The Implication of Hydrogeological Mapping and Recharge Structures to Revive Drying Springs in Hilly Region of Nepal

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Abstract: ***Springs are the primary source of water in the mid - hills and mountainous regions of Nepal. These springs are at risk of drying up or diminishing during the lean season due to climate variability, climate change, and land use modification over the catchment. This study intends to identify the potential recharge area of the Dudhpokhari Springs in the Kathmandu district and determine the impact of constructed water augmentation structures within the identified recharge areas. A hydrogeological conceptual layout was adapted, which involved hydrogeological characterization of the catchment based on available geological maps, topographic maps, land cover maps, and direct field observations. Monthly spring discharge data (248 samples) of three wells and one spring from 14th March 2018 to 14th April 2023 and rainfall data from January 2014 to December 2021 were analyzed to determine the effect of interventions. The study found that the interventions resulted in a significant increase in the discharge of the water supply. In particular, the discharge of all springs under study increased by 32.38 to 67.99% in winter and 28.39 to 55.82% in pre - monsoon. Furthermore, a previously dried well revived with discharge 9.3 liter per minute (lpm) in winter and 6.36 lpm in pre - monsoon. To analyze rainfall and springs' discharge variability and long - term monotonic trends the Mann - Kendall (MK), Sen's Slope estimator test, and Pettitt's test were utilized. Additionally, an unequal sample variance t - test was used to determine the effectiveness of the interventions in spring discharge. The statistically significant results of the study suggested that the water augmentation structures were effective in increasing the discharge of the springs, and may provide a sustainable solution to address the issue of diminishing spring water supply in the mid - hills and mountainous regions of Nepal.***

Keywords: hydrogeological mapping, potential recharge zone, springs, springshed, water augmentation structures

1. Introduction

Springs are primary sources of water for drinking, irrigation, and household consumption in the hills and mountain regions of Nepal (Poudel & Duex, 2017). Large numbers of mountain communities depend directly on spring water for drinking, livestock feeding, irrigation, and other uses (Chapagain et al., 2019). Almost 80% of the total 13 million hill and mountain people in Nepal rely on springs as their primary source of water (Sharma et al., 2016). Moreover, Springs are important to maintain water flow in streams, and water balance in lakes and ponds and contribute to downstream water availability (Rosegrant et al., 2009).

Nowadays, springs are drying up or dwindling due to climate variability, climate change, and land use change over the catchment (MOFE, 2019; Adhikari et al., 2020). Nearly 50% of the perennial springs in the Indian Himalayan Region have dried or become seasonal (Tambe et al., 2020). About 73.2% of the springs' decreased flow and 12.2% dried up over the past 10 or more years in the Thulo Khola watershed, Nuwakot, Nepal (Poudel & Duex, 2017). Average water availability from water supply schemes (Kalimati Khola, Nisane Khola, and Sardu - Khardu Khola) in the Sardu Khola watershed, Dharan, East Nepal has been estimated to be reduced by 40.2%, 29.9%, and 67.45% respectively during the lean season in comparison to wet season (IUCN, 2011). Factors including population growth, agricultural intensification, land use changes, deforestation, economic development, and climate change impacts are major concerns for sustainable water resource management (Merz et al., 2003; Negi G. C. S & Joshi B., 2002; Vaidya, 2012). Reduction in the amount of spring discharge threatens the livelihoods of many rural populations across the mid - hills and high hills of Nepal. Furthermore, it has direct consequences on wetland habitats, lake water, and river flow in low - lying areas (Richter et al., 2003).

Monsoonal precipitation dominates the annual precipitation around 80% of the total annual precipitation, whereas, during winter, pre and post - monsoon seasons contribute 3.5%, 12.5%, and 4.0%, respectively (Karki et al., 2017). This in combination with an increase in average temperature, changes in precipitation patterns, and a decrease in the number of rainy days (MOFE, 2015) will further impact the discharge of springs in the lean period and thereby increase the vulnerability of mountain communities. Moreover, spring discharge is influenced by spatial variation in topography, geology, and land use characteristics of the catchment (Kulkarni et al., 2021). Many of the spring sources within the Dudhpokhari, Kathmandu (study area) area have shown a variety of fluctuations in discharge, with a majority of springs drying, especially after the devastating earthquake in 2015. Climate variability and climate change are inevitable. But, land use management over the recharge area is within the hand of the people. Monsoon is the major source of groundwater (MOFE, 2015). The more the infiltration of precipitation, the more will be the ground recharge, hence the discharge of springs. The infiltration pattern is governed by the structures and orientation of rocks underneath, and fractures on it (Shrestha et al., 2018). The geological setting underneath determines the location and extent of the recharge areas of any spring/water sources. Different lithology depicts different hydrogeological functioning. The recharge area of a spring may lie within the watershed or beyond the watershed or multiple watersheds depending upon the local geology (Shrestha et al., 2018). Springshed is the potential recharge area of spring and differs from a watershed because the source of spring water is determined by aquifer characteristics and not by surface topography. Identification of recharge areas is thus important for the effective implementation of recharge intervention. This will ultimately increase spring water availability and reduce water stress vulnerability in the dry period.

This research intends to assess the implication of water augmentation structures in the potential recharge area identified by hydrogeological mapping in the Dudhpokhari area. Specific objectives are: 1) Identify the potential recharge area of Dudhpokhari springs by Hydrogeological mapping 2) Document the activities implemented within the recharge area 3) Analyse the effect of recharge interventions on the discharge of springs.

2. Materials and Methods

Study Sites

Dudhpokhari village that lies in Kirtipur Municipality - 8 has been studied based on the importance of the conservation of water. It is situated in the southwest Kathmandu Valley (Figure 1). The catchment of the spring lies within the geographical extent of 27.645^0 to 27.666^0 N and 85.235^0 to 85.256^0 E.

Dhudhpokhari spring is the main source of water for residing people (Kritipur Municipality 4) which has a dispersed groundwater source and thus also contributes to drinking water demand for residents of this Municipality belonging to ward number 1, 2, 3, 5, 6, 7, 8, 9 and 10. The dispersed groundwater is collected into wells and further supplied to the reservoir tanks. According to Dudhpokhari Janhit Samaj, Kathmandu, a local water management group about 2500 households in the Dudhpokhari area and 4400 households of the Kritipur Municipality are benefitted from this water source. The devastating earthquake with a registered magnitude of 7.8 Rector Scalre in central Nepal on 25th April 2015 and 7.3 on 12th May 2015 led to drastically diminish of seep water. The discharge measurements of the wells observed on 14th March 2018 were: 1.56 liter per minute (lpm) that of the main supply well (C8) with location 27.66174^0 N, 85.25884^0 E at elevation 1396m, and the capacity supplying 8 - inch water, 1.32 lpm that of 2nd well (C7) with location 27.66174^0 N, 85.25884^{0}E, elevation 1402 m and the supplying 7 - inch water and 180 lpm that of Paanch Dhara (PD) an another spring, located at 27.66107^0 N, 85.25895^0 E. There was no water discharge from the Dudhpokhari inner well (DIW) at the location 27.6600^{0}N, 85.26111^0 E, elevation 1390m till 2021.

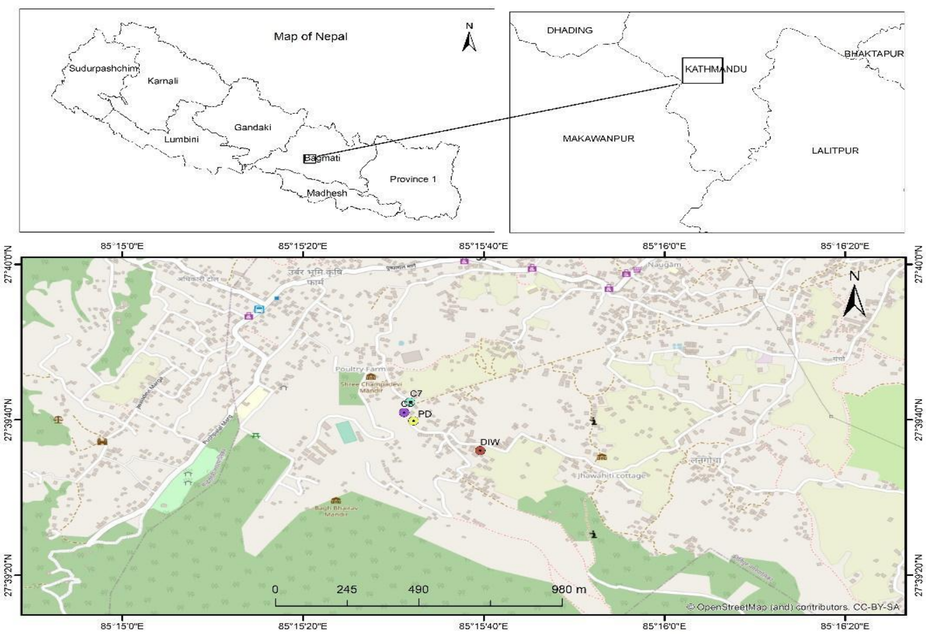


Figure 1: Location map showing district and catchment under study (source: Survey Department, Nepal 1998/1999 and modified by the researcher)

Methodological Approach

The hydrogeological conceptual layout has been adopted to identify the potential recharge areas of the springs. This method is based on the fact that accumulation and the movement of groundwater on the sub - surface are guided by the types of rock, their orientation, the openings present in the discontinuities, and structural features in the Himalayan regions (Shrestha et al., 2018). This study encompasses three steps to delineate potential recharge area; field mapping of the geology; creating a conceptual hydrogeological layout of the springshed and identifying the recharge area. A hydrogeological layout of a springshed is a geological cross - section depicting a spring and its relation to the surrounding geology viewed in 3 - D (Dass et al., 2021; Shrestha et al., 2018). Secondary data for hydrogeological mapping for all the study sites have been generated based on existing geological maps produced by the Department of Mines and Geology, Government of Nepal, 2011 and topographic features based on the digital database and topographic maps (1998 and 1999) published by Department of Survey, Nepal and the data has been updated based on the field observations.

It was very difficult to measure every seepage within the springs' area. We selected the two main wells (C8 and C7) supplying water for the Kritipur area, the Paanch Dhara (PD) spring supplying water for the local Dudhpokhari area, and the Dudhpokhari Inner well (DIW) which was already dried up as a reference point to find out the impact of the intervention. The members of Dudhpokhari Janhit Samaj (DJS) were trained to monitor the regular discharge measurements of these four water sources (C8, C7, PD, and DIW) and collected the monthly discharge data from 14th March 2018 to 14th April 2023. Two hundred and forty - eight samples of discharge were taken from four water sources. DJS took the initiative to revive the springs discharge and worked with Government Agencies; the Department of Forests and Soil Conservation, Basin Management Centre, Gandaki, Watershed Management Resource Centre, Kulekhani and Soil Conservation and Watershed Management Office, Lalitpur to intervene in water augmentation structures within identified potential recharge area. The interventions were; three runoff recharging dams (dimensions of 28.5'*23'*5', 29'*12.5'*6.5'and 32'*12'*6' cubic feet) and 14 numbers of series of check dams across the Rautekhola constructed to retain and accelerate groundwater recharge, seven recharge ponds with dimensions (29'*26.5'*6', 21'*24'*5', 30'*33'*5', 23'*25'*5', 18'*20.5'*4', 31.5'*28'*5'and 27.5'*34.5'*5'cubic feet) were constructed to trap the monsoon precipitation within identified potential recharge areas during 2019/20 and 2020/21 over the identified recharge zone.

Annual rainfall is an important factor contributing to the discharge of wells. Therefore, daily data of the nearest rainfall station (Khumaltar, Kathmandu) under the Department of Hydrology and Meteorology (DHM), Nepal from 2014 to 2021 have been taken and analyzed. The rainfall based on 2922 daily samples starting from January 2014 to December 2021 was interpreted. The discharge trends of four water sources before and after implementation were examined. The Mann - Kendall test has been calculated by utilizing the Kendall library (McLeod, 2022). The Mann - Kendall trend test is the statistical test for monotonic trends in time series data such as precipitation, discharge and others. Sen's slope and Pettitt's test have been calculated by using the trend library to measure the effect of interventions on the discharge pattern (Pohlert, 2023). Sen's slope with significance is calculated for the linear rate of change in precipitation data. Pettitt's test is a non - parametric test for a shift in the central tendency of a time series precipitation data. Overall data analyses were performed by utilizing R (Core Team, 2023).

3. Result and Discussion

Geology, physiography, and land cover

The discharge of any springs depends on commonly used different parameters such as precipitation, physiography, geology, lineaments, land use, etc. of the region where it recharges. The springshed of the Dudhpokhari area lies above the basement rocks and valley - fill deposits. The generalized slope of the valley is northeast. The exposures of basement rocks are found at around 1400 m and elevation ranges from 1354 m – 2424 m in the study area (Figure 2a).

The study area comprises three different lithological units in the catchment (Figure 2a). Chitalang Formation contains dark slate and argillaceous limestone with white quartzite (DMG, 1998). This formation has low permeability in quartzite and thickly bedded slate which indicates low potential for groundwater.

Chandragiri Formation consists of pale blueish grey to brown, medium to thick - bedded, massive, and finely crystalline limestone, at places with sandstone and phylites, locally siliceous or dolomitic limestone (DMG, 1998).

The study area has good groundwater potential in limestone with medium to high permeability. Dudhpokhari springs have been emerged in the contact region between the Chandragiri formation and the overlying alluvial fan deposit.

Due to the porousness of the Chandragiri formation, a significant amount of seepages are found in the Dudhpohari area. Alluvial Fan Deposit consists of gravel, sandy gravel, sand, and silt. This deposit has a high potential for shallow groundwater and high infiltration of surface water (DMG, 1998). It is favorable land for groundwater recharge and dry cultivation.

According to the land cover map published by ICIMOD in 2019, the dense forest area was in the highest proportion (Figure 2b), whereas agricultural lands covered most of the valley in the watershed. The thick forest area always maintains soil moisture. The study of land cover supports while recommending the types and size of water augmentation structures within the recharge area. If the recharge areas lie in settlement areas or on private land, it would be necessary to get permission from landowners.

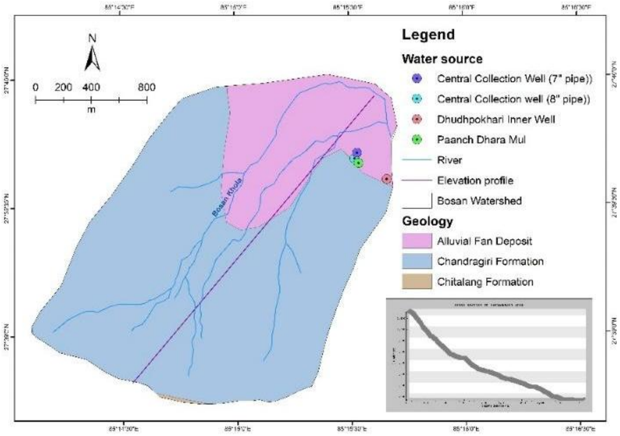


Figure 2 (a): Geological map of the Bosan watershed (Source: Department of Mines and Geology)

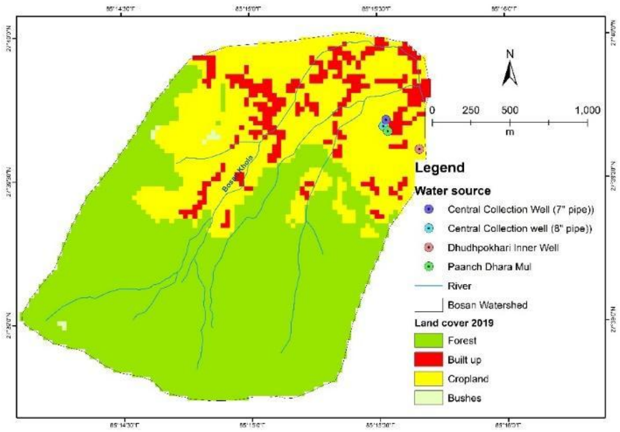


Figure 2 (b): Land cover map of 2019 of the Bosan Khola watershed (Source: Regional Database System, ICIMOD)

Conceptual hydrogeological layout and potential recharge area

The Dudhpokhari springs lie within the Raute Khola micro - catchment of the Bosan Khola catchment. It has dense vegetation with steep terrain in the hilltop area. The abrupt change in terrain as well as vegetation is the unique feature of the area. Hard rocks are abundant in steep terrain and residual/colluvial materials are found in gentle terrain. The Dudhpokhari area has a significant amount of spring discharge at the foothill of the forest area with numerous water seepages.

The cross - sectional view of the Dudhpokhari area is shown in a three - dimensional conceptual hydrogeological layout (Figure 3a). The southwest of the hilltop area comprises dark slate and argillaceous limestone with white quartzite of the Chitalang Formation. The other southwest valley beyond the Champa Devi hilltop is the axial area of a larger syncline (DMG, 1998). The Chandragiri Formation covers most of the Dudhpokhari catchment area on the surface. This formation consists of pale bluish - grey to brown, medium to thick - bedded, massive, and finely crystalline limestone, at places with sandstone and phyllite. The dominant limestone area has a good potential for groundwater recharge due to its high infiltration rate of surface water and good permeability.

The discontinuities such as joints and fractures present in the water - bearing lithological units contribute to groundwater movement towards the springshed and hence favor the springs' discharge (Figure 3a). The area has two prominent joint sets which contribute to groundwater recharge from the studied potential recharge area. The large - scale fault zone in between the Chandragiri Formation shows a distinct topographic break in the terrain. The faulted zone is considered the region of groundwater recharge as well as it can infiltrate a significant amount of surface water. Further downhill, the alluvial fan deposit is located which has a high potential for shallow groundwater and high infiltration of surface water. It is favorable for groundwater recharge for shallow water sources.

The hydrogeological mapping in the Dudhpokhari catchment supports the identification of a potential groundwater recharge area. Two groundwater potential recharge areas were delineated (Figure 3b) to target the sustained flow of springs and seepage downstream in the Dudhpokhari area. The estimated area of the potential recharge zones for uphill and downhill were 27.6 and 32.8 hectares respectively.

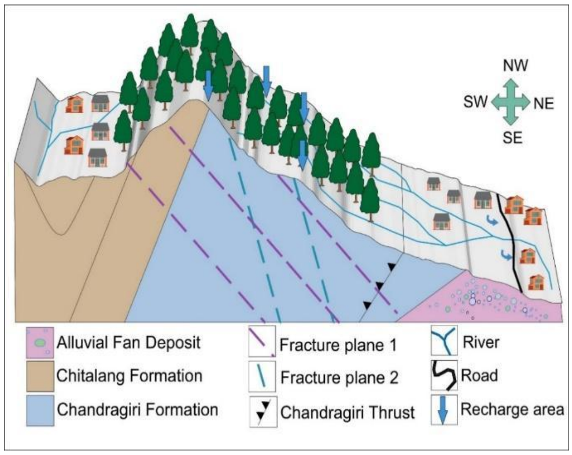


Figure 3 (a): Conceptual hydrogeological layout of Bosan catchment

Figure 3 (b): Potential groundwater recharge area of Dudhpokhari springs

Rainfall trend and discharge trend of the springs before and after intervention:

The observed data (table 1) depicted that the discharge of all three water sources increased particularly in winter and pre - monsoon season which are considered dry periods after the intervention. The DIW was revived after the intervention with winter and pre - monsoon discharge 9.3 lpm and 6.36 lpm respectively. The discharge of the C8 increased by 67.99% and 44.81% in winter and pre-monsoon seasons respectively after the intervention. Similarly, the discharge of C7 and PD increased by 66.19 %, and 32.38 % respectively in the winter season and 55.82% and 28.39% respectively in premonsoon. Interestingly, the discharge of all the water sources was found with higher discharge during post - monsoon, winter, and even in premonsoon than monsoon. It might be due to the higher residence time of the water.

Similar results were found after the experiment with simple eco - technology (i. e. spring sanctuary development) in the recharge zone of a nearly extinct spring in a Himalayan micro watershed in Uttaranchal water discharge increased from 1055 to 2153 l/day (Negi G. C. S &Joshi V., 2002). The springshed development approach to revive 5 springs using rainwater harvesting and geohydrology techniques in Sikkim, India also showed the discharge increasing substantially from 4.4 to 14.4 L/min in 2010–2011 in the lean period (Tambe et. Al., 2012). The season - wise distribution of discharge of the four water sources before and after the intervention has been given below.

Table 1: Seasonal discharge of the four water sources before and after intervention

S. No.	Season	Water source (average discharge in lpm)							
		D8		D7		PD		DIW	
		Before Intervention	After Intervention	Before Intervention	After Intervention	Before Intervention	After Intervention	Before Intervention	After Intervention
1	Monsoon	1.38	2.16	1.2	1.98	173.28	223.08	0	7.02
2	Post monsoon	1.68	3.12	1.5	2.4	184.5	246.42	0	9.6
3	Winter	1.68	2.82	1.44	2.46	187.68	248.4	0	9.3
4	Pre - monsoon	1.56	2.28	1.2	2.04	178.5	229.2	0	6.36

Trend Analysis of precipitation and discharge

The daily rainfall data as depicted by the Khumalar station, Department of Hydrology and Meteorology, Government of Nepal showed a significant pattern through time (Figure 4a). A significant rate of change and the trend were confirmed by Mann - Kendal, Sen's Slope, and Pettitt's tests (Table 2). These tests were also significant to monthly discharge data for four springs as well (Figures 4b, c, d, e, and Table 2). There were statistically significant trends in daily, monthly as well as annual precipitation and discharge data.

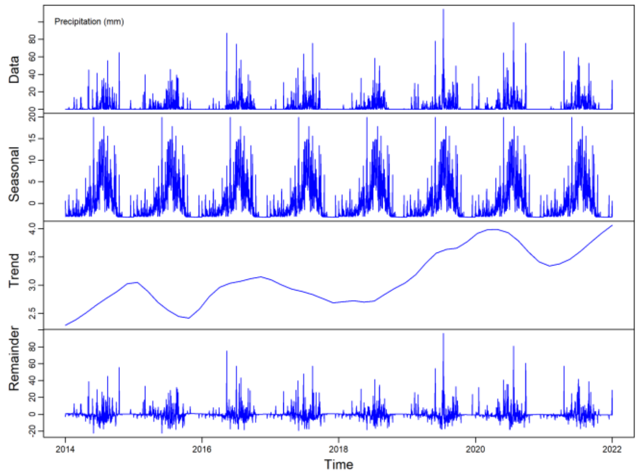


Figure 4a

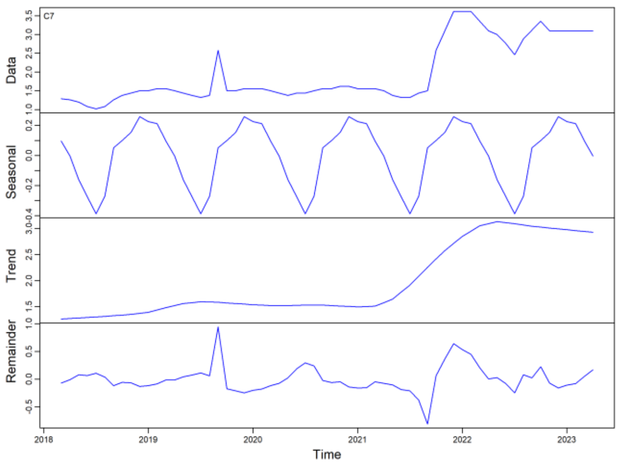
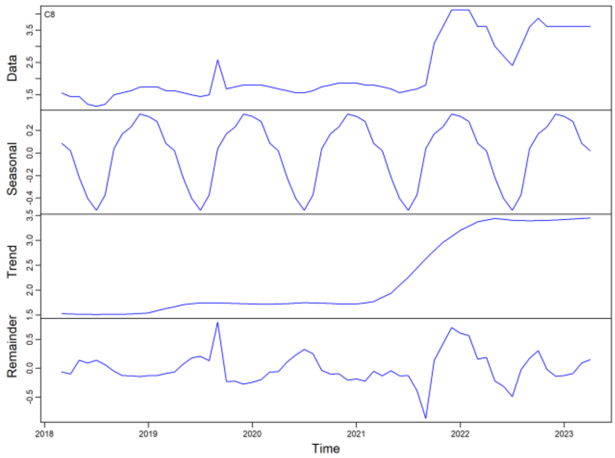


Figure 4b



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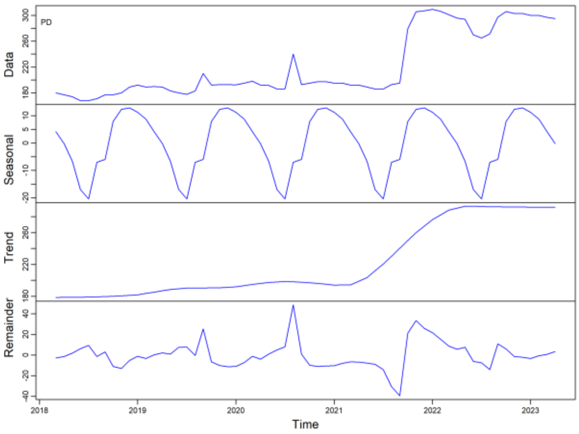

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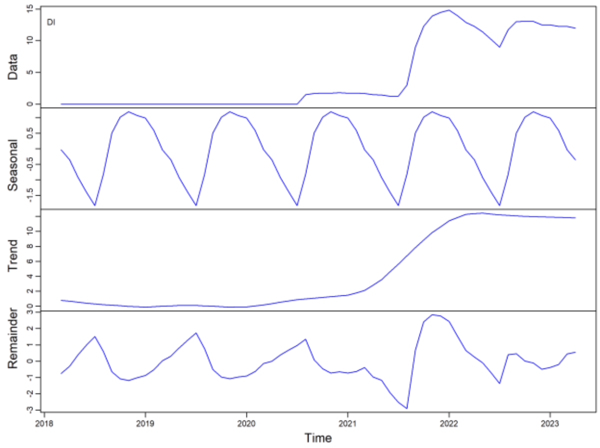

Figure 4e

Figure 4: Trend of Precipitation, and discharge of springs C8, C7, PD and DIW (Figure 4a: Trend analysis for precipitation, 4b: Trend analysis of discharge data of C8, 4C: Trend analysis of discharge data of C7, 4D: Trend analysis of discharge data of PD, 4E: Trend analysis of discharge data of DIW

Table 2: Trend analyses of precipitation and discharge data

S. N.	Variables	Test	test stat	p - value
1	Precipitation	MannKendal (tau)	0.03	< 0.005
		Sen's Slope (Z)	2.7	< 0.005
		Pettitt's test (U*)	168947	< 0.003
2	C8 - Discharge	MannKendal (tau)	0.633	< 0.001
		Sen's Slope (Z)	7.0706	< 0.001
		Pettitt's test (U*)	824	< 0.001
3	C7 – Discharge	MannKendal (tau)	0.582	< 0.001
		Sen's Slope (Z)	6.4609	< 0.001
		Pettitt's test (U*)	814	< 0.001
4	PD – Discharge	MannKendal (tau)	0.639	< 0.001
		Sen's Slope (Z)	7.2438	< 0.001
		Pettitt's test (U*)	826	< 0.001
5	DIW - Discharge	MannKendal (tau)	0.701	< 0.001
		Sen's Slope (Z)	7.5011	< 0.001
		Pettitt's test (U*)	957	< 0.001

The MK test, Sense slope test and Pettit test detected statistical significant trend. The significant trend in the precipitation depicted that there was statistical significant variability in the precipitation pattern. Discharge trend in all cases were highly significant with p value < 0.001 which indicated the significant change in discharge due to the effect of intervention within the identified recharge zone.

Significance of the Intervention (t - tests Unequal variance true)

We applied unequal two sample t - tests to determine if there were statistical significance difference between rainfall and Discharge due to the intervention of the water augmentation structures within identified recharge zone for all four springs. The parameters for t test identified are given in the table 3. All t - tests resulted significant value which means the intervention must have the significant impact.

Table 3: Unequal sample variance t - test (to test hypothesis: effect of intervention has no impact)

S. No.	Variables	t - value	df	p - value	Alternative Hypothesis
1	Precipitation vs C8	5.7348	138	< 0.001	The true difference in means is not equal to 0
2	Precipitation vs C7	5.735	138	< 0.001	
3	Precipitation vs PD	5.5705	138	< 0.001	
4	Precipitation vs DIW	5.7306	138	< 0.001	

Thus the hypothesis about the not significant impact of the intervention was rejected. It means that the precipitation has a statistically significant relation with discharge value after the intervention. From this we concluded that the discharge of springs under study has increased significantly after the intervention of water augmentation structures within identified recharge area.

4. Conclusion

Although, the dipping of the bedding plane exists opposite to the direction of the springs, due to the presence of discontinuities such as large - scale fault zone and numbers of fractures and the majority of dolomite limestone in the catchment favor the recharging of springs in the study area. The water - capturing well in the seep area which was already dried started to regain the water and the other three under study increased the discharge after the intervention within identified recharge area. The study showed that each spring has a certain recharge area which is governed by the local hydrogeology. And the intervention of proper activities over the recharge area can increase the discharge. The discharge of all the water sources was found higher during post - monsoon, winter, and even in premonsoon than monsoon. It might be due to the higher residence time of the water. A further study on this aspect is recommended. The upper recharge area of the study site lies in a forest area with sloppy terrain. A local road has been also constructed via this recharge zone. Drainage management focusing on infiltration in the region is essential to increase the ground recharge and also stabilize the catchment. This study will be a simple scientific approach to replicate the hydrogeological mapping approach to revive drying springs in the other hilly areas of the country.

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