



Estimation of Recession Constants for Springs in Danda Watershed (Uttarakhand)

Ravindra V. KALE¹ & V. C. GOYAL²

¹*National Institute of Hydrology, Roorkee, Uttarakhand, INDIA*

E-mail: ravikale2610@gmail.com, rvkale@nih.ernet.in

²*National Institute of Hydrology, Roorkee, Uttarakhand, INDIA,*

E-mail: vcg@nih.ernet.in

Abstract: The three interrelated factors which govern the groundwater flow to the spring: geology (type, distribution, and hydraulic characteristics of geologic formations), topography (landforms and relief), and local climatic conditions (timing and amount of precipitation). The geology, topography and climatic conditions play important role in the occurrence of direct runoff and ground water recharge in an area. The spring discharge hydrograph is the output of all processes, both natural and anthropogenic that govern the translation of various water inputs due to precipitation, and other sources such as glacier melt, and seepage from adjoining area in the spring's drainage area, into single output at the spring. In other words, it can be said that the springs can integrate the signal of geological and hydrological processes over large spatial areas and long periods of time and, thus, they are an indirect source of information. A recession curve analysis provides valuable information concerning storage properties and aquifer characteristics. The study of recession flow analysis particularly estimation of recession constant ($k = e^{-\alpha}$) as an indicator of the extent of base flow, has relevance in water resources planning. A major problem in determining recession constant for a particular spring using a single recession segment is high variability encountered in the recession behaviour of individual segments. To overcome the problem, a master recession curve (MRC) that normally is defined as an envelope of various individual recession curves, could be constructed. In present study, automated objective-based method (adapted matching strip method) for MRC separation has been used to estimate recession constant for the thirty springs in Danda watershed, Uttarakhand (India). Daily time series from July, 1999 to 2 March, 2001 (for the Spring_ID 1 to 11) while fortnightly discharge time series from 30 October, 1999 to 2 March, 2001 (for the Spring_ID 12 to 30) and two daily time series from 5, March 2001 to 31, December 2004 (for all the springs) have been used to separate hydrograph into three flow components namely surface runoff, interflow and groundwater flow. The recession flow analysis shows that average k values of MRC for all these springs varies between 0.94 to 0.99 with the value of goodness of fit (R^2) between MRC's and fitted curves ranging from 0.64 to 0.98.

Keywords): springs, recession flow, recession constant, flow duration curve, master recession curve, automatic adaptive matching strip method.

1. Introduction:

Hydrograph recession analysis is widely used technique for the sustainable water resources planning and management. In Himalayan area, with considerable impacts of catchments hydro-geological characteristics and recharge on the flow characteristics of the springs, such a techniques are very useful in assessment of ground water resources in the catchment by knowing the spring flow recession characteristics. Particularly, during summer/drought period, appropriate allocation of

available water resources for various purposes and an accurate forecast of future spring flow are vital for water resources managers. However, the typical hydraulic parameters describing the subsurface hydrology viz. hydraulic conductivity, specific yield and effective hydraulic conductivity etc., required in the various available hydrologic or hydraulic models are most problematic to obtain, in part because the variability of observed values spans many orders of magnitude. As the springs integrate the signal of geological and hydrological processes over large spatial areas and long periods of time; they are an indirect

source of information. For this reason, it is desirable to estimate aquifer parameters using recession analysis for description of characteristics of spring flow declination in the absence of rainfall. Arnold et al. (1995) advocated that the slope of spring flow decline following recharge event can be described by a single parameter which is known as recession constant. A report from Vogel and Kroll (1996) study in central western Massachusetts reveal that recession flow statistics are highly correlated with the product of watershed area, average watershed slope, and the baseflow recession constant. Further, they have stated that the baseflow recession constant can be used as a surrogate for both watershed hydraulic conductivity and drainable soil porosity. Recession constant also provide significant information regarding the hydro-geologic response of watershed/aquifer.

Riggs (1964) advocated that the base flow recession curve can be used an indicator of the ground water discharge to stream. Further, he has stated that the multiple or non-homogeneous aquifer feeding to the river and hence, an actual recession curves often differs from simple theoretical recession curve. For more than a century, hydrologist and hydro-geologists have been investigating the processes of stream and springs baseflow recession (e.g. Hall, 1968; Arnold et al., 1995; Amit et al., 2002; Birk and Hergarten, 2010; Tallaksen, 1995). Bako and Hunt (1988) derived baseflow recession constant using simple exponential equation to characterize the behavior of low flow. Bonacci (1993) showed that karst spring hydrographs analysis may be helpful in identification of aquifer characteristics and accordingly to know the main features of a karst rock-fissure massif. His work presented a detailed analysis and explanation of numerous cases of break points on recession curves via various recession coefficients α in Maillet's equation. Ramírez et al. (2002) have attempted to estimate recession constants for two watersheds in the Luquillo Mountains of Puerto Rico by using the sets of three MRCs for three season using the matching strip method and two variation of the correlation method. Berhail et al. (2004) have also attempted to estimate the recession constants of stream by using matching strip, correlation and wavelet transformation based method by using single recession segment and MRC.

The main objective of the present manuscript is to generate the master recession curve (MRC) for thirty springs in Danda watershed representing typical Indian Himalyan watershed to estimate recession constants by employing automatic adapted matching strip method. In order to capture the hydraulic behavior of high and low permeability fractures, optimal separation of MRC into two/three segments has been carried out for all the springs. From these separated MRC's, the estimation of recession constants for all two/three different separated

segments of MRC and optimal MRC of each spring has been carried out.

2. Study area and data used:

Danda watershed locally known as Khas Patti is located in Hindolakhil block of Devprayag Tehsil in Tehri Garhwal district of Uttarakhand. The Danda watershed lies at an elevation 777-1810 m above MSL from outlet near Dugyar to watershed boundary, between latitude $30^{\circ} 13' 36''$ N to $30^{\circ} 14' 46''$ N and longitude $78^{\circ} 37' 04''$ E to $78^{\circ} 38' 56''$ E (see Figure 1). The area falls in Survey of India (SOI) Toposheet No. 53 J/12. The Danda watershed has an area of 450.44 hectare at the gauging site near Dugyar village. The Watershed has a highly undulating topography with steep slopes and scanty vegetation. The major land use/land cover classes for the catchment under the study area can be classified as agricultural area (small % is irrigated), degraded forest, dense forest, fallow, grass with shrubs, waste land and settlement area. The main source of water is numerous springs and a few perennial streams.

The majority of soils are diluvial in nature. Most of agricultural soils usually lose top horizon either due to construction of terraces or erosion. In the terraced hillside, the down slope is sharply reduced and the soil is stabilised. On slope, soils are generally shallow and usually have a thin surface horizon and medium to coarse texture. Sub-soils are deep and heavily textured. Lithologically, Danda area falls under the Phyllites of Chandpur formation belonging to Jaunsar groups. The rock type of the area is low grade metamorphic rock with slates. These greyish coloured low grade metamorphic rocks are highly fractured and foliated. The regular foliation, bedding and fractures in the metamorphic rocks act as a preferential pathways for the recharge of the springs in the area. The watershed falls under subtropical (cool temperate) climate zone in lesser Himalayan mountain ranges of India. This watershed area falls in rain shadow zone of mountains with moderate rainfall with annual average of 900 mm. The rainfall occurs in almost all the month of the years except in October and November which receives scanty rainfall. The bulk of rainfall occurs in the month of July, August and September. The highest recorded value of maximum temperature during the spring flow measurement period was 38.5° C in the month of May and June and the recorded minimum temperatures varies between 2.8° - 4.2° C.

Danda watershed consists of 11 villages: Danda, Centauli, Mayali, Rumdhar, Gajeli, Unnana, Limgad, Tayari, Burkot, Hingolia, and part of Dugyar (see Figure 1). The springs in this physiographic setting result from

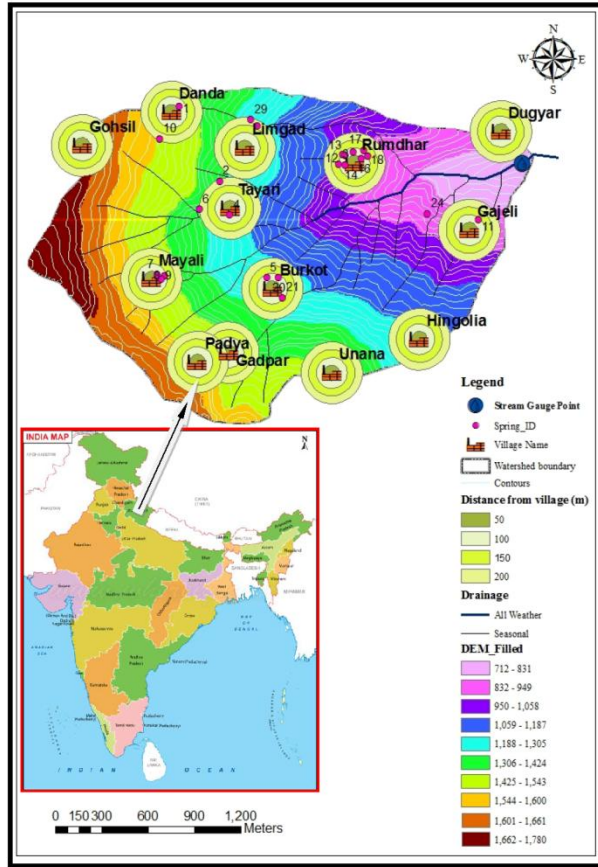


Figure 1. Study area map showing locations of springs, distance from village, catchment divide and contours (m).

gravity drainage mainly produced by fractures in the rock and overcropping of the water table from the unconfined aquifer with or without contribution from surface runoff. Springs in this watershed can be classified as a fracture springs under Bryan classification (Bryan, 1919) or fracture or joint related spring (Valdiya and Bartarya, 1991). Also, the fractures and joints are the main source of spring water (Goyal and Kumar, 1996-97). However, this area is known for scarcity of drinking water. Subsequently, a dendritic pattern of drainage system indicates that the area was not subjected to major folding or faulting, and hence, not structurally controlled. The presence of large fractures in the rocks is the main cause of rapid discharge after rainfall and thus, multi-peaked discharge hydrograph after rainfall. Similarly, occurrence of conduit flow due to presence of fault and diffused flow through slowly discharging aquifer are also responsible for separation of recession curve in three distinct segments. In this watershed, around 30 springs with varying discharge are identified which are shown in Figure 1. Daily time series from July, 1999 to 2 March,

2001 (for the Spring_ID 1 to 11) while fortnightly discharge time series from 30 October, 1999 to 2 March, 2001 (for the Spring_ID 12 to 30) and two daily time series from 5, March 2001 to 31, December 2004 (for all the springs) have been used for the recession flow analysis. A typical observed time-series discharge hydrograph of Spring_ID#8 is shown in Figure 2 along with observed rainfall hyetograph at Danda and Gajeli. Note that, there are some observation gaps in data series due to unavoidable circumstances.

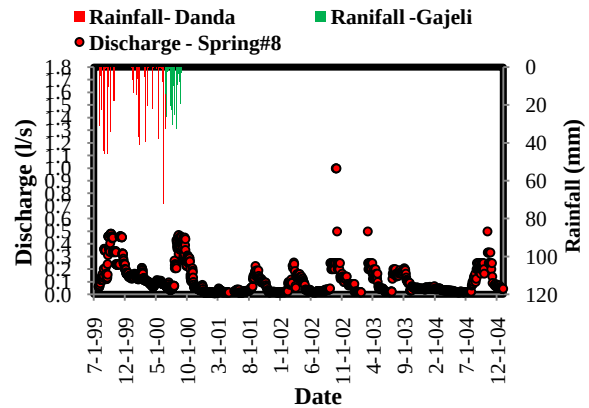


Figure 2. Observed time series of spring flow discharge of the typical spring at Mayali (Spring_ID#8) and daily rainfall in the Danda Watershed.

3. Methodology:

In order to consider the impact of different factors that affecting individual recession segment, the construction of master recession curve (MRC) is a commonly employed technique in recession flow analysis which is discussed in detail in section 3.2. Subsequently, conceptualization of the various flow components of single recession curve/MRC resulting in time-series of spring flow is essential. In well developed aquifer system, a recession curve can be divided into three stages or segments based on groundwater flow with different lag characteristics. The three significant flow components of spring flow are: (1) fast/quick recession (2) recession flow from high permeability fractures, and (3) slow recession flow from low permeability fractures.

3.1. Recession flow analysis:

Recession flow analysis focuses on the recession curve which is specific part of spring flow hydrograph following the flow peak when flow recedes. Generally, the total recession curve can be represented as the sum of two, three or more exponential functions for ground water flow in the porous or fractured medium which is given as (Chen et al. 2012)

$$Q(t) = \sum_{i=1}^N Q_{0i} e^{-\alpha_i t} \quad \text{or} \quad Q(t) = \sum_{i=1}^N Q_{0i} e^{-t/T_{Ci}} \quad (1)$$

Where, $Q(t)$ is discharge of spring at any time t (l/s), N is the number of exponentials, Q_{0i} are the initial discharges of spring at $t = 0$ (l/s); t is time since start of recession (days), α_i are the recession coefficients for each exponential recession, T_{Ci} is residence time of the ground water system, defined as the ratio of storage to flow for each exponential recession. The flow rate at any given time after the beginning of recession can be calculated using appropriate active recession exponential segment. The recession coefficient α represents the ability of the aquifer to release water and is function of the transmissivity and specific yield of the aquifer system.

The term $e^{-\alpha_i}$ in Equation 1 can be replaced by k_i , called recession constant or depletion factor, which is commonly used as an indicator of the extent of base flow. Therefore, Equation 1 can be written as

$$Q(t) = \sum_{i=1}^N Q_{0i} k_i^t \quad (2)$$

The exponential function of spring flow hydrograph depicted in Equation 1 implies that the plot of $\ln Q(t)$ vs t is a straight line on a semi-logarithmic axis, and slope of line equal to the recession parameter k_i . Rivera-Ramirez et al. (2002) has stated that a large value of k indicates that drainage is very slow, while a smaller value of k indicates a rapid drainage and little storage.

3.2. Master Recession Curve (MRC)

Determining recession constant for a spring representing a particular aquifer/catchment is difficult because of many factors that can affect each individual recession. Individual recession segments may have different slopes due to variability in storage, evaporation loss, and recharge rates (Posavec et al., 2006). To overcome the problem, a master recession curve (MRC) that normally is defined as an envelope of various individual recession curves could be constructed. Generally, several recession coefficients are often fit to a single recession curve/MRC, indicating multiple types of flow conditions influencing discharge from the aquifer system. As stated earlier, in well developed aquifer systems, three straight-line segments of $\ln Q$ vs t , with different value of α_i , occur in the recession. Therefore,

separation of spring flow recession hydrograph into two or three segments is necessary in understanding the magnitude and dynamics of spring discharge. In practice, however, transition from one line to the next is very gradual; hence it is difficult to select point of change in the slope as well as the slope itself. In this manuscript, a fully automatic objective based method presented by Posavec et al. (2010) for separation of MRC into two or three segments on the basis of FDC analysis has been used to accomplish this task.

4. Results and discussion:

The hydrological investigations as well as instrumentation in the Danda watershed are carried out by National Institute of Hydrology Roorkee under DST, Government of India sponsored project (NIH, 2003). The spring flow record collected during the aforesaid project has been used in this study for recession flow analysis and to verify the usefulness of automatic adaptive matching strip method. During this study, MRC for all the thirty springs in this watershed has been generated using automatic matching strip method. A typical MRC for Spring_ID#8 using exponential decay equation (Equation 1) is shown in Figure 3. From this figure, it can be seen that recession coefficient (α) value for this spring flow is 0.043 days^{-1} and correlation coefficient (R^2) is 0.90. As expected, the MRC is well fitted to the lower portion of the recession segments, thus the goodness of fit value i.e. R^2 value is low. The MRC is not fitting well to the upper and middle portion of recession segments. As discussed earlier, under such conditions several recession coefficients can fit to MRC, indicating multiple types of flow conditions influencing discharge from the aquifer system. Therefore, separation of MRC in three segments has been carried out using fully automatic adaptive matching strip method on the basis of flow duration curve analysis.

Figure 3 reveals that the transition from one line to the next is very gradual; hence it is difficult to select point of change in the slope as well as the slope itself. Therefore, the separation ranges can be selected from the flow duration curve (FDC) by identifying critical flow rate (Posavec et al., 2006). By using graphical evaluation of the FDC, separation criteria were represented as the probable range of percent flow rate duration. As shown in Figure 4, for the separation of MRCs of Spring_ID#8 into three segments, the selected separation ranges were between 1% and 27%, and 45% and 51% of time that indicates flow rate was equaled or exceeded. Separations are performed successively for all

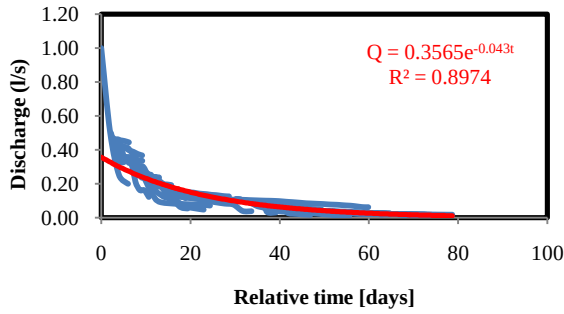


Figure 3. MRC of spring_ID#8 for the period 2001-04 by exponential regression.

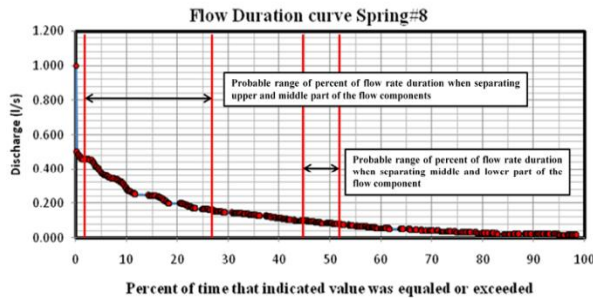


Figure 4. FDC of Mayali spring (Spring_ID#8) when separation is performed on three MRCs.

the sets of percent of flow rate duration in selected ranges; with a step equaling 1%. The optimal separation scenario having an optimal set of separation criteria, i.e. percent of flow rate duration is selected based on the highest average coefficient of determination (R^2). Figure 5 represents the separated MRC's for Spring_ID#8 having optimal separation criteria as 25% and 49% of the flow rate duration, respectively. Comparing Figures 3 and 5, it can be revealed by visual examination that the optimal MRC (Figure 5) shows good fitting with recession segments than the MRC shown in Figure 3 which is also reflected in the coefficient of determination which has been improved from 90% to 94%. Recession analysis was carried out for all other springs in Danda watershed and recession constants for all the springs are estimated (See Table 1). Note that, some springs are found dead after initial monitoring and hence those springs are not included in this Table 1.

Average recession constants (k) which obtained using generated MRC by exponential decay equation range from 0.934 to 0.989 with the goodness of fit (R^2) values ranging from 0.60 to 0.93 (Table 1). In case of optimally separated MRCs for all the springs, the average recession constants (k) range from 0.94 to 0.99 with the goodness of fit (R^2) values ranging from 0.64

to 0.98. The range of recession constants for segments 1-3 are $k_1 = 0.893$ to 0.981 , $k_2 = 0.885$ to 0.990 and $k_3 = 0.948$ to 0.996 , respectively. These ranges of MRCs segments may be attributed to rainy, winter and summer seasons. These values of recession constants indicate that drainage from the aquifer is very slow and it gradually reduces from segment 1 to segment 3 of MRCs. Thus, it can also be concluded that the aquifer has large potential to store water which helps the spring to sustain the flow for longer period.

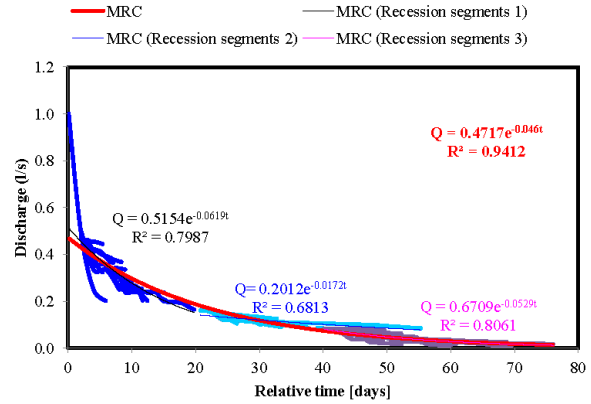


Figure 5. Optimally separated MRCs of Mayali spring (Spring_ID#8).

5. Conclusions:

Recession constant describes the slope of spring flow decline following recharge event/rainfall. The computation of recession constant is convenient way of describing recession characteristics, because it treats the complex ground water system as a lumped storage. The most important advantage of recession constant estimation is that it does not require any detailed knowledge about physical characteristics of the watershed rather it is based on the observed time-series of spring flow discharge. Therefore, it is very useful in areas like Indian Himalaya where very limited information is available on hydro-meteorological and geo-morphological characteristics of area due to difficulty in their proper assessment. The present study demonstrated the applicability of fully automatic adaptive matching strip method for spring recession flow analysis leading to the estimation of recession constants. The presented methodology is fast, reliable and applicable for generation of MRC and its optimal separation into desired segments using long multi-year time-series data sets with in-between gaps due to unavoidable circumstances and having different measurement frequency. In present study, an attempt has been made to estimate the recession constants for thirty springs in the Danda watershed, which is located

in Hindolakhil block of Devprayag Tehsil in Tehri Garhwal district (Uttarakhand State, India). From this study, it is revealed that the average recession constant (k) values obtained using generated MRC by exponential decay equation varied between 0.934 to 0.989, respectively and coefficient of determination (R^2) range varied between 0.60 to 0.93 with average value of 0.83. Optimal separation of the MRCs of all the springs into three/two segments using appropriate separation criteria from FDC, the obtained values for recession constants ranges from 0.94 to 0.99, respectively and coefficient of determination (R^2) range from 0.64 to 0.98 with average value of 0.88. Therefore, it can be concluded that the optimal separation of MRC into two/three segments resulting in overall improvement in the fitting of MRC to the recession segments as reflected in improvement of R^2 values, thus it can give more accurate information about the recession characteristics of the springs.

6. Acknowledgements:

The first author is pleased to acknowledge Sh. R. D. Singh, Director, National Institute of Hydrology Roorkee for his guidance and encouragement. The author is also grateful to Dr. Kristijan Posavec, Associate Professor, University of Zagreb, Croatia for kind help.

7. References:

- [1] J. G. Arnold, P. M. Allen, R. Muttiah, and G. Bernhardt, "Automated base flow separation and recession analysis techniques," *Ground Water*, Vol. 33, Issue 6, PP. 1010-1018, 1995.
- [2] R. M. Vogel, and C. N. Kroll, "Estimation of baseflow recession constants," *Water Resources Management*, Vol. 10, Issue 4, PP. 303-320, 1996.
- [3] H. C. Riggs, "The base-flow recession curve as an indicator of ground water," *Hydrological Science Bulletin /Journal*, Vol. 63, PP. 352-363, 1964.
- [4] F.R. Hall, "Base-flow recessions -A review", *Water Resources Research*, Vol. 4, Issue 5, PP. 973-983, 1968.
- [5] H. Amit, V. Lyakhovsky, A. Katz, A. Starinsky and A. Burg, "Interpretation of spring recession curves", *Ground Water*, Vol. 40, Issue 5, PP. 543-551, 2002.
- [6] S. Birk and S. Hergarten, "Early recession behaviour of spring hydrographs", *Journal of Hydrology*, Vol. 387, Issue 1-2, PP. 24-32, 2010.
- [7] L. M. Tallaksen, "A review of baseflow recession analysis", *Journal of Hydrology*, Vol. 165, 349-370, 1995.
- [8] M. D. Bako, and D. N. Hunt, "Derivation of baseflow recession constant using computer and numerical analysis", *Hydrological Science Journal*, Vol. 33, Issue 4, PP. 357-367, 1988.
- [9] O. Bonacci, "Karst springs hydrographs as indicator of karst aquifers", *Hydrological Science Journal*, Vol. 38, Issue 1-2, PP. 51-60, 1993.
- [11] H. D. Rivera-Ramirez, G. S. Warner and F. N. Scatena, "Prediction of master recession curves and baseflow recessions in the Luquillo mountains of Puerto Rico", *Journal of the American Water Resources Association*, Vol. 38, Issue 3, PP. 693-704, 2002.
- [12] S. Berhail, L. Ouerdachi and H. Boutaghane, "The use of the recession index for components of flow", *Energy Procedia*, Vol. 18, PP. 741-750, 2012.
- [13] K. Bryan, "Classification of springs", *Journal of Geology*, Vol. 27, Issue 7, PP. 522-561, 1919.
- [14] K. S. Valdiya, and S. K. Bartarya, "Hydrogeological studies of springs in the catchment of the Gaula River, Kumaun Lesser Himalaya, India", *Mountain Research and Development*, Vol. 11, Issue 3, PP. 239-258, 1991.
- [15] V. C. Goyal and S. Kumar, "Hydrological investigations and instrumentation in small watershed in Garhwal Himalaya", National Institute of Hydrology Roorkee, Technical Report, CS (AR)-34 (96-97), PP. 1-45, 1996-97.
- [16] X. Chen, Y. Zhang, X. Xue, Z. Zhang, and L. Wei, "Estimation of baseflow recession constants and effective hydraulic parameters in the karst basins of southwest China", *Hydrological Research*, Vol. 43, Issue 1-2, PP. 102-112, 2012.
- [17] K. Posavec, A. Bacani and Z. Nakić, "A Visual basic spreadsheet macro for recession curve analysis", *Ground Water*; Vol. 44, Issue 5, PP. 764-767, 2006.
- [18] K. Posavec, J. Parlov and Z. Nakić, "Fully automated objective-based method for master recession curve separation", *Ground Water*; Vol. 48, Issue 4, PP. 598-603, 2010.
- [19] NIH, "Integrated hydrological study (instrumentation, investigations and modelling) for sustainable development and management of two hilly watersheds in U.P", Final Project Report of DST (Govt. of India) - sponsored project, 2003.



Table 1. Calculated Recession constants (k) and correlations coefficients (R^2) for springs in Danda Watershed using MRC.

Spring ID No.	MRC by Exponential equation		Optimal separation model Q%	Recession constant when MRC separated into three segments				R^2 values for each separated segment of MRC and optimal MRC			
	k	R2		k_1	k_2	k_3	k	Seg 1	Seg 2	Seg 3	Optimal
1	0.964	0.91	9% and 45%	0.967	0.978	0.961	0.957	0.94	0.69	0.73	0.94
2	0.980	0.73	10% and 47%	0.973	0.985	0.991	0.971	0.95	0.51	0.26	0.87
3	0.951	0.85	5% and 45%	0.957	0.953	0.965	0.953	0.98	0.75	0.86	0.93
4	0.972	0.75	34% and 59%	0.981	0.989	0.962	0.970	0.67	0.65	0.83	0.84
5	0.989	0.59	5% and 53%	0.976	0.967	0.996	0.989	0.92	0.69	0.68	0.65
6	0.949	0.96	3% and 15%	0.893	0.936	0.949	0.947	0.96	0.79	0.96	0.97
7	0.934	0.93	5% and 30%		0.903	0.953	0.938		0.90	0.90	0.95
8	0.958	0.90	25% and 49%	0.939	0.983	0.948	0.955	0.80	0.68	0.81	0.94
9	0.955	0.93	16% and 67%	0.951	0.948	0.960	0.951	0.63	0.89	0.87	0.97
10	0.975	0.86	22% and 44%	0.930	0.977	0.978	0.971	0.78	0.76	0.80	0.91
11	0.988	0.81	5% and 35%	0.944	0.990	0.984	0.984	0.95	0.73	0.81	0.88
13	0.982	0.73	1% and 39%		0.950	0.983	0.974		0.74	0.67	0.90
15	0.984	0.73	6% and 98%	0.899	0.963	0.996	0.984	0.90	0.88	0.96	0.64
16	0.974	0.85	3% and 22%		0.986	0.976	0.969		0.91	0.86	0.92
17	0.974	0.77	18% and 99%	0.952	0.965	0.996	0.971	0.77	0.96	0.99	0.91
18	0.976	0.70	2% and 37%		0.986	0.973	0.973		0.37	0.86	0.92
20	0.984	0.81	2% and 28%		0.960	0.984	0.981		0.72	0.82	0.86
21	0.980	0.72	3% and 26%		0.885	0.983	0.979		0.76	0.68	0.73
25	0.977	0.87	3% and 28%		0.952	0.979	0.974		0.82	0.78	0.86
27	0.973	0.80	30% and 90%	0.971	0.977	0.990	0.972	0.93	0.75	0.97	0.94
28	0.974	0.89	19% and 74%	0.974	0.973	0.950	0.968	0.98	0.83	0.44	0.86
29	0.945	0.95	7% and 28%		0.946	0.951	0.949		0.86	0.98	0.98
30	0.944	0.97	4% and 77%		0.951	0.954	0.950		0.92	0.98	0.98