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Water Stress on Springs of Lesser Himalayan Region

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Springs of Uttarakhand, India are back bone for domestic water availability during rainy and especially during non rainy season even though they are highly ignored. A study was taken up at Chandrabhaga and Danda watersheds in the mountainous region of Garhwal, Uttarakhand to analyse rainfall and spring flow pattern and to suggest water transfer plan to supplement the water availability during lean season. Regular spring flow and automated hydro-meteorological data were collected for July 1999 to June 2010. The second order polynomial relationship is found best fit between annual rainfall and annual average spring flow. Spring wise water availability 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 such as 24, 12 and 06 hrs in a day. Based on water availability of the springs, the water transfer plans, working under gravity for springs has been suggested. Study suggested a temporary storage of spring water, water transfer plan among the springs and planning to increase the infiltration and water retention power of soil.

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It is also recommended to promote horticulture along with animal husbandry for effective socio-economic development.

Keywords: Lesser-western himalaya; spring; water demand; water transfer.

1. INTRODUCTION

The lesser Himalayan range dominantly consists of tectonic setting that is characterized by multiple deformations resulting in superimposed folding and repeated faulting and thrusting [1]. The rocks of lesser Himalayan are highly weathered and immensely fractured that helps them to act as filter and regulates the groundwater paths for the springs as conduit (rapid) or diffused (slow) flow [2,3]. In rapid flow system, the aquifer is generally unable to store water over long time and the spring hydrograph produced may have peaks immediately after rainfall event. In slow flow system, the aquifer retains water for much longer time with less fluctuation in spring hydrograph. The springs of Liulin karst aquifer responds remarkably to precipitation [4]. The Niangziguan karst springs of China are found declining since 1950s in response to climate change and anthropogenic activities. Contribution of climate change to depletion of Niangziguan springs is 2.30 m^3/s and contribution of anthropogenic activities ranges from 1.89 to 2.90 m^3/s [5]. The lesser Himalayan Gaula river in South Central Kumaun is seriously effected by deforestation of hill slope resulting in drying up of spring and reduced discharge [6].

The spring flow yield during rainy / non-rainy season is found affected by rainfall and recharge area characteristics [7,8]. The recession of seasonal springs is much more rapid than the perennial springs. The highest water producing rate is obtained from fluvial originating spring with highest mean rate as 405×10^3 l/d, whereas, the colluvium originating spring produces the lowest rate with mean lowest rate as 7.2×10^3 l/d [8]. Variations in spring discharge are remarkable and noticeable indicating rapid infiltration of rain water and recharge in colluvium originating springs [9,10,6]. The springs (perennial, seasonal) derived from seepage water flowing through the shallow weathered and fractured zone indicates strong response to rainfall [11]. The impact of rainfall on spring flow, the relationship between rainfall spring flow and rainfall-spring flow lag for Chandrabhaga and Danda spring's are presented [12,13].

The study further deals with estimation of water stress on springs of Chandrabhaga and Danda watersheds, a representative area of Garhwal, Uttarakhand. Monthly availability/stress of springs that are under use, has been estimated and an under gravity water transfer plan has been suggested to improve the water availability.

2. STUDY AREA

The Lesser Himalayan geological formation of study area (Garhwal) falls under the Trans Himalaya tectonic zone with rocks of Chandpur formation [14]. The rocks of Chandpur formation are defined 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" [15]. 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 non-monsoon, water is scarce and available only through springs that is collected to small channels and utilized by their diversion [16].

Chandrabhaga watershed is located geographically between latitude N30° 18' and N30° 19' and longitude E78° 35' and E78° 36' (Fig. 1A). The altitude in this watershed ranges from 1150 m to 2350 m above mean sea level (MSL). Average annual rainfall of this watershed is of the order of 1200 mm. The area falls under the Jakhnidhar block of Tehri-Garhwal district (Uttarakhand). A population survey indicated human and cattle population of the watershed (Chandrabhaga) as 1445 and 447 respectively in year 1991 which was 1562 and 409 in year 2009. A slight increase in human and slight decrease in cattle population is observed in a period of around 18 years.

Danda watershed is located geographically between latitude N30° 14' and N30° 16' and longitude E 78° 37' and E78° 39' (Fig. 1B). 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 population survey in Danda indicated human and cattle population of the watershed (Danda) as 1732 and 893 respectively in year 1991 which was 1276 and 367 in year 2009. A slight decrease both in human and cattle population is observed. The Chandrabhaga and Danda watersheds are under sub-humid region with area around 4.0 and 3.0 km^2 respectively and are shown in Figs. 1A & 1B.

Watersheds have many gravitational fracture springs, which are mainly emerged 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 and due to deforestation and thinning of forest cover and/or may be the rainfall pattern. Within the watershed, there exists 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.

3. MATERIALS AND METHODS

Data collection is the first step for planning and managing of natural resources for a watershed. Using automatic hydrological instrumentation, database for two watersheds (Chandrabhaga and Danda) was generated. 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 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 throughout the watersheds (Figs. 1A & 1B), the measurements were taken on alternate days or after two days. A total of forty two springs were under observation for both the watersheds. 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 approach. The data measurement started in July 1999 and continued till June 2010. Few springs were added in year 2002, 2003 and 2005.

A human and animal population survey was done for the watersheds for spring wise dependability of users and their location was identified through

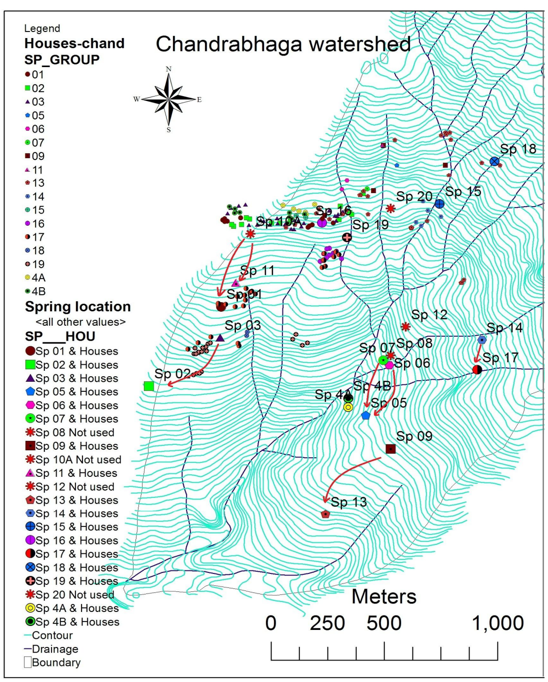

Fig. 1A. *Chandrabhaga* watershed with springs, dependent houses and water transfer plan

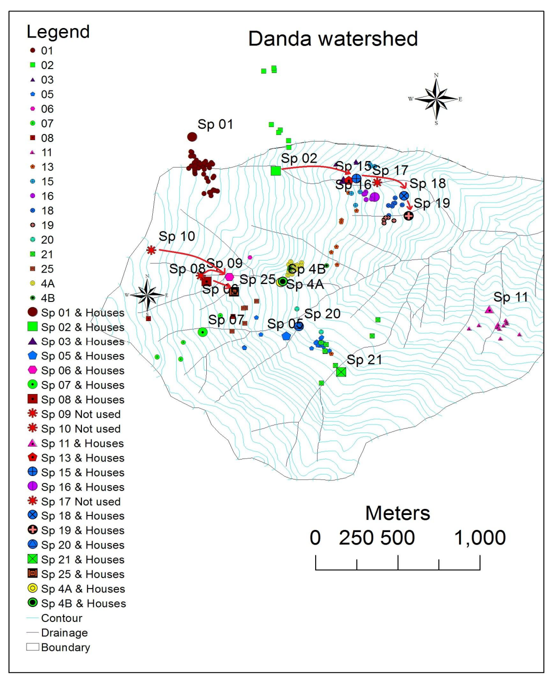

Fig. 1B. *Danda* watershed with springs, dependent houses and water transfer plan

Geographical Positioning System (GPS) (Figs. 1A & 1B). Domestic water requirements were estimated in two different ways. In first method, the human and animal population was multiplied with standard water use norms. The estimates so obtained are called as the required domestic water demand. In the other method, the actual water use information (drinking, cleaning, animal use) was surveyed from the family and is called as the actual domestic water use. Individual survey information was grouped to spring wise and demand and use on each spring was estimated. The water stress on individual spring was 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 was the use of available spring water for 24 hours a day, the second was the use for 12 hours a day and the third was the use for 6 hours a day. The relationship between annual (June to May) rainfall and average spring flow was also developed considering the data of 1999 to 2009 excluding the year 2004 and for Chandrabhaga springs and 2000 to 2009 for Danda springs using excel programme.

4. RESULTS AND DISCUSSION

Overall, the springs of watersheds responded in four different ways. One; the spring flow was never dead or had a nil flow. Such springs were defined as the springs with a continuous flow (CF). Two; the spring were dead or nil flow once or twice in total record period. Such springs were defined as the springs with interrupted flow (IF). Third; the springs were dead or nil flow in summer of every year or alternate year and revived with subsequent monsoon rainfall. Such springs were defined as frequently dead (FD). Forth; the springs that were suddenly or gradually dead and never revived in coming time were defined as permanently dead (D) as shown in Table 1.

Table 1. Springs of C*handrabhaga* and *Danda* watersheds, data status and overall 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
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)	11	01-Jun-00	30-Jun-10	IF(02)
			(Observed road cutting in year 2007 – 2008)				
12	01-Jul-00	30-Jun-02	D(C&D)	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(C&D)	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.*

The springs 8, 10A, 12 & 20 were not used by habitats in *Chandrabhaga* watershed. The spring 19, 20 were disturbed and destroyed during hill road cutting/widening and construction of retaining wall in year 2006 and 2007. The flow of the springs 19 and 20 was continued through the holes of the constructed retaining walls but it was not measurable. The spring 12 continued with reduced flow since June 2002, indicated no response of July to September 2002 monsoon rainfall and was with no flow since March 2003 onwards. It may be due to cutting and flattening of land for house construction in close vicinity of spring's upland. Similarly, in *Danda,* the springs 9, 10 and 17 were not used. The spring 10 was dead in June 2004 and spring 17 in March 2008. The reasons could not be identified. But it could the local construction and man made changes. Spring 18, 19, 21 and 25 indicated a very low and interrupted flow since beginning and therefore measurements discontinued from very beginning of the project, but these springs were used by the habitats. The measurements in *Danda* watershed were continued only with 17 springs (Table 1). Spring's data length considered for the analysis is reported in Table 1 along with some identified past human interferences.

4.1 Spring Flow Analysis

Flow record of springs indicated that some springs have a continuous flow, some have interrupted flow and some are frequently dead or permanently dead. Few springs have gone dead due to human interference like construction and development and for those springs the recording was discontinued (Table 1).

Yearly rainfall (June to May) and average spring flow of all springs for the period and for the watersheds (*Chandrabhaga* and *Danda*) are given in Table 2 and were used to develop relationships using excel.

4.2 Rainfall Spring Flow Relationships

Annual (June to May) flow averaged for 21 springs of *Chandrabhaga* and 17 springs of *Danda* has been related to annual rainfall for the watersheds. The effect of rainfall on annual 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**

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

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

Table 2. Yearly rainfall and average spring flow from *Chandrabhaga* and *Danda* watersheds

Water year	*Chandrabhaga*		*Danda*	
(June to May)	Rainfall, mm	Average flow of all 21 springs, m^3	Rainfa ll	Average flow of all 17 springs, m^3
1999	1048	5704	NA	NA
2000	772	5834	850	5943
2001	735	3024	288	3808
2002	1619	7602	590	5412
2003	678	4132	584	4020
2004	1182	NA	732	5998
2005	1444	6300	1017	7817
2006	1365	7537	784	6304
2007	923	6583	6583	8006
2008	1072	7007	1037	7812
2009	649	2707	599	3014

in which, TSp is annual flow averaged for springs (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 (Fig. 2).

The log relationships supported that the spring flow is minimum for below average rainfall and is maximum for above average rainfall. The correlation for the second order polynomial is better than that obtained for log form and is respectively 0.77 and 0.83 for Chandrabhaga and Danda watersheds. Equation one suggested that spring flow for Chandrabhaga watershed reached to a saturation for rainfall above average annual rainfall of 1200 mm. However, such saturation was not observed for the springs of *Danda* watershed for which average annual rainfall is 900 mm. It suggested that Danda watershed has a very high infiltration capacity.

Developed relationships (eq. 1 to 4) were also compared with the similar area of Uttarakhand hills[17]. The developed second order polynomial and log relationship areas;

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 obtained log relationship 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 springs 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 (Fig. 3). Frequent peaks in the months of August, December and March indicated that the maximum monthly flow is the most effected by rainfall. Such frequent peaks were not seen with average and minimum monthly flows and suggested that these flows are less affected by rainfall.

The minimum monthly flow averaged for the springs was compared with monthly required domestic water demand and monthly actual domestic water uses (Fig. 4). It was 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 (Fig. 4) indicating a stressed situation in the months for Danda watershed.

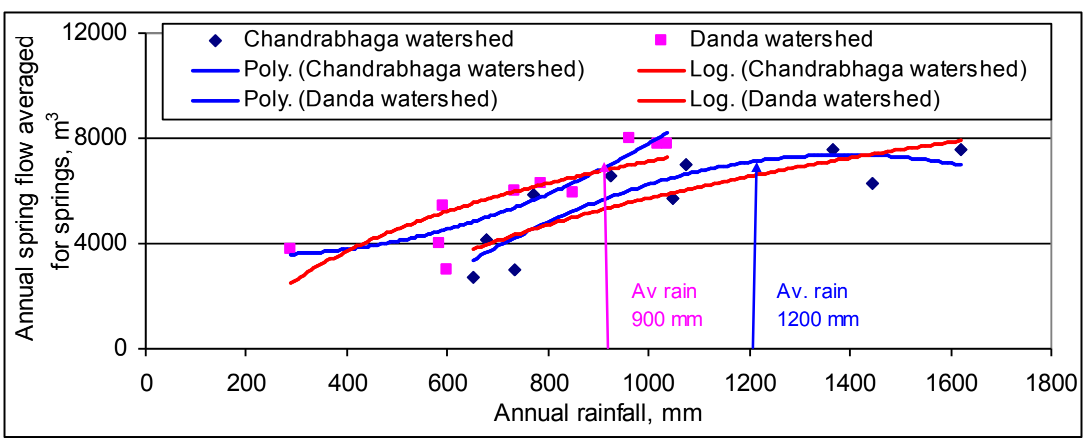

Fig. 2. Relationship between annual rainfall and annual spring flow averaged for springs for *Chandrabhaga* and *Danda* watersheds

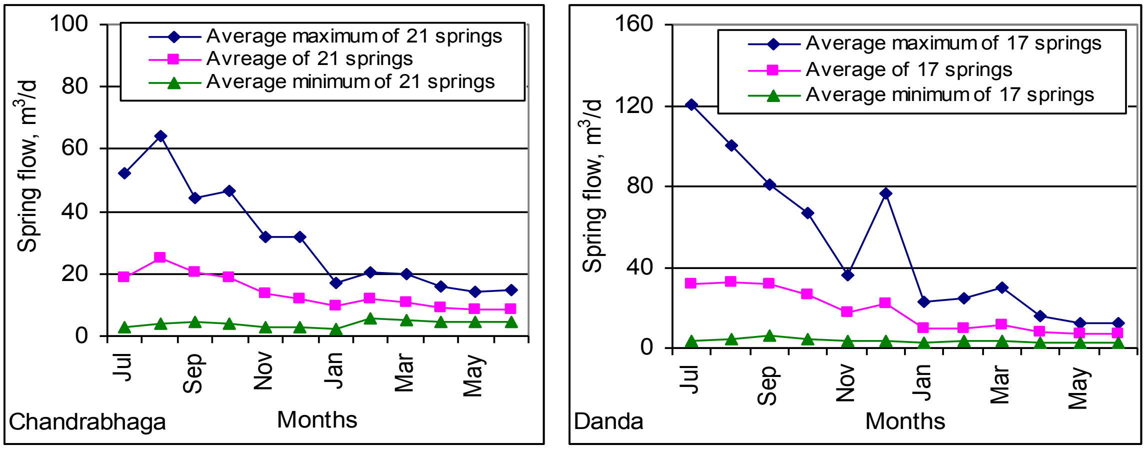

Fig. 3. Maximum, minimum and average monthly flow for springs of *Chandrabhaga* and *Danda* watersheds

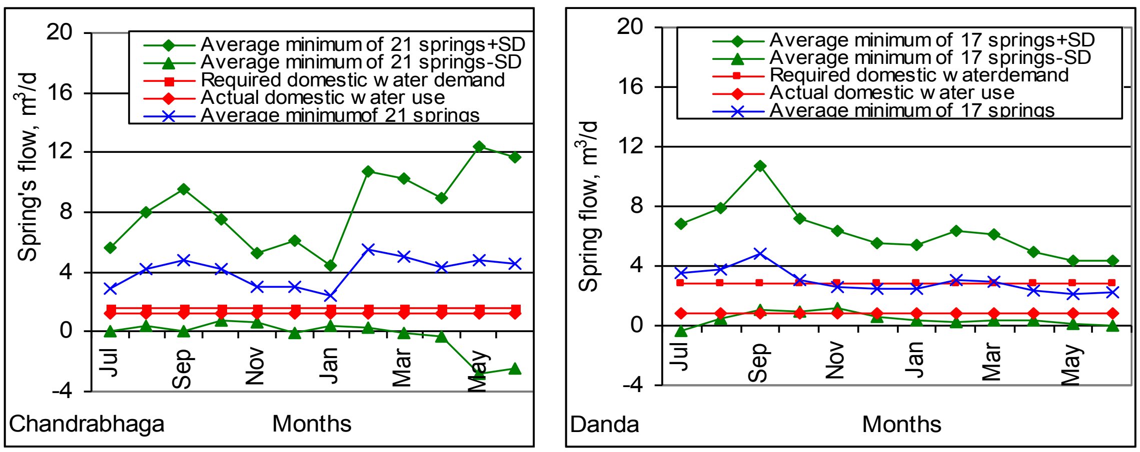

Fig. 4. Minimum monthly flow along with required domestic water demand and actual domestic water uses for *Chandrabhaga* and *Danda* watersheds

4.3 Domestic Water Availability and Requirements

Since, the springs are the only dependable reliable source of water in the two watersheds. 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 3 & 4 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 is as 24659 l/d (Table 3). 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 suggested that minimum flow is not able to meet domestic water use as well as domestic water demands of users on few springs. It also suggested 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 3).

Table 3. 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 Max.	Av.	Min.	Male @45 l/day	Female @45 l/day	Minor @25 l/day	Animal Big @10 l/day	Small @5 l/day	Required domestic water demand	Actual domestic water uses
			l/day	l/day	l/day	Nos.	Nos.	Nos.	Nos.	Nos.	l/day	l/day
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 4. 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 Max.	Av.	Min.	Male @45 l/day	Female @45 l/day	Minor @25 l/day	Animal Big @10 l/day	Small @5 l/day	Required domestic water demand	Actual domestic water uses
		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

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 is as 15325 l/d, around 1/3 of required domestic water demand. One third use of the required water demand simply highlights the difficulty in availing water and indicated 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 suggested that minimum flow is not able to meet domestic water use as well as domestic water demands of few springs. 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 4).

4.4 Water Stress on the Springs

Stress of water on individual spring was identified by comparing the minimum, average and maximum spring flow 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 Tables 5 & 6 for the respective 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 5) indicated deficit when compared to actual domestic water uses (case 1) and thus suggested the requirement of spring water storage 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 indicated the deficit when used for 12 hours a day. Springs 1, 2, 4B, 5, 11, 13, 17 and 18 indicated the deficit even when the springs were used for 24 hours a day. This suggested the requirement of an increased recharge to springs followed by storage of flow.

With average spring flow and with six hour use, the springs 2, 4B, 13, 17 and 19 were under deficit and suggested the requirement of storage for the rest of the day. The spring number 17, which is under deficit when used for 12 hour, suggested increased recharge followed by storage of flow. For maximum spring flow and with six hours use, the springs 13, 17 indicated the requirement of spring water storage for rest of the day time when the springs were not in use (Table 5). 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 were never used and thus can be classified as surplus springs.

For *Danda* watershed with minimum spring flow and six hours of spring use, springs 1, 4A, 6, 7, 11, 13, 15 and 16 indicated deficit when compared to actual domestic water uses (case 1) and thus suggested the requirement of storage for rest of the day, the springs were is not use. Springs 1, 6, 7, 11, 15 and 16 indicated deficit when springs were used for 12 hours a day and springs 1 and 6 indicated deficit even if springs are used for 24 hour a day. This suggested the requirement of increased recharge to springs 1 and 6 followed by storage of flow in springs 1, 6, 7, 11, 15 and 16 (Table 6). For average spring flow and with 6 hour of spring use, the springs 1 and 16 were under stress and suggested 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 suggested increased recharge followed by storage of flow. For maximum flow and with six hours spring use in a day, only the spring 16 indicated deficit and suggested the requirement of storage for rest of the day. Since, the springs 9, 10 and 17 (Table 6) were 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 were considered always in stress as the monthly average spring availability could not be estimated from available data.

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 respective scenarios are reported in Tables 5 & 6 respectively for Chandrabhaga and Danda.

A temporary solution to the problem is the creation of storage tanks for storage of water, for the period the springs are 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.

Table 5. 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

Table 6. Springs under deficit for two different scenarios (24, 12, 06 hrs.) of spring use 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

4.5 Water Transfer Plan for Watershed Springs

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 after its use in 24 hours a day, were considered as springs to supply water to springs having deficient of water. A sound and durable water transfer plan is suggested requiring no energy for its operation. The water transfer plan is suggested 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 has to transfer water so that water can be supplied by gravity, otherwise external energy will be required and will be difficult to get at required time.

Fulfilling above conditions, a plan was 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 to 4B, 5 (ii) from spring 3 to 2 (iii) from spring 9 to 13 (iv) from spring 10A to 1, 11 and (V) from spring 14 to 17. Since, the spring 18 is on highest location among all springs, no transfer of water can be suggested but an increase in infiltration in the vicinity of its catchment is suggested to increase the spring flow. A water transfer plan for *Chandrabhaga* watershed is shown in Fig. 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 Fig. 1B.

Further the springs of the watersheds with surplus water could be utilized for irrigation by creating storage or 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. CONCLUSION

(1) There exists a second order polynomial relationship between annual spring flow and the annual rainfall on water year basis similar to that observed in literature. The average minimum flow from the springs are least affected by rainfall.
(2) The average water availability through all springs is 266766 l/d in Chandrabhaga and 262055 l/d in Danda watershed, which is always greater than required domestic water demand. On the other hand the minimum water availability through all springs is always less than the required domestic water demand but is greater than actual domestic water use. It suggests that the water availability is limiting factor for water use and there is a need to increase the minimum water availability through springs.
(3) The water stress of springs 3, 4A, 7, 9, 14, 15, 16 and 19 can be avoided by proper water storage of non-use periods for *Chandrabhaga* watershed. However the springs 1, 2, 4B, 5, 11, 13, 17 and 18 will still remain under stress and needs rejuvenation. Similarly, for *Danda* watershed, the water stress of springs 4A, 7, 11, 13, 15 and 16 can be avoided by storage, but the spring 1 and 6 need rejuvenation.
(4) Water transfer plan in collaboration with the existing social laws, from “excess” spring to “deficit” spring, through gravity flow are suggested for both the watersheds.

6. RECOMMENDATIONS

Water storage structures are essentially required to store spring flow of the non use periods during non-monsoon/summer months. Rejuvenation planning is required for selected springs. Management planning is also required with water transfer 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 for required selected springs. Efficient drip/ surge irrigation with horticulture are recommended in association with animal husbandry so as to maximize the use of limited spring water potential.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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