	98.5	156.7	1,967.8
Mean	110.4	109.0	108.8	98.5	88.3	121.7	190.9	221.7	197.1	161.8	125.1	121.7	1,654.8
Lowest	40.2	33.3	41.5	28.1	22.8	41.5	55.4	90.6	123.1	113.8	77.8	83.2	794.0
Highest	159.6	265.7	167.0	166.5	154.9	348.5	333.5	420.3	330.5	227.7	159.0	157.2	2,232.4
SD	37.6	57.4	39.6	37.5	30.6	76.1	86.4	96.5	54.8	28.7	27.7	25.4	433.1

Trench construction and water harvesting treatments were started in year 2006

(374.5 mm) in 2011, for September (463.5 mm) in 2010, for October (93.5 mm) in 2009, for November (22.5 mm) in 2018, and for December (78.5 mm) in the year of 2014 highest rainfall was recorded. The lowest discharge was recorded in nine months, that is, January, March, April, May, June, July, August, September, and October in the year 2000 BTI (Table 6). Lowest discharge was recorded in February (33.3 m^3) and November (77.8 m^3) in 2006 whereas, for December (83.2 m^3) it was recorded in 2015. The lowest annual discharge (794.0 m^3) was observed in year 2000 BTI, followed by in 2006, 2009, 2007, and 2008. However, annual highest (1,369.5 mm) rainfall was recorded in the year 2010 followed by (1,210.3 mm) in 2000 BTI. The results were revealed that treatments (trenches, rooftop water harvesting, and plantation) recharged soil profile and aquifers of water spring and it manifests in discharge of spring.

The relationship between rainfall and discharge was established to explore the effect of spring recharging techniques on water spring discharge in different years (Table 7). The monthly discharge with monthly rainfall was significant positively correlated for the year 2008, 2009 (at 10% level of significance), 2010 (at 2% level of significance), 2011 (at 5% level of significance) 2012 to 2014, 2016, 2017 (at 0.01% level of significance), 2018 (at 1% level of significance), however, in the year 2006, 2007, and 2015 it was non-significant. It is worth to mention that negative correlation (non-significant) between the discharge and rainfall was observed in the year of 2000 BTI. It was exhibited that treatments increased percolation, hence discharge was increased and it can be inferred that if trenches made in recharging zone and water harvested from concrete area will tremendously enhance discharge. The above results was indicated that treatments enhanced percolation of rainfall in aquifer as year 2000 rainfall and discharge was negatively correlated, however, ATI rainfall and discharge was significantly correlated from year 2008 onwards. The non-significant correlation with rainfall in the year 2006 and 2007 might be due to initial years of treatment inception besides, due to some rats' activity that resulted runoff out of the system led no infiltration/percolation in the soil profile and water spring aquifer. Out of 14 y annual rainfall and evaporation ratio was more than one in 7 y and in rest 7 y the ratio was less than one. The highest ratio (1.51) was recorded in 2010 followed by in 2011 (1.39), 2014 (1.23), and in year 2000 (1.19) BTI and the lowest was 0.74 in the year 2006 (Fig. 6).

The month wise discharge and the rainfall relation was also worked out over the years (Table 8). The results revealed that discharge and rainfall was positively correlated in January and September at 2%, in February at 5%, in June at 1% level of signficance, and in rest of the months

Table 7
Linear relationship between monthly rainfall and discharge in different years

Year	Slope	R^2	Significance level
2000	–0.0259	0.0048	Non-significant
2006	0.1533	0.1299	Non-significant
2007	0.1337	0.0912	Non-significant
2008	0.235	0.2000	10%
2009	0.1968	0.2368	10%
2010	0.2821	0.4073	2%
2011	0.3067	0.3557	5%
2012	0.4794	0.7245	0.01%
2013	0.7108	0.9063	0.01%
2014	0.4188	0.6637	0.01%
2015	0.2731	0.0906	Non-significant
2016	0.5671	0.6366	0.01%
2017	0.7526	0.6756	0.01%
2018	0.949	0.5937	1%
2019	1.3833	0.7511	0.01%

Table 8
Monthly rainfall and discharge linear relationship of different months over the years

Month	Including year 2000 BTI			ATI from 2006		
	Slope	R^2	Significance level	Slope	R^2	Significance level
January	0.5606	0.0899	Non-significant	1.1119	0.424	2%
February	0.3764	0.122	Non-significant	0.5012	0.226	10%
March	–0.1667	0.0082	Non-significant	–0.0004	7E-08	Non-significant
April	0.6833	0.1834	Non-significant	0.5878	0.1889	Non-significant
May	–0.3682	0.2201	10%	–0.2461	0.1444	Non-significant
June	0.342	0.2154	10%	0.5712	0.5713	1%
July	0.3526	0.1813	Non-significant	0.3219	0.1883	Non-significant
August	0.3232	0.0639	Non-significant	0.4213	0.1243	Non-significant
September	0.2972	0.4069	2%	0.2958	0.4326	2%
October	0.0884	0.0075	Non-significant	0.0103	0.0001	Non-significant
November	1.2306	0.0862	Non-significant	1.6598	0.1804	Non-significant
December	0.5591	0.2217	10%	0.4669	0.1918	Non-significant

BTI, Before treatment inception; ATI, After treatment inception

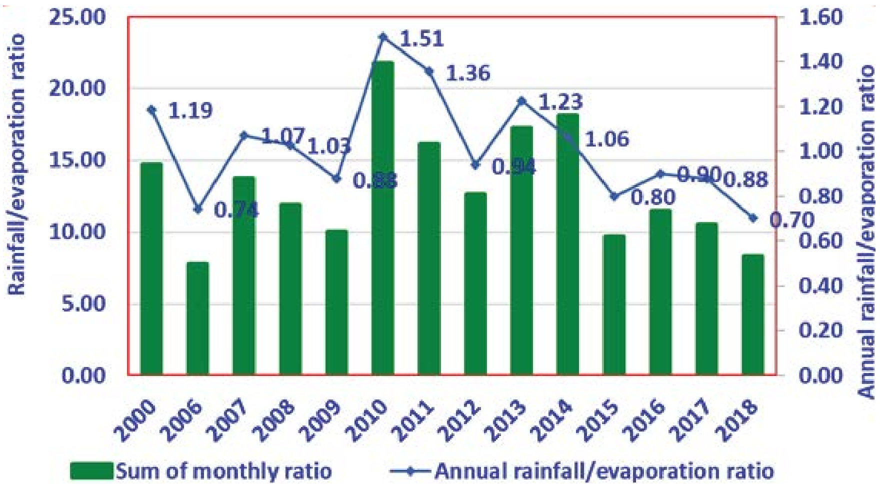


Fig. 6. Annual rainfall and evaporation ratio in the different years.

non-significant positve correlation was obtained however, in the March, May, and October discharge and rainfall was negatively correlated. The negative correlation during March and May may be due to rainfall might have been contributed to meet high evaporative demand of atmosphere rather than profile recharge and contribution to the discharge enenhncment. The rainfall and discharge correlation showed a positive relationship in the Petoyan Spring, that is based on a simple correlation between two variables that have a value (R^2) of 0.630 [33].

3.7. Weekly discharge and rainfall relations of different years

The weekly discharge with weekly rainfall was significantly correlated (Table 9) in the year 2008 and 2009 (at 1% level of significance), and 2010 to 2018 (at 0.01% level of significance). The non-significant positive correlation was observed in the year 2006 and non-significant negative correlation in the year 2000 BTI and 2007 in a second year of ATI. The heavy rats' activity during 2007 and 2006 that did not allowed water to infiltrate in soil profile and this might be one of the reasons of negative correlation. The initial year of implementation might also be responsible for this because initial years only runoff contributed for profile recharging but plantation did not contributed due to no-significant shadow on trenches to reduce evaporation from trenches.

Table 9
Weekly rainfall and discharge linear relationship in different years

Year	Slope	R^2	Significance level
2000	–0.0225	0.0082	Non-significant
2006	0.0072	0.0007	Non-significant
2007	0.0091	0.0009	Non-significant
2008	0.1429	0.134	1%
2009	0.1000	0.167	0.01%
2010	0.1698	0.2581	0.01%
2011	0.1609	0.1981	0.01%
2012	0.3071	0.4246	0.01%
2013	0.7415	0.8407	0.01%
2014	0.3611	0.6325	0.01%
2015	0.2641	0.2304	0.01%
2016	0.4949	0.544	0.01%
2017	0.385	0.3361	0.01%
2018	0.6235	0.373	0.01%
2019	0.0701	0.2284	0.01%

The particular Standard Meterological Week (SMW) discharge during the experimentaion period (2006–2018) over the years was also correlated with rainfall of same week. The results revealed that 29, 31, 33, and 42 SMW discharge was signicantly correlated with rainfall at 10% level of significance. The 3, 25, 26, 34, and 37 SMW was positively correlated with rainfall at 5% level of significance. The 5 and 8 SMW at 2%, and 7, 27, and 38 at 1%, and 24 SMW discharge was significantly correlated with rainfall of the same week. The 19, 35, 39, 40, and 47 SMW was non-significantly correlated with rainfall of that SMW. The rest of SMW disharge was non-siginificant positively correlated with rainfall of the same week.

3.8. Relation of daily rainfall to daily discharge

The daily recorded data of rainfall with daily discharge of 24 h in m^3 was correlated from 2012 onwards and results are presented in Fig. 7. The discharge and rainfall correlation was significant at 0.01% in the years 2012–2018. The highest correlation coefficient was observed in the year 2013 and lowest in the year 2015 followed by in the year 2017 (Fig. 7). The daily discharge and rainfall can be good way to predict discharge of spring with basic discharge data. The literature survey was revealed that relationship based on daily rainfall and daily discharge is never before analysed.

3.9. Growth of Alnus spp. planted on trench risers and its relation with water discharge

The plantation of *A. nepalensis* was done in the year of 2006 at spacing of 3.0 m × 3.0 m (trees 1,111/ha) on

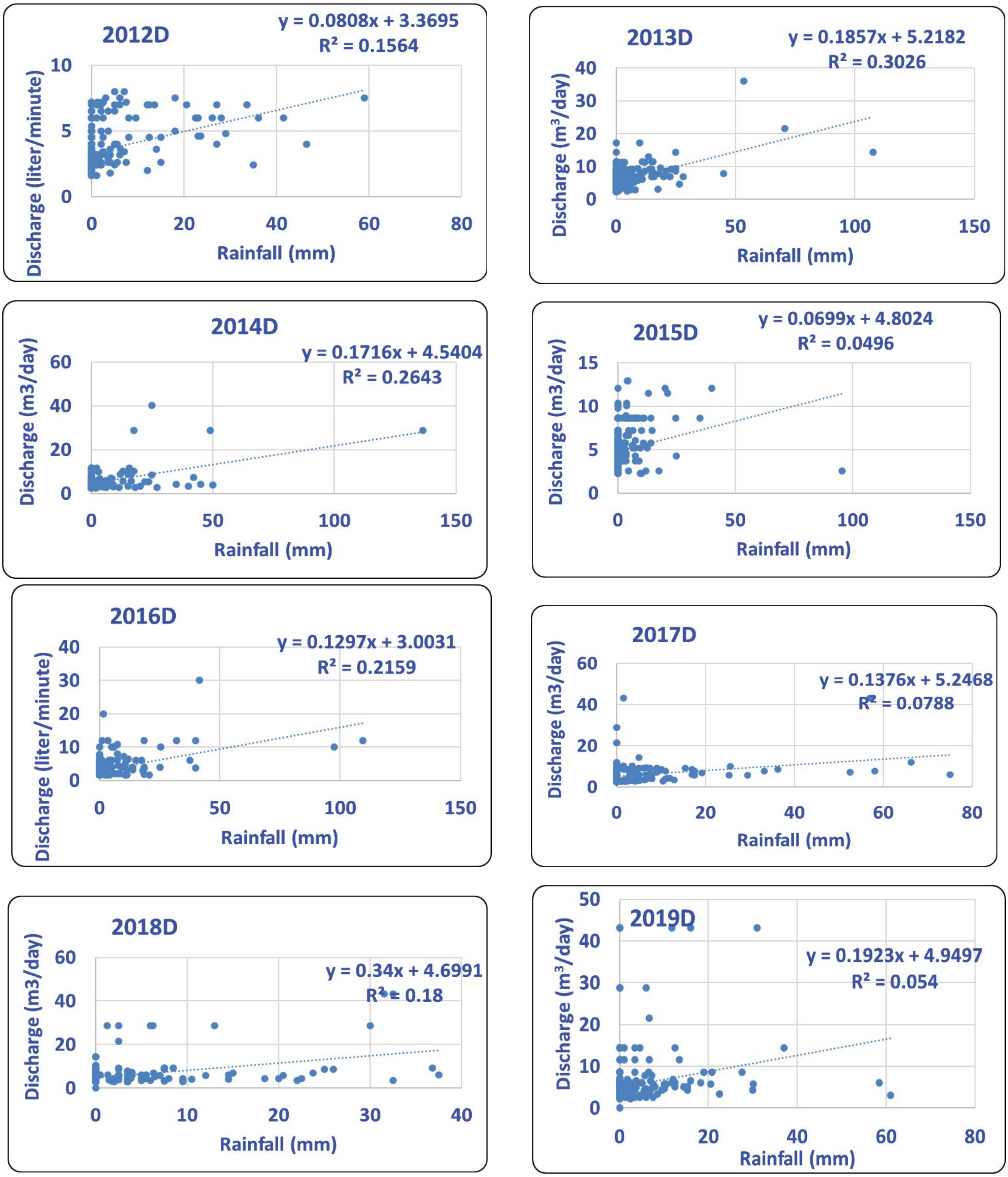


Fig. 7. Daily rainfall and daily discharge correlation of different years.

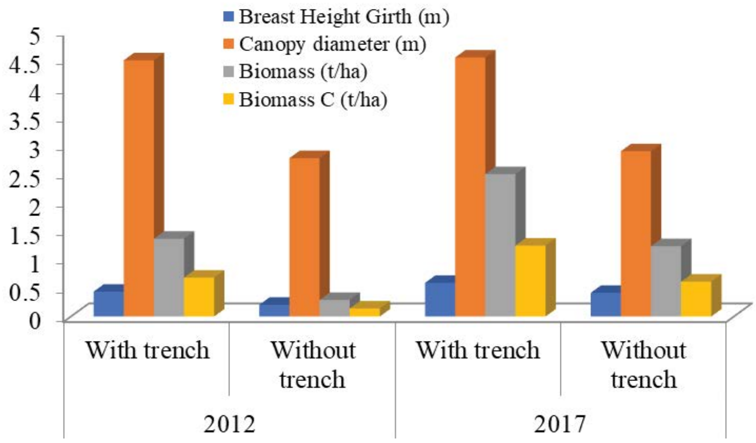


Fig. 8. Growth, biomass, and biomass C of *Alnus nepalensis* with and without trench plantation.

trenches and runoff water was harvested in these trenches. Harvested runoff water in trenches enhanced growth of *A. nepalensis* planted on trenches as compared to without trenches. With trench plantation, girth (0.43 m) was almost double and biomass (1.36 t/ha) was approximately three times higher in 2012, whereas in 2017 girth (0.59 m) was 42% more and biomass (2.49) was double compared to without trench plantation (Fig. 8).

In 2012, the combined effect of plantation and harvested runoff enhanced spring water discharge from (942.3 m^3) 2006 to (1,874.7 m^3) in 2012 and (2,035.0 m^3) in 2017. Researchers [8,18,34] were also reported increase in base flow of spring with the help of mechanical and vegetative (*A. nepalensis*, *Quercus leucotrichophora*, and *Prunus cerasoides*) measures.

4. Proposed solutions

The proposed solution to overcome the water problem is to make efficient use of the available water and at the same time increasing capacity of available water resources through adopting treatments in spring recharging zone as mentioned below:

- In the villages trenches can be excavated in recharging zone and plantation should be established on trench risers. The runoff from rooftop and fields should be diverted to these trenches.
- Over flow of spring should be stored in tanks to irrigate lands in close proximity of the area.
- Increased infiltration is required on respective spring recharging zone by using mechanical and vegetative measure.
- The spring discharge and monthly or weekly rainfall can be correlated and sound results can be obtained but over the years monthly/annually/weeklybrainfall correlation with discharge may not give accurate results.

5. Conclusion

The rooftop and surface water harvesting in treches resulted higher (117%) mean discharge of spring. The vegetative plantation helped to reduce evaporation and in increasing discharge. The annual discharge and rainfall positively correlated from the year 2006 onwards but negative relationship with rainfall was observed with inclusion the data of year 2000. The seasonal discharge was posively correlated with rainfall and slight improvement in correlation coefficient was observed, when data was taken from 2006 to 2018 in comparsion to relationship developed by including 2000 data. The significant correlation of discharge and rainfall was observed in 4 months (January, February, June, and September) over the years (2006–2018). The monthly and weekly discharge and rainfall of different years was significantly correlated with rainfall from the year 2009 to 2018. But negative correlation was observed in the year 2000 when treatment was not established in the field. Similarly, daily discharge and rainfall from 2012 to 2018 was significat posittively correlated. The above results showed that combined effect of rooftop water harvesting in treches and plantation of *A. nepalensis* increased the average water discharge by 211% of spring annually. The spring can be rejuvenated and discharge can be enhanced tremendously by harvesting water from hard rock or concrete cement areas in trenches. This study will help in recharging springs whose discharge reduced and become seasonal even dried springs can be rejuvenated.

Conflict of interest

The authors declare no conflict of interest.

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