CHAPTER 2

RAINFALL RUN-OFF AND BASEFLOW ESTIMATION

2.1 Introduction

The west coast of India receives abundant rainfall from the southwest monsoon. The Western Ghats escarpment (Sahyadri mountain range) that runs parallel to the west coast plays an important role in its distribution. The monsoon causes heavy rainfall on the windward side of the escarpment, distinguishing it from the much drier leeward side (Suprit and Shankar, 2008). This results in high discharge from the small rivers originating on the Ghats and draining into the Arabian Sea in the west. The Mhadei River is a tributary of the Mandovi River that originates in the Western Ghats and drains into the Arabian Sea. It has been grouped under Bhatsol Basin (Sub-basin: Vasishti and Others) by CGWB on the Watershed Atlas of India.

2.2 Rainfall Analysis

The Mhadei River watershed receives abundant rainfall due to the southwest monsoon during the months of June to September. Thirteen rain-gauge stations in and around the watershed have been identified and normal monthly rainfall data has been collected (Table 2.1). Over 90% rainfall occurs during the monsoon months from June to September while the remaining 10% rainfall is received during the non-monsoon months. Highest rainfall is received during the month of July followed by a gradual decrease in subsequent monsoon months. There is also a considerable variation in rainfall increasing from the coast towards the Western Ghats. Rainfall during the monsoon consists of several bursts with weak spells and sometimes monsoon breaks in between (Rao, 1976). In the present study both Isohyetal and Thiessen polygon methods have been used to compute the average normal rainfall for the Mhadei River watershed.

2.2.1 Thiessen Polygon Method

In this method, the watershed is divided into polygons with the rain gauge station in the middle of each polygon assumed to be representative for the rainfall on the area of land included in its polygon. Thiessen polygons are obtained by drawing perpendicular bisectors to the lines joining adjacent rain gauge stations on a base map. Each polygon area is assumed to be influenced by the rain-gauge station inside it (Fig 2.1). An area factor is computed for each station as a ratio of the land area influenced by that station to the area of the entire watershed. Large area factor implies that the rainfall of that station is manipulated over a larger area and therefore less accurate.

The average annual rainfall computed using Thiessen polygon method for the Mhadei River watershed is 3955mm (Table 2.2). The Valpoi rain-gauge station has the maximum influence (39%) on the Mhadei River watershed followed by Amgao, Collem and Kankumbi station.

2.2.2 Isohyetal Method

In Isohyetal method, the point rainfalls are plotted on a suitable base map and the lines of equal rainfall (isohyets) are then drawn as contours giving consideration to orographic effects and storm morphology (Fig. 2.2).

The average annual rainfall using Isohyetal Method for the Mhadei River watershed is 3933mm (Table 2.3). There is not much difference between the Thiessen polygon and the Isohyetal averages. However, Isohyetal method gives consideration to orographic effects and storm morphology (Raghunath, 1992), and the Mhadei River watershed is a mountainous watershed, therefore Isohyetal method has been adopted for further computations. As a result of the orographic influence the rainfall increases progressively from the western boundary of the watershed towards the Western Ghats located in east from about 3500mm to over 5000mm (Fig. 2.2). However, further east on the Karnataka plateau it decreases rapidly to about 2500mm.

Table 2.1 Normal monthly rainfall (mm) of the rain-gauge stations in and around Mhadei River watershed.

Stations in Karnataka	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual
Amgao	710	1385	969	249	109	6	0	1	1	1	3	11	3445
Castlerock	1112	2304	1643	543	176	7	4	0	0	1	1	1	5792
Chapoli	821	1266	957	203	106	22	0	0	0	0	0	8	3384
Gavali	833	1468	1268	321	78	8	0	0	0	0	1	4	3979
Jamagao	495	792	685	179	69	9	0	0	0	0	0	1	2230
Jamboti	318	594	416	104	55	9	0	1	2	2	5	13	1520
Kankumbi	1019	1725	1268	348	160	24	0	0	0	2	11	21	4578
Khanapur	331	728	377	129	116	40	6	1	1	5	27	80	1840
Tilariwadi	1076	1538	1045	355	156	27	3	0	0	0	0	35	4236
Stations in Goa													
Bicholim	924	1284	674	325	187	48	4	1	0	0	9	86	3542
Colem	1015	1825	1098	550	257	52	10	1	0	1	18	112	4938
Ponda	857	1200	797	383	165	71	13	2	0	0	10	88	3586
Valpoi	978	1505	946	397	200	55	7	1	0	1	14	97	4200

Source: IMD, Master Plan for Mhadei/Mandovi River basin, 1999

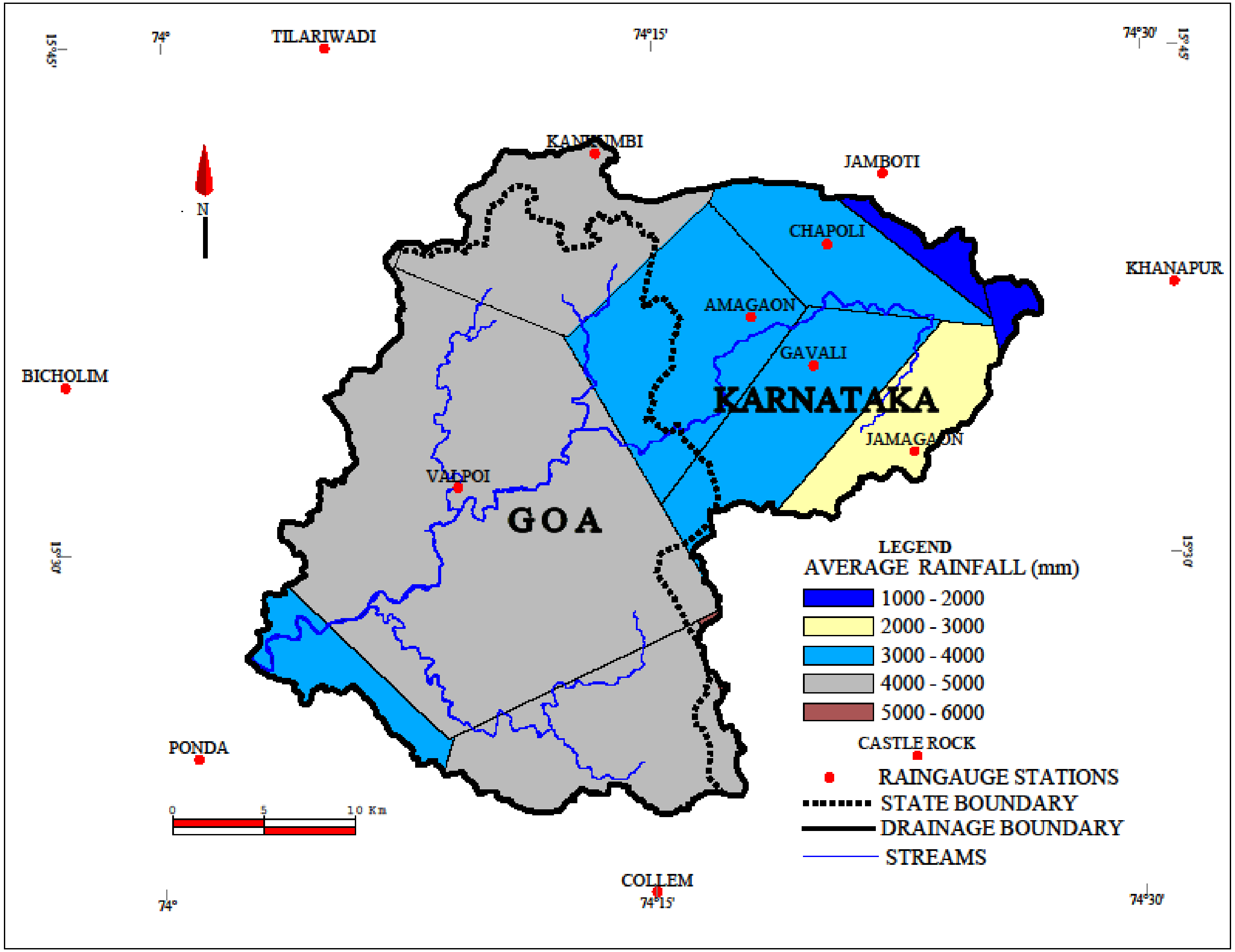

Figure 2.1 Map showing Thiessen polygons for Mhadei River watershed

Table 2.2 Average rainfall using Theissen polygon method

Rain-gauge station	Area of polygon (km^2)	Area Factor	Normal annual rainfall (mm)	Rainfall in Mhadei (mm)
Jamagaon	51.04	0.057	2230	127
Colem	100.05	0.110	4938	543
Ponda	33.40	0.037	3586	133
Valpoi	351.90	0.390	4200	1638
Amgao	107.23	0.119	3445	411
Castlerock	0.94	0.001	5792	6
Chapoli	58.60	0.065	3384	220
Gavali	81.63	0.091	3979	361
Jamboti	13.68	0.015	1520	23
Kankumbi	92.93	0.103	4578	473
Khanapur	6.98	0.008	1840	14
Tilariwadi	1.08	0.001	4236	4
Bicholim	0.00	0.000	3530	0
Total	899.46	0.998		3955

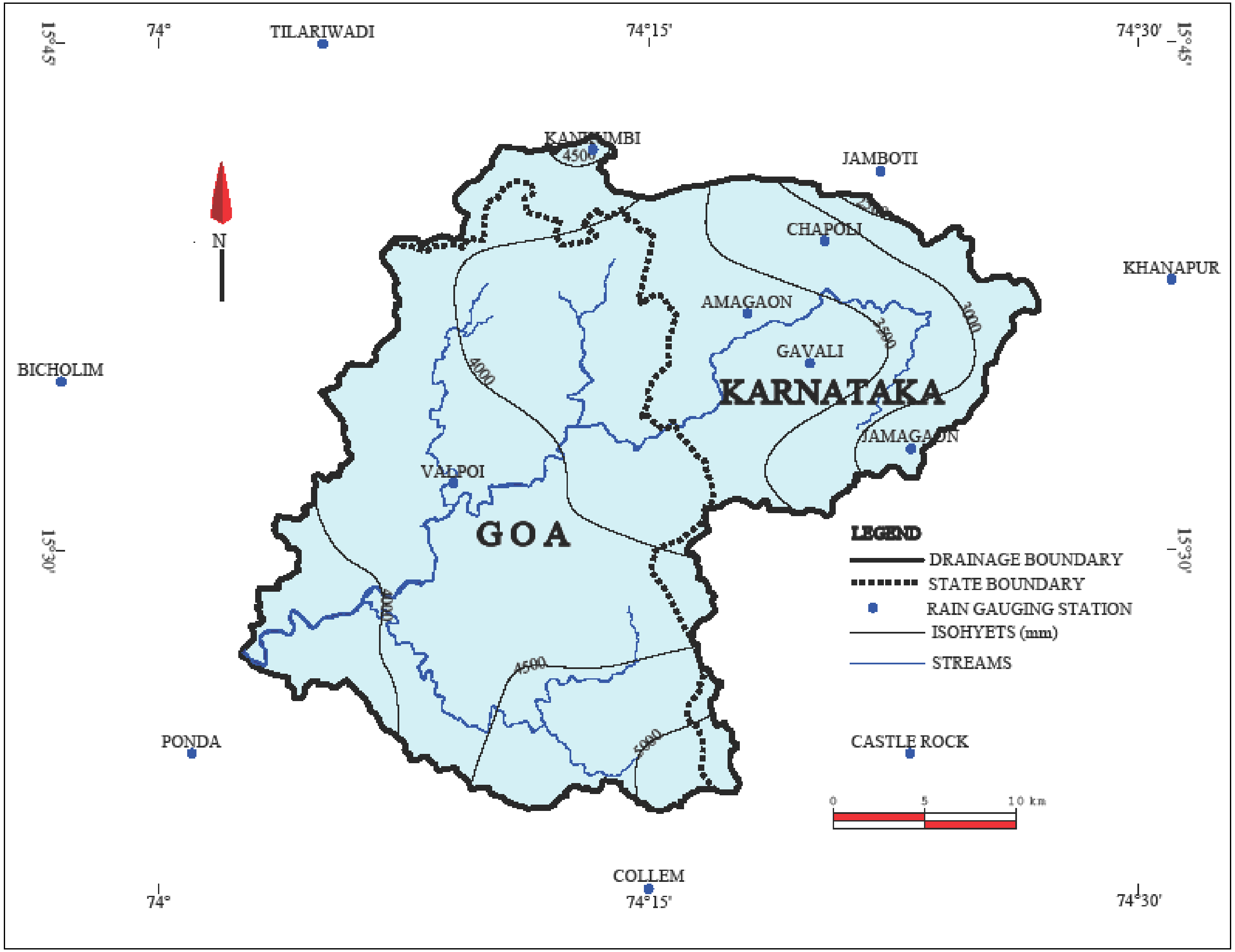

Figure 2.2 Isohyetal map for Mhadei River watershed

Table 2.3 Average rainfall using Isohyetal method

Sr. No.	Isohyetal Interval (mm)	Mean Rainfall (mm)	Area in Mhadei watershed (km^2)	Area Percent	Area Factor	Average rainfall (mm)
1	5500-5000	5250	19.85	2.21	0.0221	116
2	5000-4500	4750	76.95	8.56	0.0856	406.6
3	4500-4000	4250	323.83	36.00	0.3600	1530
4	4000-3500	3750	326.59	36.31	0.3631	1361.6
5	3500-3000	3250	101.33	11.27	0.1127	366.3
6	3000-2500	2750	49.36	5.49	0.0549	151
7	2500-2000	2250	1.54	0.01	0.0001	0.2
		Total	899.45	100	1.0000	3933

2.3 Rainfall Run-off Estimation

The average annual rainfall and the resulting rainfall volume for Goa and Karnataka regions using Isohyetal method have been computed separately (Table 2.4).

The total area of the Mhadei River watershed is 899 km^2. The area of the Mhadei River watershed that lies in Goa State is 573 km^2 (64%) while the area of the Mhadei River watershed that lies in Karnataka State is 326 km^2 (36%). The average rainfall in the entire Mhadei River watershed using Isohyetal method is 3933 mm. The average rainfall in the Goa region of the Mhadei River watershed is 4160 mm while that in the Karnataka region of the Mhadei River watershed is 3536 mm. As seen from Table 2.4, about 2383 MCM i.e., 67% of the rain water is received by the Goa region of the watershed while 1155 MCM i.e., 33% of rain water is received by the Karnataka region of the watershed. The total volume of rain water received in the Mhadei River watershed is therefore 3538 MCM.

The average monthly rainfall (mm) has also been computed for Mhadei River watershed and the resulting volume of monthly rainfall is shown in Table 2.5.

Table 2.4 State-wise average annual rainfall and volume of rainfall using Isohyetal method.

Isohyetal Interval (mm)	Average annual Rainfall (mm)	Area in the Mhadei watershed (km^2)	Area in Goa (km^2)	Area in Karnataka (km^2)	Resulting volume of rainwater (MCM)		
					In Mhadei River watershed	In Goa region	In Karnataka region
5500-5000	5250	19.85	13.55	6.3	104	71	33
5000-4500	4750	76.95	70.81	6.14	365	336	29
4500-4000	4250	323.83	288.2	35.81	1376	1224	152
4000-3500	3750	326.59	200.39	126.2	1225	752	473
3500-3000	3250	101.33	0	101.33	329	0	329
3000-2500	2750	49.36	0	49.36	136	0	136
2500-2000	2250	1.51	0	1.51	3	0	3
	Total	**899**	**573**	**326**	**3538**	**2383**	**1155**

Table 2.5 Average monthly rainfall and resulting volume of rainfall in Mhadei River watershed

Period	Month	Average rainfall (mm)	Volume of rainfall (MCM)
Monsoon	June	871	783
	July	1450	1304
	August	991	891
	September	351	316
Non-monsoon	October	161	145
	November	35	32
	December	4	4
	January	1	1
	February	0	0
	March	1	1
	April	10	9
	May	58	52
	Total annual	**3933**	**3538**

Thus, the total volume of monsoon rainfall received in the Mhadei River watershed is 3294 MCM while the total volume of non-monsoon rainfall is 244 MCM.

2.4 River Discharge Analysis

The Mhadei River discharge is gauged by Central Water Commission (CWC) at Ganjem station located close to the outlet of Mhadei River (Fig 2.3). The average monthly river discharge data for 17 years measured at Ganjem river-gauging station on the Mhadei River outlet is given in Table 2.6. The same is graphically represented in Fig. 2.4 along with the normal monthly rainfall in the Mhadei River watershed.

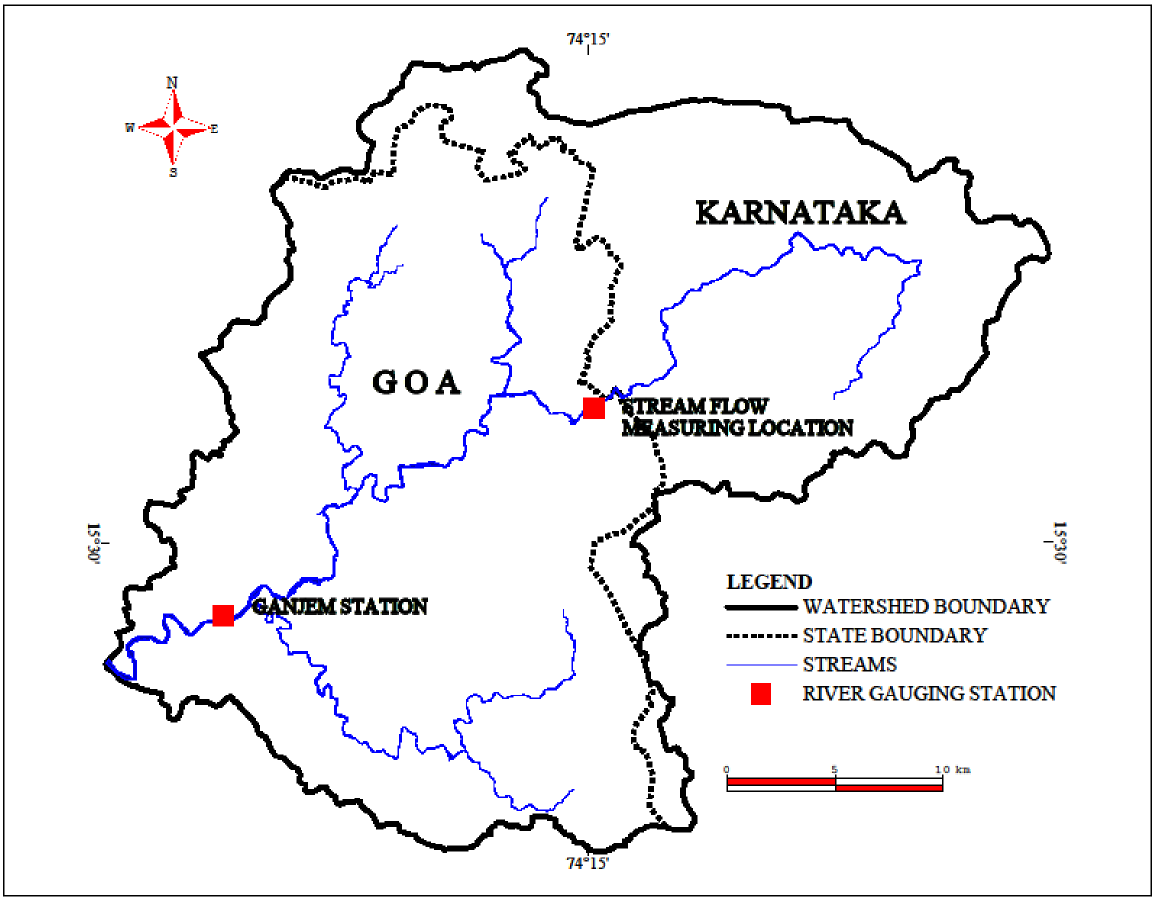

Figure 2.3 Map showing Ganjem river-gauging station of CWC and location of stream flow measurements carried out during the present study.

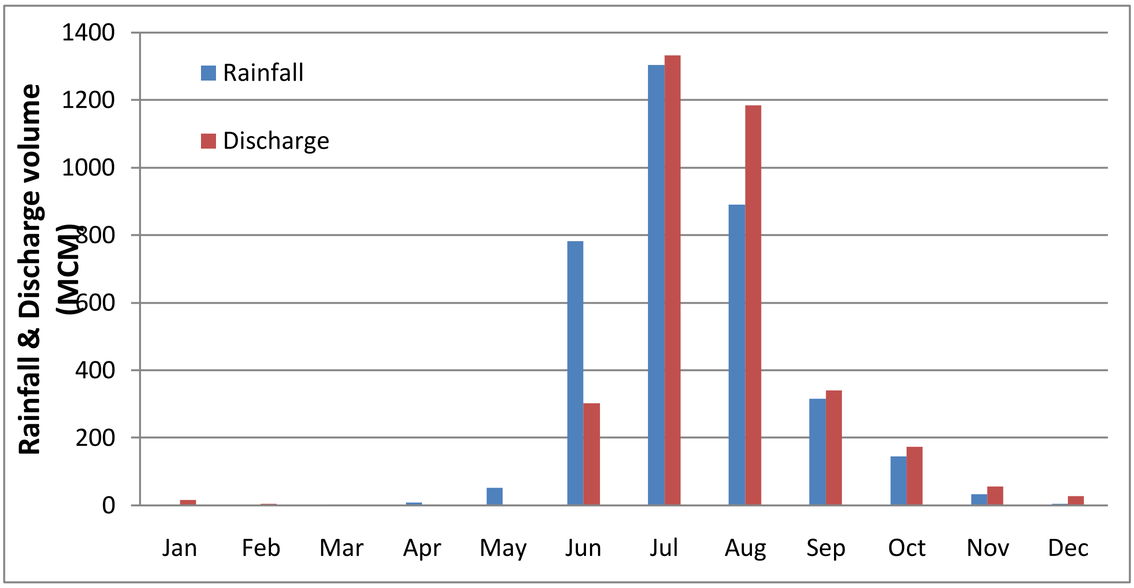

Figure 2.4 Histogram showing average monthly discharge of Mhadei River measured at Ganjem station and normal monthly rainfall volume in Mhadei River watershed

Table 2.6 Monthly average discharge data measured at Ganjem River-gauging station on Mhadei River (Source: CWC).

Month	Discharge (MCM)
June	303.24
July	1333.36
August	1184.56
September	340.35
October	173.45
November	54.61
December	27.15
January	16.33
February	5.05
March	3.42
April	2.52
May	2.52
Total annual	**3446**

As seen from Fig. 2.4, during the beginning of the monsoon season, i.e., during May and June the rainfall dominates the run-off. This is due to the antecedent moisture conditions in the ground which allows large portions of the rainfall as soil moisture saturation and storage followed by groundwater recharge. During the month of July a marginal increase in the surface runoff is witnessed which increases substantially during the month of August. During July little of groundwater contributes to the surface runoff components whereas during August the component of baseflow to the surface run-off becomes significant. That means the soil moisture retention and groundwater recharge continues in the first three months of the rainy season. The baseflow contribution sustains till January as seen from the figure indicating higher groundwater levels during these months. The average annual discharge of Mhadei River watershed at Ganjem river-gauging station is 3446 MCM which is 97% of the total volume of annual rainwater (3538 MCM) received by the watershed. Thus, only 3% of the total annual rainfall is attributed to groundwater recharge.

2.5 Baseflow Estimation

Rainfall on a catchment is considered to partition between overland flow, ground infiltration and evapo-transpiration. Overland flow is that part of the total run-off which travels over the land surface to reach a stream channel. The ground infiltration further gets distributed into soil moisture storage, interflow and groundwater recharge. Interflow is water moving laterally within the zone of aeration in the direction of the topographic slope. The interflow combines with the overland flow to represent the surface run-off. The groundwater recharge is subsequently, totally or partially, discharged into streams in the form of springs or seepages and is called baseflow. Baseflow supports the stream discharge during dry weathers when there is little or no rainfall. Thus, the total run-off is a function of three components namely, overland flow, interflow and baseflow. These three components of total run-off are shown schematically in Fig. 2.5.

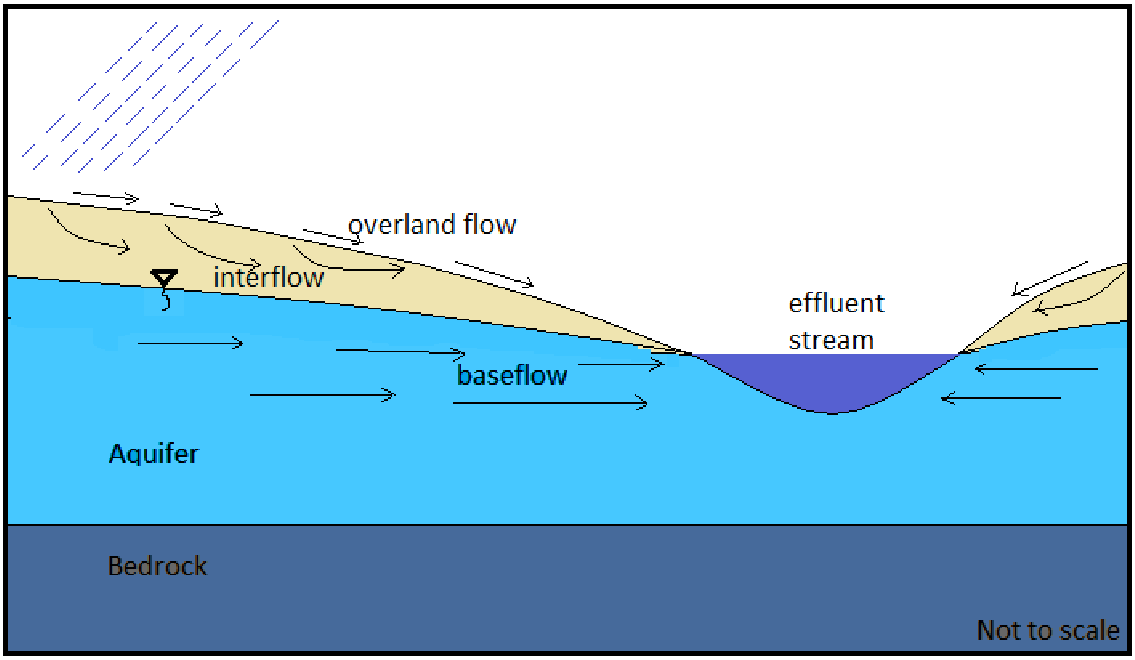

Figure 2.5 A schematic section showing the various components those contribute to the total discharge of a stream.

In order to quantify the baseflow volumes in Mhadei River watershed, stream-flow measurements were carried out on a single stream at Goa-Karnataka State border (Fig. 2.3) for the months of December and April. As it is not feasible to physically measure the baseflow volume from all the streams coming from Karnataka due to inaccessibility, it is proposed to derive ***unit area baseflow*** using the field measured values. Using this unit area baseflow, the total non-monsoon baseflow coming from all the streams from Karnataka is computed on monthly basis. Further, the stream hydrograph analysis has been used to quantify the annual baseflow contribution in Mhadei River watershed.

2.5.1 Stream Gauging Measurements

Stream-flow measurements were carried out on Mhadei River at the Goa- Karnataka State boundary near village Uste in the months of

December 2007 and April 2008 using Velocity-Area method. The method requires the choice of a length of river reach sufficient to allow accurate timing of a float released in the middle of a channel and far enough upstream to attain ambient velocity before entering the reach. By measuring the distance of the reach and the time taken for the float to travel the length of the reach, the water velocity can be calculated by dividing the length by the time (Hiscock, 2005). The procedure is repeated a number of times to obtain the average maximum surface velocity, which is then converted to mean velocity using coefficients (Table 2.7). By measuring the flow area upstream and downstream of the reach and taking the average value, the mean cross-sectional area of flow for the reach is obtained (Plate 2.1). The river discharge is then found by multiplying the mean velocity by the cross-sectional area of flow (Tables 2.8 and 2.9).

Table 2.7 Coefficients to obtain mean velocity of a river from the surface velocity (Hiscock, 2005)

Average Depth in Reach (m)	Co-efficient
0.3	0.66
0.6	0.68
0.9	0.70
1.2	0.72
1.5	0.74
1.8	0.76
2.7	0.77
3.7	0.78
4.6	0.79
≥ 6.1	0.80

Plate 2.1 Stream-flow measurements being carried out at Goa-Karnataka State boundary

Table 2.8 Stream-flow measurements on Mhadei River at Goa-Karnataka State boundary in the month of December 2007

1	**Upstream River Section**	
A	Location	**Latitude: N15°33'20"** **Longitude:E74°15'10"**
B	Total width of the section	**35.60 m**
C	Average depth of the section	**0.57 m**
D	Cross-sectional area	**20.29 m^2**
2	**Downstream River Section**	
A	Location	**Latitude: N15°33'19.5"** **Longitude: E74°15'04"**
B	Total width of the section	**36.57 m**
C	Average depth of the section	**0.54 m**
D	Cross-sectional area	**19.75 m^2**
3	**Average cross-sectional area**	**20.02 m^2**
4	**Surface velocity**	
A	Distance between upstream and downstream section	**160.5 m**
B	Average time taken by float to travel the above distance	**9min 25 sec**
C	Surface velocity of river water	**0.257 m/sec**
5	**Mean velocity of stream flow** **= 0.257 x 0.68**	**0.174 m/sec**
6	**Stream flow (Discharge)** **= 20.02 x 0.174**	**3.48 cumec**

Thus, the discharge measured in the month of December is 3.48 cubic meters per second (cumec). This is equal to 9 MCM per month. The contributing area to the above measured discharge is estimated to be 296 km^2 from the Karnataka region of the watershed.

It is noted that the average discharge measured at Ganjem river-gauging station for the month of December is 27.15 MCM/month. The area contributing to the above measured discharge at Ganjem station is 880 km^2 which is 98% of the entire Mhadei River watershed.

Table 2.9 Stream flow measurements on Mhadei River at Goa-Karnataka State boundary in the month of April 2008

1	**Upstream River Section**	
A	Location	**Latitude: N15°33'20"** **Longitude:E74°15'9.4"**
B	Total width of the section	**13.7 m**
C	Average depth of the section	**0.342 m**
D	Cross-sectional area	**4.6854 m^2**
2	**Downstream River Section**	
A	Location	**Latitude: N15°33'19.7"** **Longitude: E74°15'8.8"**
B	Total width of the section	**22.19 m**
C	Average depth of the section	**0.4412 m**
D	Cross-sectional area	**9.791 m^2**
3	**Average cross-sectional area**	**7.2382 m^2**
4	**Surface velocity**	
A	Distance between upstream and downstream section	**126 m**
B	Average time taken by float to travel the above distance	**36 min**
C	Surface velocity of river water	**0.0583 m/sec**
5	**Mean velocity of stream flow** **= 0.0583 x 0.68**	**0.04 m/sec**
6	**Stream flow (Discharge)** **= 7.2382 x 0.04**	**0.289 cumec**

Thus, the discharge measured in the month of April 2008 is 0.289 cumec. This is equal to 0.75 MCM per month. The contributing area to the above measured discharge is 296 km^2 from the Karnataka region of the watershed.

It is noted that the corresponding average discharge measured at Ganjem river-gauging station for the month of April is 2.52 MCM/month. The area contributing to the above measured discharge at Ganjem station is 880 km^2 which is 98% of the entire Mhadei River watershed.

2.5.2 Quantification of Baseflow

Baseflow for December: The discharge measured for the month of December from the Karnataka region of the watershed is 9 MCM per month and the area contributing to this discharge is 296 km^2. Thus, the unit area baseflow from the Karnataka region of the watershed for the month of December can be calculated as:

Discharge/Area= 9 MCM /296 km^2 = 0.0304 MCM/km^2

Since the total area of the Mhadei River watershed that lies in the Karnataka state is 326 km^2 therefore, the total baseflow from the Karnataka region for the month of December 2007 can be calculated as:

Unit area base flow X total area = 0.0304 X 326 = 9.9 MCM

Similarly, the average discharge measured at Ganjem river-gauging station for the month of December is 27.15 MCM. The area contributing to the above measured discharge at Ganjem station is 880 km^2. Thus, the unit area baseflow for the entire Mhadei River watershed for the month of December can be calculated as:

$$\text{Discharge/Area} = 27.15 \text{ MCM} / 880 \text{ km}^2 = 0.0308 \text{ MCM/km}^2$$

Thus, the value of the unit area baseflow computed for the entire Mhadei River watershed for the month of December is in close agreement with the value of the unit area baseflow computed for the Karnataka region by stream flow measurements during the present study.

Thus, the baseflow measured for the month of December from the Karnataka region of the watershed (9.9 MCM) is 37% of the base flow measured for the entire Mhadei River watershed (27.15 MCM) in the month of December.

Baseflow for April: The discharge measured for the month of April from the Karnataka region of the watershed is 0.75 MCM and the area contributing to this discharge is 296 km^2. Thus, the unit area baseflow from the Karnataka region of the watershed for the month of April can be calculated as:

$$\text{Discharge/Area} = 0.75 \text{ MCM} / 296 \text{ km}^2 = 0.0025 \text{ MCM/km}^2$$

Since the total area of the Mhadei River watershed that lies in the Karnataka State is 326 km^2 therefore, the total baseflow from the Karnataka region for the month of December can be calculated as:

Unit area base flow X total area = 0.0025 X 326 = 0.826 MCM

Similarly, the average discharge measured at Ganjem river-gauging station for the corresponding month of April is 2.52 MCM. The area contributing to the above measured discharge at Ganjem station is 880 km^2. Thus, the unit area baseflow for the entire Mhadei River watershed for the month of April can be calculated as:

Discharge/Area= 2.52 MCM / 880 km^2 = 0.0028 MCM/km^2

Thus, the value of the unit area baseflow computed for the entire watershed for the month of April is in close agreement with the value of the unit area baseflow computed for the Karnataka region by stream flow measurements during the present study.

The baseflow measured for the month of April from the Karnataka region of the watershed (0.826 MCM) is found to be 33% of the baseflow measured for the entire Mhadei River watershed (2.52 MCM).

Baseflow computation for non-monsoon period: The baseflow contribution for the other non-monsoon months from Karnataka region has been computed by linearly extrapolating the values of December and April months to the remaining months of non-monsoon period from October to May (Table 2.10). Further, using the monthly baseflow volume unit area baseflow has been computed for each month of non-monsoon period.

Table 2.10 Baseflow computation for non-monsoon season from Karnataka

Month	Discharge measured at Ganjem station (MCM)	Linearly extrapolated baseflow proportion from Karnataka (%)	Baseflow volume from Karnataka (MCM)	Unit area baseflow calculated for non-monsoon months
October	173.45	39	67.65	0.2075
November	54.61	38	20.75	0.0637
December	27.15	37	9.90	0.0304
January	16.33	36	5.88	0.0180
February	5.05	35	1.77	0.0054
March	3.42	34	1.16	0.0036
April	2.52	33	0.826	0.0025
May	2.52	32	0.806	0.0025
Total	**285**		**109**	

The total non-monsoon baseflow contribution from Karnataka region computed using unit area baseflow works out to be 109 MCM which is 38% of the total non-monsoon baseflow (285 MCM) of the entire Mhadei River watershed. As seen from Table 2.8, the baseflow drastically decreases from January onwards and the river cannot sustain sufficient water to meet the water demands on its banks. There are several patches of agricultural lands and settlements which heavily depend on the available baseflow. The dry weather flow is utilised extensively in the downstream region of the watershed by storing the water within river banks by constructing *bandharas* across the streams.

The contribution of baseflow from Karnataka region compared to the baseflow measured at Ganjem station for the non-monsoon months is shown graphically in Fig. 2.6.

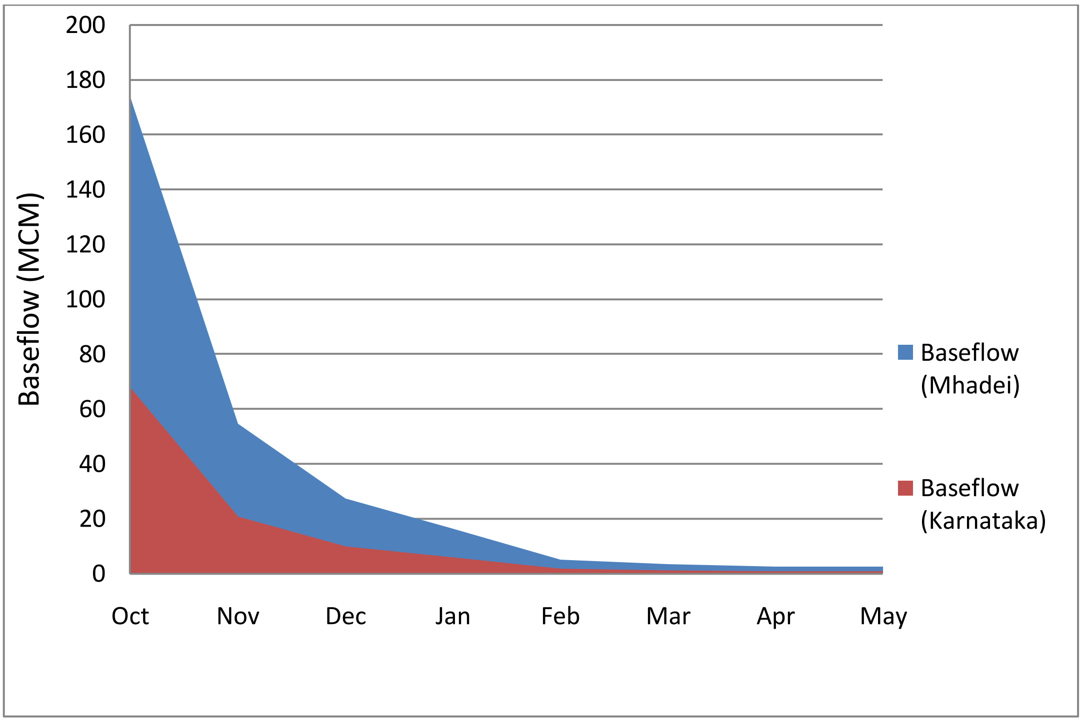

Figure 2.6 Comparison of non-monsoon baseflow (MCM) contributed from Karnataka region with non-monsoon baseflow (MCM) of the entire Mhadei river watershed

2.5.3 Baseflow Computation using Stream Hydrograph Analysis

A stream hydrograph is described as a graphical plot showing measured stream discharge as a function of time. Surface run-off and baseflow components of total run-off combine to generate a stream hydrograph. The baseflow represents the relatively steady contribution to stream discharge from groundwater return flow while the surface run-off represents the additional discharge contributed by rainfall event. A stream hydrograph may be plotted as storm hydrograph, seasonal hydrograph or long-term hydrograph. Storm hydrograph is plotted when a relatively short interval of time spanning the approach and passing of a storm is involved. Seasonal hydrograph is plotted when longer time interval representing the full range of seasonal flow is involved. A time span extending over a period of many years enables plot of long-term hydrograph.

In the present study, stream hydrograph analysis of the seasonal (monthly) discharge data of Ganjem river-gauging station has been carried out. The baseflow can be separated either using Constant discharge method, Concave method or Constant slope method. The Constant discharge method assumes that baseflow is constant throughout the rainfall period while the Concave method assumes that the declining hydrograph trend prior to the onset of rainfall continues till the occurrence of peak flow (Linsley et al, 1975). Since it is unlikely that the baseflow will remain constant after the onset of rainfall in Mhadei River watershed given the high infiltration occurring in the months of May and June (as indicated in Fig. 2.4) and the highly drainable nature of the aquifers in the watershed (as brought out later in Chapter 4), the Constant slope method has been adopted for separation of the baseflow (Fig. 2.7 and Table 2.11).

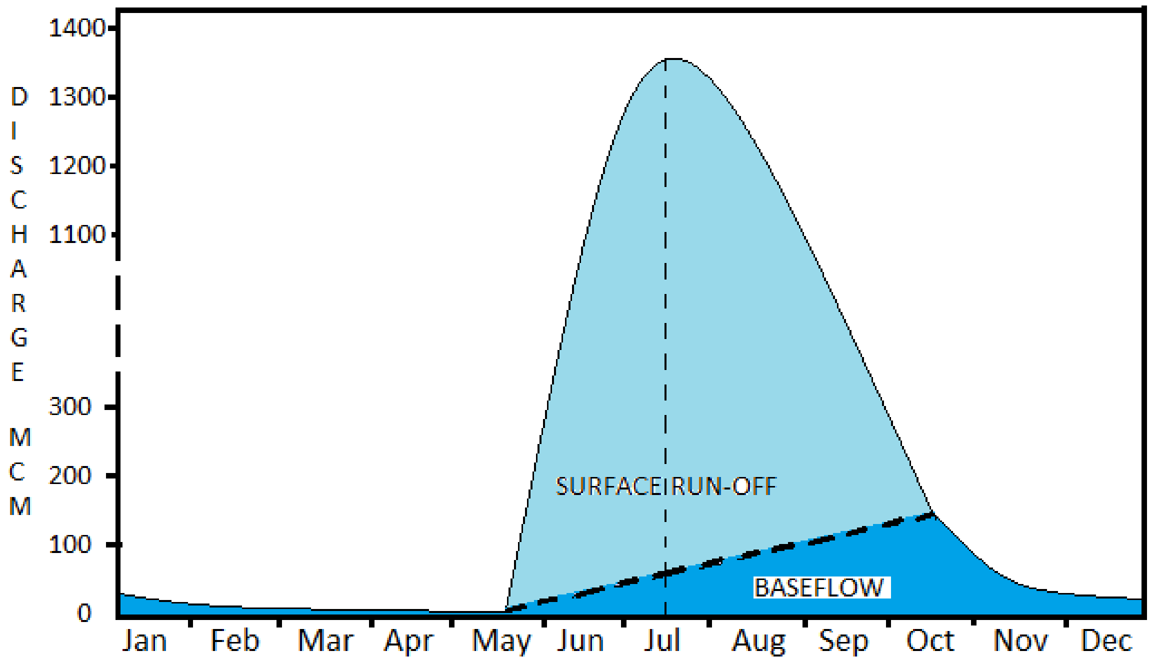

Figure 2.7 Mhadei River hydrograph separation using Constant slope method

As seen in Fig. 2.7, the hydrograph indicates a slow decline in the flow prior to the onset of rainfall. This is typical of a stream relying on baseflow (groundwater) for its discharge (Watson and Bernett, 1993). Then, as the surface run-off begins to reach the stream in ever increasing amounts the hydrograph rises sharply (June to July). Further, as the intensity of rainfall diminishes, the hydrograph moves over a peak and declines steeply till the surface run-off ceases to reach the stream (July to October). Here onwards the trend of the hydrograph is again governed by the baseflow.

Table 2.11 Baseflow computation of Mhadei River watershed using Stream hydrograph separation (Constant slope method)

Months	Volume of rainfall (MCM)	River discharge (MCM)	Monsoon baseflow (MCM)	Non-monsoon baseflow* (MCM)
January	1	16	-	16
February	0	5	-	5
March	1	3	-	3
April	9	3	-	3
May	53	3	-	3
June	783	303	37	-
July	1303	1333	71	-
August	891	1185	105	-
September	315	340	140	-
October	146	173	-	173
November	32	55	-	55
December	4	27	-	27
Total	**3538**	**3446**	**353**	**285**
			638	

* All the flow volume measured during non-monsoon months is considered as baseflow

As seen in Table 2.11, it is estimated that 638 MCM (19%) of the total discharge measured at Ganjem station is baseflow component. The total discharge of a stream is a function of the surface run-off component and baseflow component. Therefore, the surface run-off component can be calculated by subtracting the total baseflow from the total discharge. This works out to be 2808 MCM per annum for the Mhadei River watershed. As the total rainfall received by a catchment gets partitioned into surface run-off, groundwater recharge and evapo-transpiration, the volume available for the two later components is 730 MCM (volume of rainfall - surface run-off). Assuming 1% (35 MCM) of the total rainfall received in the catchment is lost as evapo-transpiration, the groundwater recharge works out to be 695 MCM. Of this 638 MCM is discharged as baseflow, therefore the effective groundwater recharge works out to be 57 MCM. The groundwater recharge computed using water table fluctuation method works out to be 41.86 MCM (Chapter 4). Therefore, the effective evapo-transpiration loss amounts to 50 MCM i.e., 1.5%. of the total rainfall.

2.6 Discussion

The Mhadei River watershed receives abundant rainfall to the tune of more than 3900 mm from the southwest monsoon from June to September. This value is more than the average rainfall (3200 mm) for the entire Goa State. However, the presence of Western Ghats in the watershed causes uneven distribution of the rainfall resulting in higher rainfall on the Goa side of the escarpment and relatively less rainfall on the Karnataka plateau. The rainfall also exhibits a systematic spatial pattern from west to east. It increases moving from western boundary of the watershed towards the Western Ghats and further shows a uniform decline moving from the Western Ghats towards the eastern boundary of the watershed. The total volume of rain water received in the Mhadei River watershed is 3538 MCM. Of this, 67% is contributed from the Goa region and 33% is contributed from the Karnataka region of the watershed. The total volume of monsoon rainfall received in the entire Mhadei River watershed works out to be 3294 MCM while total volume of non-monsoon rainfall is 244 MCM.

The average annual discharge of Mhadei River watershed at Ganjem river-gauging station is 3446 MCM which is 97% of the total volume of annual rainwater (3538 MCM) received by the watershed. Thus, only 3% of the total annual rainfall is attributed to groundwater recharge. Histogram of the monthly rainfall and discharge data indicate that the groundwater recharge dominantly takes place during the first three months of the monsoon season.

It is estimated that 638 MCM (19%) of the total discharge measured at Ganjem station is baseflow component. The total non-monsoon baseflow contribution from Karnataka region computed using *unit area baseflow* works out to be 109 MCM which is 38% of the total non-monsoon baseflow (285 MCM) of the entire Mhadei River watershed.