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Original Research Article

WATER STRESS ON SPRINGS OF MIDDLE HIMALAYAN

ABSTRACT

Springs of *Uttarakhand, India* are core behind domestic water availability during rainy and especially during non rainy season even then they are highly ignored. A study was taken up at *Chandrabhaga* and *Danda* watersheds in the mountainous region of *Garhwal, Uttarakhand*. Regular spring flow measurements and automated hydro-meteorological data were collected for July 1999 to June 2010 around eleven years. The second order polynomial relationship is found best in between total annual rainfall and total annual spring flow. Spring wise available water was compared with required domestic water demand and actual domestic water uses for identification of springs under water deficit /surplus for three scenarios of spring uses as 24, 12 and 06 hrs in a day. Based on water availability of springs, the water transfer plans working under gravity for springs are suggested. In addition to temporary storage of spring water and water transfer plan, planning is required to increase the infiltration and water retention power of soil. It is recommended to promote horticulture along with animal husbandry for effective socio-economic development.

KEY WORDS: *Mid-western Himalaya; Springs;Water demand; Water transfer*

1. INTRODUCTION

The middle Himalayan ranges consist dominantly of tectonic setting that is characterized by multiple deformations resulting in superimposed folding and repeated faulting and thrusting. The rocks are highly weathered and immensely fractured which helps them to act as filter that regulates the groundwater paths for the spring as conduit or diffused flow (Waltham, 1972). The highly weathered and immensely fractured system allows a conduit (rapid) to diffused (slow) transit of water through the aquifer (Francesco Fiorillo, 2009). In rapid flow system, the aquifers are generally unable to store water over long period of time and the spring hydrographs produced may have peaks immediately after rainfall events. In slow flow system the aquifer retains water for much longer length of time with less fluctuation in spring hydrograph.

The springs of Liulin karst aquifers respond remarkably to precipitation input (Yonghong Hao et al., 2006). The Niangziguan karst Springs of China are found declining since the 1950s in response to climate change and anthropogenic activities. The results show that the contribution of climate change to depletion of Niangziguan Springs is 2.30 m^3/s and the contribution of anthropogenic activities ranges from 1.89 to 2.90 m^3/s (Yonghong Hao et al., 2009). The lesser Himalayan *Gaula* river in South Central *Kumaun* is seriously effected by deforestation of hill slope resulting in drying up of springs and reduced discharge (Valdiya and Bartarya, 1991).

Negi and Joshi (1996, 2004), in their study, found that the yield of spring flow during rainy and non-rainy seasons is affected by rainfall and recharge area characteristics and the recession of seasonal springs was much more rapid than the perennial springs. The highest water producing rate is obtained from fluvial originating springs and the highest mean rate is 405×10^3 l/d whereas the colluvium originating springs produce the lowest rate with mean lowest rate as 7.2×10^3 l/d (Negi and Joshi, 2004). Variations in discharge followed by rainfall are remarkable and noticeable, indicating rapid infiltration of rain water and recharge in colluvium originating springs (Rai et al., 1998). The flow in hill springs is seriously affected by deforestation and human activities (Valdiya and Bartarya, 1989, 1991). The springs are perennial to seasonal, derived from seepage water flowing through the shallow weathered and fractured zone indicating strong response to rainfall (Tambe Sandeep et al. 2012).

This paper deals with estimation of water stress on the springs of a representative area of Garhwal, Uttarakhand in Chandrabhaga and Danda watersheds. Spring wise monthly availability/stress of springs that are under use, has been estimated and an under gravity water transfer plan is suggested to improve the water availability.

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2. STUDY AREA

The Middle Himalayan geological formation of study area (*Garhwal*) falls under the Trans Himalaya tectonic zone with rocks of *Chandpur* formation (Gansser, 1974). Valdiya (1980) has described the rocks of *Chandpur* formation as "the olive green and grey phyllite inter-blended and finely inter-banded with meta-silt stone and a very fine grained wackes with local metavolcanics". The major rock types are phyllites and schists, which are highly fractured, foliated and weathered. Availability of water in Uttarakhand hills is scarce and variable in periods of monsoon to non-monsoon. In monsoon period the water is abundant and in summer, water is scarce and available only through springs and that concentrating to small channels and utilized by their diversion (Negi and Joshi 2002).

Chandrabhaga watershed is located geographically between latitude N30^0 18' and N30^0 19' and longitude E78^0 35' and E78^0 36' (*figure 1A)*. The altitude in this watershed ranges from 1150 m to 2350 m above mean sea level (MSL). Average annual rainfall in this watershed is of the order of 1200 mm. The area falls under the *Jakhnidhar* block of *Tehri-Garhwal* district (Uttarakhand). Danda watershed is located geographically between latitude N30° 14' and N30° 16' and longitude E 78° 37' and E78° 39' (*figure 1B).*The altitude of this watershed ranges from 780 m to 1700 m above MSL. Average annual rainfall in this watershed is of the order of 900 mm. The study area, locally known as *Khas Patti* is located in the *Hindolakhal* Block (Devprayag Tehsil) (Agarwal et., 2012). The Chandrabhaga and Danda watersheds are under sub-humid region with areas around 4.0 and 3.0 km^2 respectively and shown in *figures 1A & 1B*.

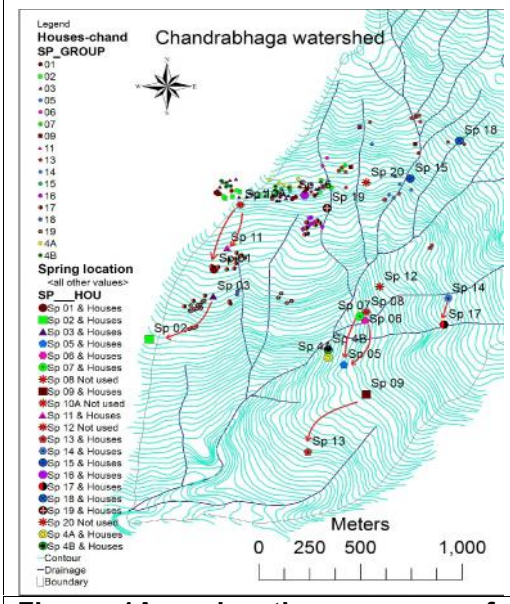

Fig. 1A: location map for Chandrabhaga watershed on soi sheet (53j11/sw) with springs, dependent houses and water transfer plan.

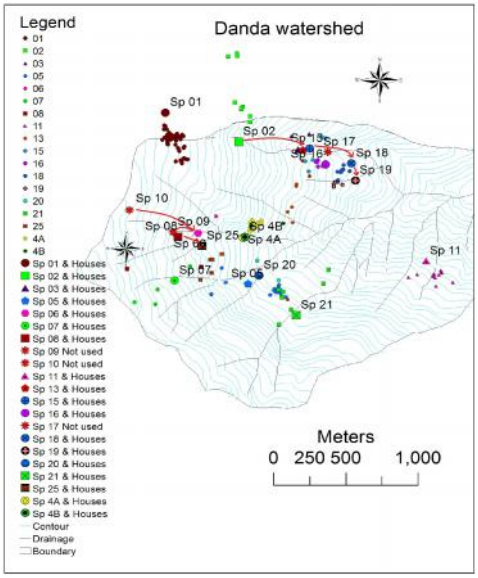

FIG. 1B: location map for Danda watershed on soi sheet (53j12) with springs, dependent houses and water transfer plan.

Watersheds have many gravitational fracture springs, which are mainly produced due to; (a) presence of fractures in the rock and (b) and the over cropping of water table at the surface. Springs nearly dry up in early summer as the soils, which have water retaining capacity are being degraded due to deforestation and thinning of forest cover and/or may be due to the rainfall pattern. Within the watershed, there exist some springs with sufficient available water, and if properly managed, the springs with water deficit can be supplied with the surplus water from the other springs.

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3. MATERIALS AND METHODS

The collection of data is the first step for planning and managing of natural resources of a watershed. Using automatic hydrological instrumentation, a database for the two watersheds (Chandrabhaga and Danda) was prepared. The rainfall measurements were based on four to five automatic rain-gauges installed in each watershed. The spring flow measurements were manually recorded by measuring the time taken for a specific amount of water coming out of the spring. During high flow season in monsoon months, the specific amount of water measured was 5.0 litres and in non-monsoon months the amount was reduced to 1.0 litre. Since, the springs are distributed through out the watersheds (*figures 1A & 1B*), the measurements were taken on alternate days or maximum in three days interval in both the watersheds. A total of **forty two** springs were under observation for both the watersheds and the daily spring flow discharge was recorded. As for as possible all the springs of the watersheds were considered for observation leaving one or two that fall under deep forest and are not in easy approach. The data measurement started in July 1999 and continued till June 2010. During this period few springs were added in year 2002, 2003 and 2005.

In order to fulfil the objectives, a detailed survey of the watershed was carried out. Spring wise dependability of population and its location was identified through Geographical Positioning System (GPS) for the watersheds (*figures 1A & 1B*).The domestic water requirement was estimated in two different ways. One; through the survey of human and animal population and multiplied by standard norms of water use called the **required domestic water demand** and in the other method, the actual water use information (drinking, cleaning, animal use) was taken from the family called the **actual domestic water use**. Individual family information is grouped spring wise and the demand and use on each spring is estimated. The water stress on individual spring is identified by comparing maximum, average and minimum spring flow of each spring with both **actual domestic water uses** (case 1) and **required domestic water demand** (case 2) for three different scenarios of spring use for both watersheds. The first scenario is the use of available spring water for 24 hours in a day, the second is the use for 12 hours in a day and the third is the use for 6 hours in a day.

RESULTS AND DISCUSSIONS

In general few springs reported a continuous flow (CF), few with interrupted flow (IF), few were frequently dead in summer (FD) and few were permanently dead (D) as shown in *table 1*. In Chandrabhaga watershed the springs 8, 10A, 12 & 20 were not used by habitats. The spring 19, 20 were destroyed during rode cutting and construction of retaining wall in year 2007 and 2006. The flow in the springs was continued through the holes of the constructed retaining walls but not measurable. The spring 12 was dead in June 2002 due to disturbance created by local construction. Similarly, in Danda the springs 9, 10 and 17 were not used. The springs 10 gone dead in June 2004 and spring 17 in year March 2008. The reasons could not be identified in record. But it could the local construction and changes. Spring 18, 19, 21 and 25 indicated a very low and interrupted flow since beginning and therefore could not be measured from the beginning of the project, but these springs were used by the habitats. Thus the measurements in Danda watershed was continued with only 17 numbers of springs (*table 1*). Spring's data length considered for the analysis is reported in *table 1* along with past human interferences.

Table 1. SPRINGS OF CHANDRABHAGA AND DANDA WATERSHEDS, DATA STATUS AND GENERAL FLOW BEHAVIOUR.

Chandrabhaga Watershed				Danda Watershed			
Sp.	Spring data length			Sp.	Spring data length		
No.	Start	End	Remarks	No.	Start	End	Remarks
1	01-Jul-99	30-Jun-10	CF	1	01-Jul-99	30-Jun-10	CF
2	01-Jul-99	30-Jun-10	CF	2	01-Jul-99	30-Jun-10	CF
3	01-Jul-99	30-Jun-10	CF	3	01-Jul-99	30-Jun-10	CF
4A	01-Jul-99	30-Jun-10	CF	4A	01-Jul-99	30-Jun-10	CF
4B	01-Jul-99	30-Jun-10	CF	4B	01-Apr-05	30-Jun-10	CF

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5	01-Jul-99	30-Jun-10	IF(01)	5	01-Jan-03	30-Jun-10	CF
6	01-Jul-99	30-Jun-10	CF	6	01-Jul-99	30-Jun-10	IF(04)
7	01-Jul-99	30-Jun-10	IF(01)	7	01-Jul-99	30-Jun-10	CF
8	01-Jul-99	30-Jun-10	IF(02)	8	01-Jan-03	30-Jun-10	IF(01)
9	01-Jul-99	30-Jun-10	CF	9	01-Jul-99	30-Jun-10	IF(01)
10A	01-Jul-99	30-Jun-10	CF	10	01-Jul-99	25-Jun-04	D(C&D)
11	01-Jul-99	30-Jun-10	IF(07) (Road cutting , Yr 7-8)	11	01-Jun-00	30-Jun-10	IF(02)
12	01-Jul-00	30-Jun-02	D(Const. & Devp)	13	01-Nov-99	30-Jun-10	IF(03)
13	01-Jul-03	30-Jun-10	CF	15	01-Nov-99	30-Jun-10	CF
14	01-Jul-00	30-Jun-06	D(Const. & Devp)	16	01-Jun-02	30-Jun-10	IF(01)
15	01-Jul-00	30-Jun-10	IF(01)	17	01-Nov-99	20-Mar-08	CF
16	01-Jul-00	30-Jun-10	IF(01)	20	01-Nov-99	30-Jun-10	CF
17	01-Jul-05	30-Jun-10	IF(01)	18	Very low flow since beginning.		Nil flow
18	01-Jul-03	30-Jun-09	FD(C&D)	19	Very low flow since beginning.		Nil flow
19	01-Jul-05	30-Jun-07	FD(C&D)	21	Very low flow since beginning.		Nil flow
20	01-Jul-05	30-Jun-06	FD(C&D)	25	Very low flow since beginning.		Nil flow
Springs not in use		8, 10A, 12, 20			Springs not in use		9, 10, 17

* CF: Continuous flow; IF: Interrupted flow (number of time); D: Dead; FD: Frequently dead; C&D: Construction and development.

4.1 Spring flow analysis

A summery of flow records of each spring indicates that some springs have a continuous flow, some have interrupted flow and some are frequently dead or permanently dead. Some springs gone dead are due to human interference like construction and development and for that recording was discontinued (*table 1*).

4.2 Rainfall Spring Flow Relationship

Yearly spring flow for water year June to May for 21 springs of Chandrabhaga and 17 springs of Danda has been related to yearly rainfall in the watersheds. The effect of rainfall on total amount of spring flow for the respective watersheds has been assessed in the form of log and second order polynomial relationships below as;

Chandrabhaga watershed

$$TSp=-0.0082TRa^2+22.08TRa-7564 \qquad r^2=0.77 \qquad \text{--- (1)}$$

$$TSp=4293\ \ln(TRa)-263981 \qquad r^2=0.67 \qquad \text{--- (2)}$$

Danda watershed

$$TSp=0.0072TRa^2-3.352TRa-3967 \qquad r^2=0.83 \qquad \text{--- (3)}$$

$$TSp=3726.8\ \ln(TRa)-18617 \qquad r^2=0.65 \qquad \text{--- (4)}$$

in which, TSp is yearly spring flow (m^3) and TRa yearly rainfall (mm). The log relationships for the watersheds are almost similar in nature with correlation 0.67 and 0.65 respectively for Chandrabhaga and Danda (*figure 2*). In principal the relationships support that (i) for rainfall below average the spring flows will be minimum, (ii) for average rainfall the spring flow will be average and (iii) for above average rainfall the flows of the spring will be maximum. The correlations for the second order polynomial are better than for log form and are respectively 0.77 and 0.83 for Chandrabhaga and Danda watershed. Equation one suggest that spring flow for Chandrabhaga watershed reaches to saturation for rainfall above average annual rainfall of 1200 mm. However, such saturation is not observed for springs of Danda watershed for which average annual rainfall is 900 mm. It suggests that Danda watershed has a very high infiltration capacity.

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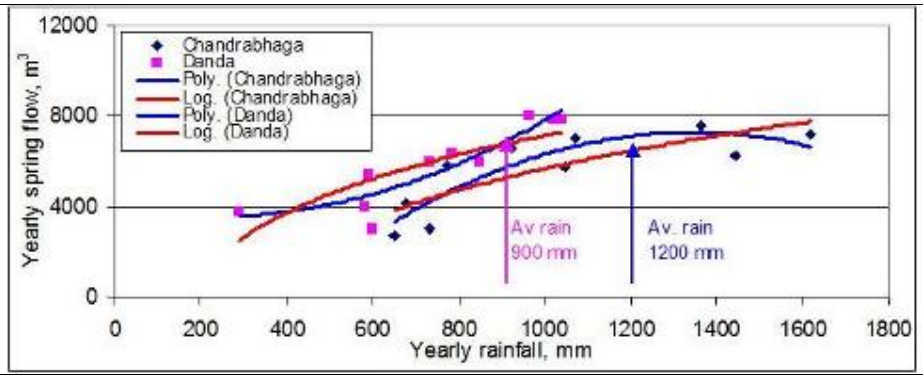

FIG. 2: Relationship between total yearly rainfall and total spring flow for Chandrabhaga and Danda watersheds.

In order to compare the present relationships (eq. 1 to 4) with literature, the data of Vashisht and Sharma (2007) for similar area in Uttarakhand hills is used and the relationships are developed. The developed second order polynomial and log relationship equations are as;

Vashisht and Sharma (2007):

$$TSp=0.0081TRa^2-12.28TRa-8045 \qquad r^2=0.75 \qquad \text{--- (5)}$$

$$TSp=4844.1\ \ln(TRa)-29114 \qquad r^2=0.65 \qquad \text{--- (6)}$$

The log relation is similar to that developed in the present study with correlation 0.65. The second order polynomial equation with correlation 0.75 is similar in nature to that obtained for Danda watershed.

In order to understand the spring behaviour and variability, the monthly flow for the record period was presented as maximum, average and minimum monthly flow for the months of year and averaged for the springs for both the watersheds (*figure 3*). The frequent peaks in the months of August, December and March indicate that the maximum monthly flow is the most effected by the rainfall. Such frequent peaks are not seen in average and minimum monthly flows and suggest that these flows are less affected by rainfall.

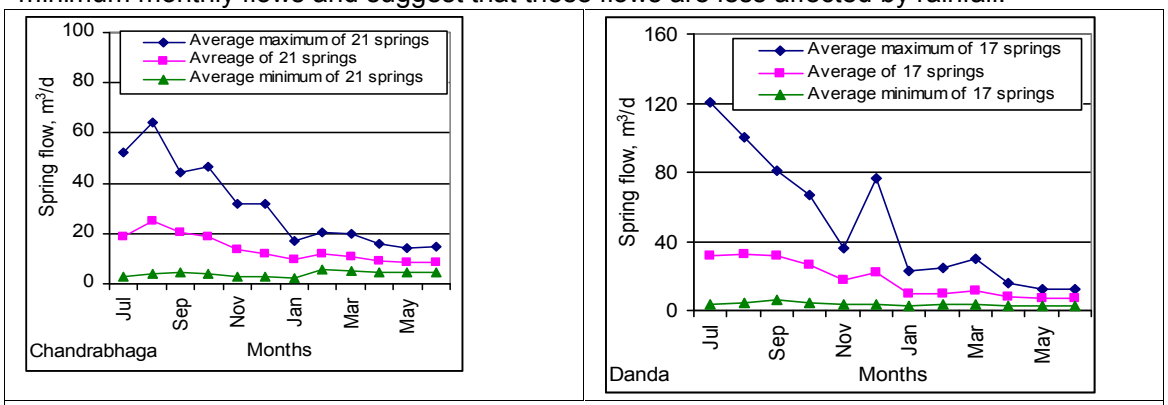

FIG. 3: Maximum, minimum and average monthly flow for springs of Chandrabhaga and Danda watersheds.

The minimum monthly flow averaged for the springs is compared with monthly required domestic water demand and monthly actual domestic water uses also averaged for the springs and shown in *figure 4*. It is found that the monthly required domestic water uses is always less than minimum monthly flow for both the watersheds suggesting that the minimum monthly flow is able to meet monthly actual domestic water uses. The minimum monthly flow is close to monthly required domestic water demand in months July, Dec., Jan., Apr., May & June & for Chandrabhaga watershed and is less than required domestic water demand for Danda watershed in the months Feb., Apr., May, & June (*figure 4*) indicating a stressed situation in the months for Danda watershed.

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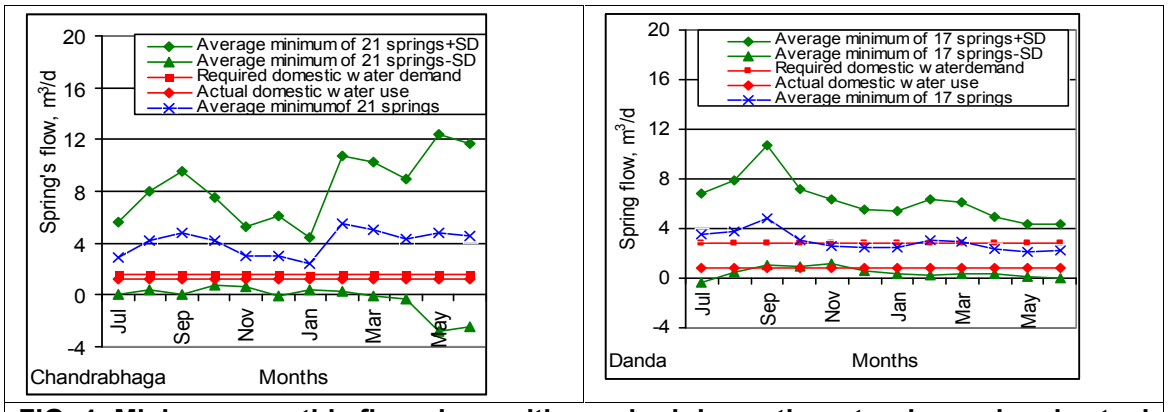

FIG. 4: Minimum monthly flow along with required domestic water demand and actual domestic water uses for Chandrabhaga and Danda watersheds.

4.3 Domestic water availability and requirements

Springs are the only dependable reliable source of water in the two watersheds. All other sources are unreliable and uncertain. Thus, the spring wise water availability is considered for determining the adequacy of water to the people of the watershed, especially for their domestic requirements. The spring wise maximum, average and minimum daily flow, human population, animal population, required domestic water demand and actual domestic water use are shown in *tables 2 & 3* respectively for Chandrabhaga and Danda watersheds.

The total required domestic water demand for Chandrabhaga watershed with dependant population of 187 male, 308 female, 370 minors and 215 animals is 33215 l/d and actual domestic water use as 24659 l/d (*Table 2*). The minimum flow availability through all springs is in between actual domestic water uses and required domestic water demands. The spring wise stress could be seen for springs 1, 2, 4B, 5, 11, 13, 17 & 18 with actual domestic water use (24659 l/d) and with springs 1, 2, 3, 4B, 5, 7, 11, 13, 15, 16, 17 and 18 when required domestic water demand are compared with minimum flow availability (27932 l/d). It suggests that minimum flow is not able to meet domestic water use as well as domestic water demands of few springs. It also suggests that water use is limited by minimum spring flow availability. The average daily spring flow availability is 266766 l/d and is around nine times of minimum spring flow available through springs and is high to meet the demands (*Table 2*).

The total required domestic water demand for Danda watershed with dependant population of 423 male, 375 female, 472 minors and 364 animals is 50470 l/d and actual domestic water use as 15325 l/d and is around 1/3 of required domestic water demand. One third use of the required water demand simply highlights difficulty in availing water and the living standard of habitation. The minimum flow availability through all springs is in between actual domestic water uses and required domestic water demands. The spring wise stress could be seen for springs 1, 6, 18, 19, 21 & 25 with actual domestic water use (15325 l/d) and with springs 1, 4A, 6, 7, 11, 13, 15, 16, 18, 19, 21 & 25 when required domestic water demand are compared with minimum flow availability (36201 l/d). It suggests that minimum flow is not able to meet domestic water use as well as domestic water demands of few springs. It also suggests that water use is limited by minimum spring flow availability. The average daily spring flow availability is 262055 l/d and is around seven times of minimum spring flow available through springs and is high to meet the demands (*Table 3*).

Table 2. Spring flow availability, population, required domestic water demand and actual domestic water use survey (november, 2009) for chandrabhaga watershed.

Sl. no.	Spring no.	No. of houses	Spring flow availability			Male @45 l/day	Female @45 l/day	Minor @25 l/day	Animal		Required domestic water demand	Actual domestic water uses
			Max.	Av.	Min.				Big @10 l/day	Small @5 l/day		
			l/day	l/day	l/day	Nos.	Nos.	Nos.	Nos.	Nos.	l/day	l/day

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1	1	11	32075	8290	946	13	22	22	10	4	2245	1545
2	2	14	31933	11370	2399	11	30	32	11	14	2825	2640
3	3	25	305317	48371	5484	41	47	81	12	21	6210	4073
4	4A	7	77141	18309	1652	7	13	12	8	2	1290	1213
5	4B	8	76402	14177	800	7	13	13	9	3	1330	1213
6	5	2	58848	6055	79	4	3	2	1	1	380	405
7	6	2	67188	11050	2018	2	4	5	2	1	420	365
8	7	1	111475	13131	211	1	2	7	1	1	325	175
9	9	3	81426	20371	2312	8	7	7	2	2	880	625
10	11	1	26043	4656	115	1	3	7	1	1	370	145
11	13	30	104524	24131	2226	42	50	63	38	16	6175	4455
12	14	5	42141	10275	1348	7	7	21	3	1	1190	785
13	15	2	114612	20929	517	1	5	8	4	3	525	350
14	16	10	37961	7503	1506	11	20	31	3	3	2215	1170
15	17	27	87719	11545	1544	25	43	33	14	14	4095	3155
16	18	2	99868	10829	123	1	2	2	0	3	200	220
17	19	19	112110	25774	4652	5	37	24	4	2	2540	2125
Total		**169**	**1466783**	**266766**	**27932**	187	**308**	**370**	**123**	**92**	**33215**	**24659**

Table 3. Spring flow availability, population, required domestic water demand and actual domestic water use survey (november, 2009) for Danda watershed.

Sl. no.	Spring no.	No. of houses	Spring flow availability			Male @45 l/day	Female @45 l/day	Minor @25 l/day	Animal		Required domestic water demand	Actual domestic water uses
			Max.	Av.	Min.				Big @10 l/day	Small @5 l/day		
		Nos.	l/day	l/day	l/day	Nos.	Nos.	Nos.	Nos.	Nos.	l/day	l/day
1	1	44	226827	26086	807	86	85	107	54	29	11055	4530
2	2	8	211360	33414	7000	33	30	51	18	28	4430	1015
3	3	3	165719	20097	4462	10	9	9	4	2	1130	270
4	4A	12	359536	39916	3664	53	33	32	9	3	4775	1105
5	4B	3	25009	5460	3011	7	8	17	3	6	1160	340
6	5	16	161187	33964	8286	48	43	44	14	12	5395	1430
7	6	1	57105	7686	102	3	4	1	3	1	375	125
8	7	4	199017	14434	440	11	6	9	2	3	1025	310
9	8	2	103708	11148	783	6	5	2	6	6	635	185
10	11	13	45274	11545	1401	37	31	36	10	15	4135	1265
11	13	8	88027	13939	1527	19	18	23	8	15	2395	705
12	15	6	54498	8739	1223	17	18	22	16	2	2295	670
13	16	5	84334	5729	475	7	6	10	3	1	870	395
16	20	2	238398	29898	3020	8	7	7	2	5	895	325
14	18	7	NA	NA	NA	11	12	17	14	8	1640	640
15	19	5	NA	NA	NA	20	15	15	8	6	2060	520
17	21	8	NA	NA	NA	27	26	25	7	22	3190	895
18	25	5	NA	NA	NA	20	19	45	7	12	3010	600
Total		**152**	**2019999**	**262055**	**36201**	**423**	**375**	**472**	**188**	**176**	**50470**	**15325**

4.4 Water stress on the springs

In order to identify the stress of water on individual spring, the minimum, average and maximum spring flow of each spring was compared with both **actual domestic water uses** (case 1) and **required domestic water demand** (case 2) for three different scenarios of spring uses as 24 hours, 12 hours & 6 hours and is indicated under “deficit” in *table 4 & 5* for the watersheds.

For **minimum** spring flow and with six hours spring use, the springs 1, 2, 3, 4A, 4B, 5, 7, 9, 11, 13, 14, 15, 16, 17, 18 and 19 (*table 4*) indicate deficit when compared to actual domestic water uses (case 1) and thus suggests the requirement of storage of spring water

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for the rest of the day when the springs are not in use. Springs 1, 2, 3, 4A, 4B, 5, 7, 11, 13, 14, 15, 16, 17 and 18 indicate the deficit when used for 12 hours a day. Springs 1, 2, 4B, 5, 11, 13, 17 and 18 indicates the deficit even if the springs are used for 24 hours a day. This suggests the requirement of increased recharge to springs followed by storage of flow.

Table 4. Springs under deficit for three different scenarios (24, 12, 06 hrs.) of spring use for chandrabhaga watershed under actual domestic water uses (case 1) and under required domestic water demand (case 2).

Combination of available spring flow, domestic water use, demand		Scarcity of water in 21 springs (1, 2, 3, 4A, 4B, 5, 6, 7, **8**, 9, **10A**, 11, **12**, 13, 14, 15, 16, 17, 18, 19, **20**) of Chandrabhaga watershed under different scenario of domestic water use		
		24 hours use in a day	12 hours use in a day	6 hours use in a day
Springs under deficit with actual domestic water uses. (Case 1)	Monthly spring flow. Minimum	1, 2, 4B, 5, 11, 13, 17, 18	1, 2, 3, 4A, 4B, 5, 7, 11, 13, 14, 15, 16, 17, 18	1, 2, 3, 4A, 4B, 5, 7, 9, 11, 13, 14, 15, 16, 17, 18, 19
	Monthly spring flow. Average	Nil	17	2, 4B, 13, 17, 19
	Monthly spring flow. Maximum	Nil	17	13, 17
Springs under deficit with required domestic water demand. (Case 2)	Monthly spring flow. Minimum	(Springs of case 1) + 3, 7, 15, 16	(Springs of case 1) + 19	(Same as case1)
	Monthly spring flow. Average	17	(Springs of case 1) + 13	(Springs of case 1) + 1, 11, 14, 16
	Monthly spring flow. Maximum	Nil	(Springs of case 1) + 17	(Springs of case 1) + 16, 19
Springs not in use.	Always surplus	8, 10A, 12, 20	8, 10A, 12, 20	8, 10A, 12, 20
Springs always in deficit	Always deficit	Nil	Nil	Nil

For average spring flow and with six hour use, the springs 2, 4B, 13, 17 and 19 are under deficit and suggest the requirement of storage for the rest of the day. The spring number 17 which is under deficit when used for 12 hours suggests increased recharge followed by storage of flow. For maximum spring flow and with six hours use, the springs 13, 17 indicate the requirement of spring water storage for the rest of the day when the springs are not in use (*table 4)*. The spring 17 which is under deficit when used for 12 hours again suggests increased recharge followed by storage of flow. The springs 8, 10A, 12 and 20 are never in use and thus can be classified as surplus.

For Danda watershed with minimum spring flow and six hours of spring use, springs 1, 4A, 6, 7, 11, 13, 15 and 16 indicate deficit when compared to actual domestic water uses (case 1) and thus suggests the requirement of storage for rest of the day when the spring water is not used. Springs 1, 6, 7, 11, 15 and 16 indicate deficit when springs are used for 12 hours a day and springs 1 and 6 indicate deficit even if springs are used for 24 hour a day. This suggests the requirements of increased recharge to springs 1 and 6 followed by storage of flow in springs 1, 6, 7, 11, 15 and 16 (*Table 5*). For average spring flow and with 6 hour of spring use, the springs 1 and 16 are under stress and suggest the requirement of storage for rest of the day when the springs are not in use. For the same condition with 12 hours spring use in a day, the spring 1 is under stress suggests increased recharge followed by storage of flow. For maximum flow and with six hours spring use in a day, only the spring 16 indicates deficit and suggests the requirement of storage for rest of the day. Since, the springs 9, 10 and 17 (*Table 5*) are never in use, these springs can be considered as surplus and can be used for transfer of water. The springs 18, 19, 21 and 25 are considered always in stress as the monthly average spring availability could not be estimated from available data.

Table 5. Springs under deficit for two different scenarios (24, 12, 06 hrs.) of spring use

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for Danda watershed under actual domestic water uses (case 1) and under required domestic water demand (case 2).

Combination of available spring flow, domestic water use, demand		Scarcity of water in 18 springs (1, 2, 3, 4A, 4B, 5, 6, 7, 8, **9**, **10**, 11, 13, 15, 16, **17**, 18, 19, 20, 21, 25) of Danda watershed under different scenario of domestic water use		
		24 hours use in a day	12 hours use in a day	6 hours use in a day
Springs under deficit with actual domestic water uses. (Case 1)	Monthly spring flow. Minimum	1, 6	1, 6, 7, 11, 15, 16	1, 4A, 6, 7, 11, 13, 15, 16
	Monthly spring flow. Average	Nil	1	1, 16
	Monthly spring flow. Maximum	Nil	Nil	16
Springs under deficit with required domestic water demand. (Case 2)	Monthly spring flow. Minimum	(Springs of case 1) + 4A, 7, 11, 13, 15, 16	(Springs of case 1) + 2, 4A, 5, 8, 11, 13	(Springs of case 1) + 2, 3, 4B, 5, 8
	Monthly spring flow. Average	1	(Springs of case 1) + 11, 16	(Springs of case 1) + 2, 4A, 4B, 5, 6, 7, 8, 11, 13, 15
	Monthly spring flow. Maximum	Nil	1, 16	(Springs of case 1) + 1,4B, 5, 7, 11, 13, 15
Springs not in use.	Always surplus	9, 10, 17	9, 10, 17	9, 10, 17
Springs always in deficit	Always deficit	18, 19, 21, 25	18, 19, 21, 25	18, 19, 21, 25

Since, the required domestic water demand (case 2) is slightly more than the actual domestic water uses (case 1), the stress on the spring increases when required domestic water demand is compared with minimum, average and maximum spring flows. The additional springs that turn from surplus to deficit under the respective scenarios for Chandrabhaga and Danda springs are reported in *table 4 & 5* respectively.

The temporary solution to the problem is the creation of storage tanks for storage of water, for the period the spring is not in use, and water transfer from surplus to water stressed springs, working under gravity. The permanent solution is to increase the infiltration and to reduce the rapid transit of water through the aquifer adopting watershed improvement practices. Adopting watershed improvement practices, the quick responding springs could be very effectively improved to slow responding springs.

4.5 Water transfer plan for watershed springs

A water transfer plan must be sound, durable and should use minimum energy for its operation. In order to fulfil the requirements, the water transfer plan is developed considering; (1) Donor spring should have surplus water after fulfilling its own demand, (2) Donor spring should be at higher elevation than the spring to which it is to supply water so that water can be supplied by gravity, otherwise external energy will be required and is difficult to get at required time. Water transfer plan from surplus spring to water deficit springs, working under gravity, for springs that are under use has been suggested for water management and to improve the water availability. The springs having surplus water with 24 hours use a day, were considered as springs to supply water to springs having deficient of water.

Fulfilling above conditions, a plan is suggested for transfer of water from springs 3, 4A, 6, 7, 9, 14, 15, 16, 19 and 8, 10A, 12, 20 having surplus of water to springs 1, 2, 4B, 5, 11, 13, 17, 18 having deficit for Chandrabhaga watershed. Transfer plan for springs is as; (i) from springs 6, 7 $\rightarrow$ to 4B, 5 (ii) from spring 3 $\rightarrow$ to 2 (iii) from spring 9 $\rightarrow$ to 13 (iv) from spring 10A $\rightarrow$ to 1, 11 and (V) from spring 14 $\rightarrow$ to 17. The spring 18 being on highest location among all springs, no transfer of water can be suggested but an increase in

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infiltration in the vicinity of its catchment is suggested to increase the spring flow. A water transfer plan for Chandrabhaga watershed is shown in *figure 1A*. Water transfer plan for Danda watershed is from springs 2, 3, 4A, 4B, 5, 7, 8, 11, 13, 15, 16, 20 and 9, 10, 17 having surplus of water to springs 1, 6 and 18, 19, 21, 25 having deficit. It is proposed to transfer the water from springs as; (i) from springs 8, 10 → to 6 (ii) from spring 8 → to 25 (iii) from spring 2 → to 3 → to 18 → to 19. The spring 1 being on highest location among all springs, no transfer of water can be suggested but an increase in infiltration in the vicinity of catchment is suggested to increase the flow. A water transfer plan for Danda watershed is shown in *figure 1B*. Further the springs of the watersheds with surplus water could be utilized for irrigation by creating storage or by directly. Efficient methods of irrigation such as drip / surge are recommended with horticulture crops so as to maximize the use of limited spring potential.

5. CONCLUSIONS

(1) There exists a relationship between total spring flow and the total rainfall on water year basis. The total spring flow increases with total amount of rainfall. In principle the relationship supports that for a rainfall below average, the spring flows will be minimum, for average rainfall the spring flow will be average and for above average rainfall the spring flow will be maximum.

(2) For Chandrabhaga watershed, the required domestic water demand and actual domestic water uses are less than minimum flow for all months of the year. Similarly for Danda watershed, the actual domestic water uses are less than minimum flow for all months of the year but not the required domestic water demand.

(3) Average and minimum water availability through all springs is respectively 266766 and 27932 l/d for Chandrabhaga and 262055 and 36201 l/d respectively for Danda watershed. The required domestic water demand for Chandrabhaga watershed for existing population is 33215 l/d compared to actual water use of 24659 l/d. The actual water use is slightly less but close to the required domestic demand. The required domestic water demand of Danda watershed for existing population is 50470 l/d compared to actual domestic water use as 15325 l/d around 1/3 of required demand.

(4) In Chandrabhaga for minimum spring flow and with 6 hour use in a day, the springs 1, 2, 3, 4A, 4B, 5, 7, 9, 11, 13, 14, 15, 16, 17, 18 and 19 are under deficit when compared to actual domestic water uses. For 24 hours spring use in a day, the springs 1, 2, 4B, 5, 11, 13, 17 and 18 are under deficit. The springs 3, 4A, 6, 7, 9, 14, 15, 16, 19 and 8, 10A, 12, 20 are having surplus water and springs 1, 2, 4B, 5, 11, 13, 17, 18 are under deficit. Chandrabhaga springs 1, 2, 4B, 5, 11, 13, 17 and 18 requires both watershed treatment as well as storage of water during non use period. Springs 3, 4A, 7, 14, 15 and 16 require only storage of water during non use period.

(5) In Danda for minimum spring flow and with 6 hour use in a day, the springs 1, 4A, 6, 7, 11, 13, 15, and 16 are under deficit when compared to actual domestic water uses. For 24 hour spring use in a day, the springs 1, 6 are under deficit. The springs 2, 3, 4A, 4B, 5, 7, 8, 11, 13, 15, 16, 20 and 9, 10, 17 are having surplus of water to transfer to springs 1, 6 and 18, 19, 21, 25 having deficit. Danda springs 1 and 6 require both watershed treatment as well as storage of water during non use period. Springs 4A, 7, 11, 15 and 16 require only storage of water during non use period.

(6) Water storage structures are essentially required to store spring flow for the non use periods during non-monsoon months. Planning is required especially for proper storage of spring water and management and if required the transfer of water in collaboration with the existing social laws, from “excess” spring to “deficit” spring, through gravity flow. Water harvesting structures are required to store rainwater in monsoon months in order to increase flow in required selected springs. Efficient drip/ surge irrigation method are recommended with horticulture crops with animal husbandry so as to maximize the use of limited spring water potential.

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