Study on hydrological behaviour of a natural spring

A. K. Vashisht* and H. C. Sharma

Department of Irrigation and Drainage Engineering,
G.B. Pant University of Agriculture and Technology,
Pantnagar 263 145, India

In the middle and greater Himalaya, natural springs are the main source of domestic water consumption, but their discharge does not remain constant with time. Erratic rainfall directly affects the recharging of the spring catchment. In this communication, the behaviour of a perennial spring with rainfall variation is analysed from eight years' data recorded daily. It is concluded that the time required for the water from the remotest part of the feeding catchment of the spring to reach the outlet (time of concentration) is equal to 57 days.

Keywords: Hydrological behaviour, natural springs, rainfall, time-lag, time of concentration.

WATER, as a natural resource and fundamental basis for the existence of life, is abundant in the Himalaya, but its uneven distribution both in space and time comes in the way of development needs of the region[1]. Despite the fact that the mountains provide life-giving water to millions of people living downstream through a perennial river system, these people face acute shortage of water during summer[2]. In the Himalayan mountains, 'naulas' (1–2 m deep, appropriately lined wells to recover water from seepage) and 'dhara' (springs) are the main sources of water for drinking and household consumption, because water supply is either irregular or unwholesome, and it is also well known that people will move wherever water moves[3]. In rural areas, women and children wake up early in the morning and travel long distances to fetch water. According to a report[4], 72% women and 14% children have to bear the responsibility of carrying potable water. On an average, 60% of the women have to walk ½ km, while 10% of them have to walk 4 km to fetch water.

These life-supporting springs are either drying up or becoming seasonal, causing hydrological imbalance in the fragile upland watersheds. Also, the difference in the volume of water flowing down the rivers during dry and rainy seasons is continuously increasing and in some cases it is more than 1000 times, resulting in too-little-and-too-much-water syndrome – a common feature of the desert country[3,5]. A perceptible reason to this problem has been the population increase and decline in water yield of springs owing to erratic rainfall during three consecutive months (mid-June to mid-September). The problem has intensified further by rapid, unplanned urban growth and the mismanagement of vital natural resources that has led to the present situation. In the name of tourism, mushrooming of hotels and resorts by the buying of land on which springs are located further worsen the situation for the local people.

Historical data strongly support the above-mentioned facts, e.g. over the last 150 years the number of springs has declined from 360 to 60 in Almora region[6]. Deforestation, grazing and trampling by livestock, erosion of top fertile soil, forest fires and development activities (e.g. road-cutting, mining, building construction, etc.) have reduced the spongy action of land and have created hydrologic imbalance in the fragile watersheds of this region[3]. Therefore, the real crux of the problem is how to increase water retention in the fragile watersheds to augment a sustainable yield and secondly, how to manage the spring discharge when it is in excess during monsoon and post-monsoon season, to avoid its wastage. Due to the site-specific nature, all spring recharging catchments have their own constraints and management considerations[2]. Behaviour of a spring can only be administrated and forecasted by studying its temporal discharge variation, commonly known as the spring hydrograph. Such analyses are also useful for rainfall/run-off mathematical models, graphical separation of different flow components, estimation of discharge statistics, and indexing the storage capacity of catchment areas[7]. Discharge of a spring does not remain constant with time. Fluctuation in spring discharge is due to variations in the rate of recharge and the prevailing hydrologic and geologic conditions. As hydrologic and geologic conditions of a watershed do not vary frequently, discharge variability of a spring can be credited to only one factor, i.e. rainfall.

The aforesaid discussion mainly focused on the 'spring behaviour with respect to rainfall'. In the present work, daily discharge of one perennial spring along with rainfall was monitored and recorded for eight years (i.e. from 1999 to 2006) and analysed for the time-lag period between rainfall and consequent increase in spring discharge.

The spring is located at the University of Forestry and Horticulture, Ranichauri at 30°18.779′N lat. and 078°24.561′E long. at an elevation of 1858 m asl, in Tehri Garhwal District, Uttarakhand. The location of the Hill Campus Spring is shown in the Figure 1. The temperature of the region varies from 3°C to 28°C. The annual rainfall varies from 1200 to 1400 mm, of which 70–80% is normally received during June–September. The soils of the spring recharging catchment are formed under cool and moist climate from rocks of biotite schist and phyllitic material. These are shallow, gravelly and impregnated with weathered fragments of stones and parent rock. The soils are brown to greyish-brown and dark grey in colour, besides being generally non-calcareous and neutral to slightly acidic in reaction. Moderate to highly acidic soils are met at higher elevations, where rainfall is high and strong enough to leach down the bases from the soil minerals

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*For correspondence. (e-mail: akvashisht74@yahoo.com)

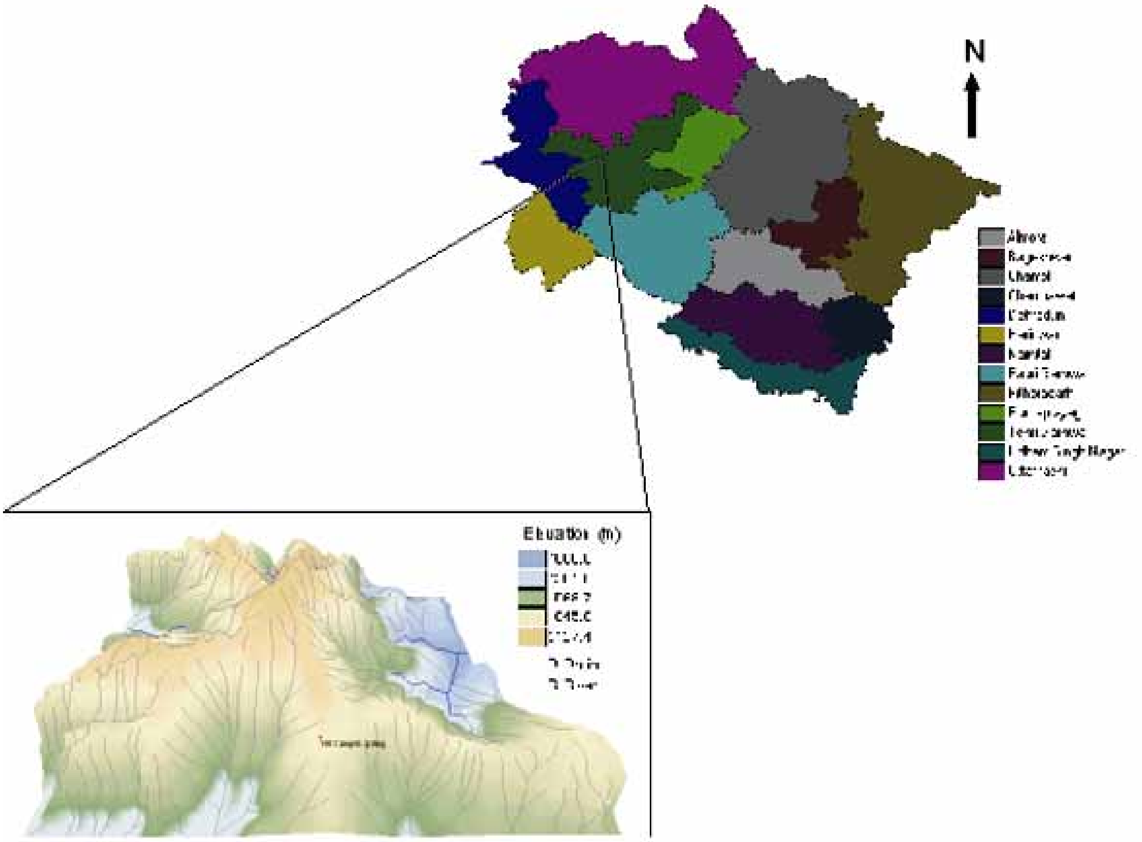

Figure 1. Three-dimensional view of the location of the Hill Campus Spring.

Figure 2. Variation in daily discharge of Hill Campus Spring from 1999 to 2006.

under temperate climatic conditions. The vegetation of the area is dominated with oak and minor shrubs like *Myrsine Africana*, *Berberis lyceum*, *Rubus ellipticus* and *Sarcococca hookeriana*.

For procuring data required for the study, the Hill Campus Spring was observed from 1999 onwards and its discharge was measured daily. With the help of a bucket, measuring cylinder and stop watch, three observations of the discharge rates were taken and averaged for final reading. The recorded data were analysed and daily discharge of the spring for eight years, i.e. from 1999 till 2006 has been graphically exhibited in Figure 2. The daily discharge averaged over eight years is also shown in Figure 2 (black line). The spring discharged water with an average of around 10,000 l during January, did not cross the 15,000 l discharge line. From the last week of the February to the first week of March, a considerable increase in spring discharge was noticed for the years 2000, 2002 and 2005. This increase in discharge of the spring was attributed to recharging of the spring catchment as a result of good rainfall received during the winter months of 1999, 2001 and 2004 respectively. Following this peak, the average discharge curve entered a recession period and started declining gradually, reaching the yearly minimum in the first week of the July. The difference in patterns of the recession curves for various years depends upon the time-span of dry summer. Thereafter, it was noticed that there was a rapid boost in yield of the spring and it attained the yearly maximum discharge sometime by September end. This behaviour of the spring was due to monsoon rainfall. For all the eight years, in general, spring discharge curves followed a similar pattern like the average discharge curve, except in a few cases, where the effect of local weather disturbances came into picture (localized rainfall

Table 1. Behaviour of Hill Campus Spring from 1999 to 2006

Year	Rainfall (mm)	Annual spring discharge (l)	Maximum (l)	Minimum (l)	Maximum/ minimum ratio
1999	939.70	4,915,253	34,833.6	6912.0	5.04
2000	1334.40	6,494,314	43,632.0	8409.6	5.19
2001	719.10	2,924,539	12,355.2	6768.0	1.83
2002	1254.60	4,681,837	28,800.0	7862.4	3.66
2003	1173.80	3,931,206	26,582.4	6163.2	4.31
2004	1174.70	4,590,619	31,291.2	3873.6	8.08
2005	1386.90	6,904,546	42,984.0	7675.2	5.60
2006	897.00	3,556,373	28,800.0	5976.0	4.82

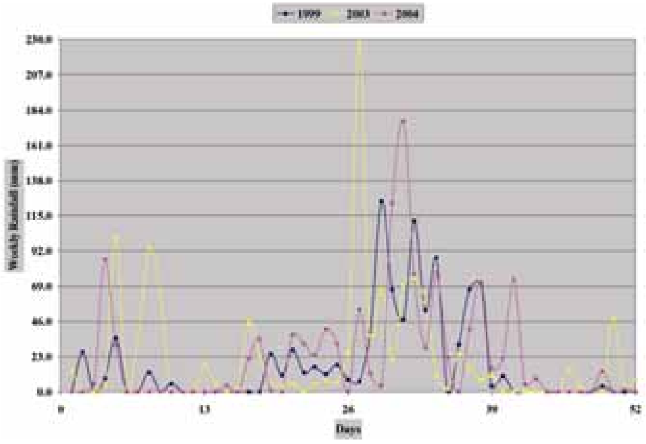

Figure 3. Weekly rainfall for the years 1999, 2003 and 2004.

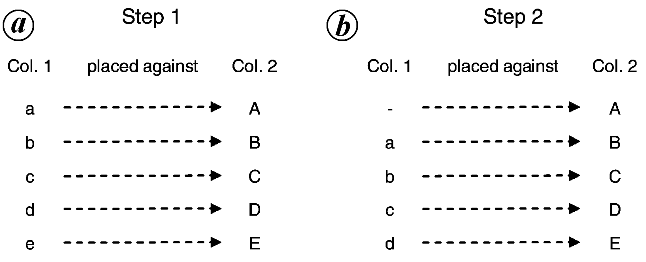

Figure 4. Symbolic representation of analysis procedure.

showers or prolonged dryness). The annual yields of the Hill Campus Spring along with yearly maximum and minimum daily discharges are given in Table 1.

In Table 1, the annual variation of spring discharge from maximum to minimum is also presented in the form of ratios. In other words, computed maximum/minimum ratio can also be described as discharge rate uniformity of the spring. Lesser the ratio, more uniform the discharge rate of the spring throughout the year and vice versa. All the ratios were lesser than 5.60, except for the year 2004, for which it was 8.08. The year 2004 received 1174.70 mm of rainfall, which was slightly more than the eight-year annual average of 1110 mm. But maximum/minimum discharge ratios for the years 2000, 2002 and 2005 were 5.19, 3.66 and 5.60 respectively, despite the fact that these had also received rainfall more than the annual average. From these raw data, it was difficult to interpret the exact cause of such variation. Proceeding in the manner to reach the basis of this deviation, weekly cumulative rainfall for the specifically chosen three years, i.e. 1999, 2003 and 2004 was plotted against weeks and is shown in Figure 3.

The logic for selecting only these three years is explained as follows. The year 1999 received 939.70 mm annual rainfall, which was approximately 25% less than that received in 2003 and 2004. However, annual spring discharge for the year 1999 was nearly 5,000,000 l, which was 20% and 6.6% more than the annual discharge for the years 2003 and 2004 respectively. Perusal of Figure 3 shows that 2003 received high intensity rainfall showers compared to 1999 and 2004, and it was uniformly distributed throughout the year. This uniform distribution of annual rainfall kept the maximum/minimum ratio comparable to the other years. Therefore, the maximum/minimum discharge ratio for 2003 was less, but most of the rainwater turned into run-off without getting infiltrated into sloppy catchment. Whereas in 2004, the interval between consecutive spells of rainfall was more compared to that 2003, which led to the non-uniform behaviour of spring discharge and hence increased maximum/minimum discharge ratio.

It is a well-known fact that the spring discharges the infiltrated and/or deep percolated rainwater after a certain time-lag. This time-lag factor depends upon (i) water intake rate which in turn depends on the land-use pattern, nature and degree of disturbance resulting from deforestation and human activities; (ii) slope of catchment, and (iii) geology of the catchment area. All these factors are site-specific in nature. Keeping the aforementioned discussion in mind, an effort was made to evaluate the time-lag between rainfall shower and increase in spring discharge. In the first step, cumulative daily rainfall (Col. 1, Figure 4 *a*) and cumulative daily spring discharge (Col. 2, Figure 4 *a*) data for all eight years were placed in a paired column and then correlation coefficient was evaluated. In the second step (Figure 4 *b*), cumulative daily rainfall column was given one day time-lag, i.e. the first numeric figure of cumulative daily rainfall column (Col. 1, Figure 4 *b*) was placed

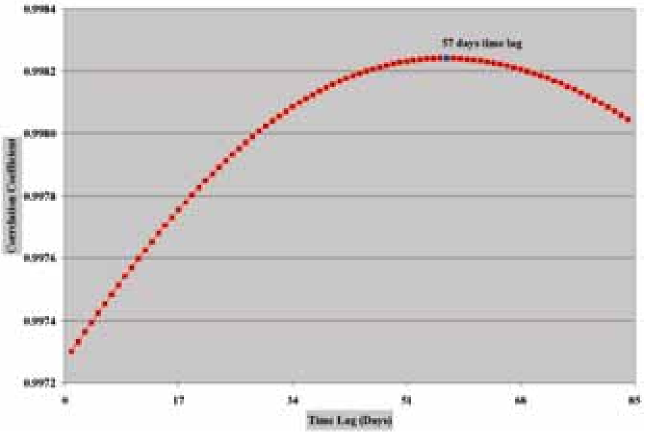

Figure 5. Correlation coefficient with respect to time-lag.

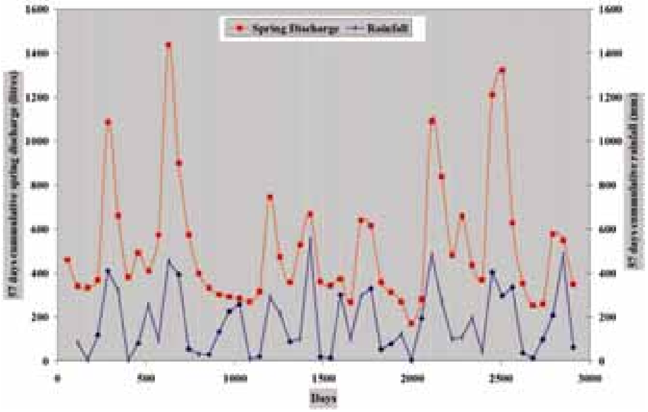

Figure 6. Pattern of 57 days cumulative rainfall and spring discharge.

against the second numeric figure of cumulative daily spring discharge (Col. 2, Figure 4 *b*) and again correlation coefficient was evaluated.

Proceeding in this manner by giving one day time-lag at each step, correlation coefficient was evaluated till it reached a maximum and started declining thereafter. Computed correlation coefficient values against the 84-day time-lag period are given in Figure 5. From the graph, it is apparent that the correlation coefficient value for the time-lag period of 57 days (i.e. approx. 8 weeks) was the highest. Hence, it is concluded that the time of concentration value for the feeding catchment of the Hill Campus Spring is equal to 57 days.

For verification, eight years' daily rainfall and spring discharge data were again used and their 57 days cumulative values were computed. In the 57 days cumulative rainfall column, the 57 days time-lag was incorporated (Figure 6). Perusal of Figure 6 shows that the 57 days cumulative rainfall and spring discharge curves follow a similar pattern, verifying the conclusion drawn.

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Significance of δ^{15}N variations in a sediment core from the equatorial Indian Ocean during the past ~35 ka

R. Ramesh[1,]*, M. S. Sheshshayee[2] and M. Tiwari[1]

[1]Planetary and Geosciences Division, Physical Research Laboratory, Ahmedabad 380 009, India
[2]Department of Crop Physiology, University of Agricultural Sciences, GKVK Campus, Bangalore 560 065, India

We report nitrogen isotope variations of organic carbon, in a precisely dated core from the equatorial Indian Ocean. We observed that peaks in the δ^{15}N of organic carbon lagged those in δ^{13}C of *Globigerinoides sacculifer* by 2–3 ka. Nitrogen loss from the oceans by intense productivity (seen as peaks in δ^{13}C) on the surface and consequent denitrification in the intermediate waters of the northern Indian Ocean led to an ensuing period of low oceanic nitrogen and high δ^{15}N. Our results indicate that even in sub-millennial timescales, ocean productivity and nitrogen budget appear to be tightly coupled.

Keywords: *Globigerinoides sacculifer*, nitrogen isotope variations, ocean productivity, organic carbon.

THE equatorial Arabian Sea is important for palaeoclimatic studies as it experiences the effect of summer (or southwest, SWM) as well as winter (or Northeast, NEM) monsoons[1,2]. It has been proposed that during the Last Glacial Maximum (LGM, ~21,000 calendar yrs BP), the SWM was weaker[3,4] with a feeble indication of stronger NEM than at present[1], with associated stronger oceanic currents[2]. As the relative influences of NEM and SWM are different

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*For correspondence. (e-mail: rramesh@prl.res.in)