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Long-Term Rainfall Analysis and Runoff Estimation in Mountainous Watershed: A Case Study from Mhadei River Basin, Goa and Karnataka

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ABSTRACT

The present study covers an interstate river basin falling in Karnataka and Goa states. An attempt has been made to estimate the surface runoff contributions in the respective watershed areas falling in Karnataka and Goa. The stream flow measurements at a few locations have been carried out during the summer months to ascertain the base flow contribution from the upstream Karnataka region. It has been estimated that the major part of the surface runoff is generated in Goa region than in Karnataka. The study is likely to generate the authentic base line data for judicial distribution of the water resources among the interstate stakeholders.

Keywords: Rainfall Analysis, Runoff Estimation, Mountainous Watershed, Western Ghats, Goa.

INTRODUCTION

When a river system drains through more than one State the task of equitable distribution of its water resources becomes difficult and questionable. Harnessing of the river water by the riparian states in the upper reaches of the watershed often leads to interstate conflicts. Major part of the present study area *i.e.* the watershed of Mhadei River lies in Goa and partly in Karnataka making it an interstate river. Mhadei River has been under scrutiny for such an activity of water harnessing by the neighboring state of Karnataka. Karnataka has proposed to build river water retention and diversion structures in the upper reaches of Mhadei River that lies in Karnataka state. The state of Goa has expressed concern about the likely effects of such river water retention and diversion structures on the ecological balance and economic development in the lower reaches of the Mhadei River Basin. Various possible impacts such as reduction in the discharge of the river, lowering of groundwater table, sea water intrusion, threat to the bio-diversity and ecological balance of the Western Ghats, effect on the fishery industry, agriculture and other small scale industries located along the Mhadei River are anticipated. However, on the other hand, the Karnataka government intends to supply drinking water from the proposed projects to its developing towns like Dharwad and Hubli, which otherwise face acute shortage of drinking water.

In view of this, the systematic study of water resources distribution and contributions from Goa and Karnataka regions becomes inevitable. Thus, in this paper, long term rainfall analysis and stream-flow measurements have been used to compute surface run-off and base flow contribution to Mhadei River from watersheds lying in Goa and Karnataka. The main objectives of the present study are to estimate surface run-off and base flow contribution in Mhadei watershed and in particular from watersheds lying in Goa and Karnataka and to assess the possible impacts of the proposed river water diversion in the upper reaches by Karnataka on hydrological and hydro-geological regimes in the State of Goa

GEOLOGICAL SETTING

The study area dominantly comprises of the rocks of the Goa Group equivalent to the Chitradurga Group of the Dharwar Supergroup (2900-2600 Ma) resting on the Peninsular Gneisses (Gokul *et al.*, 1985). Three formations of the Goa Group namely Barcem, Bicholim and Vageri Formations are exposed in the study area. They exhibit a general NW-SE trend. The rock types exposed in the study area includes gneiss, meta-basalt, quartz-sericite schist, quartz-chlorite schist, pink ferruginous phyllite, limestone and metagreywacke. The Bondla mafic-ultramafic complex represented by gabbro and pyroxenite are also exposed. A small outcrop of the Deccan Traps (65 Ma) occur along the north-eastern margin of the study area comprising of horizontally laid basaltic flows. All these rocks have undergone lateritisation to varying extent.

THE STUDY AREA

The study area, the Mhadei River Basin, lies between Latitudes 15° 22' 14.85" and 15° 42' 8.3" N Longitudes 74° 02' 25.6" and 74° 25' 00" E. Mhadei River and Khandepar River are the two major tributaries

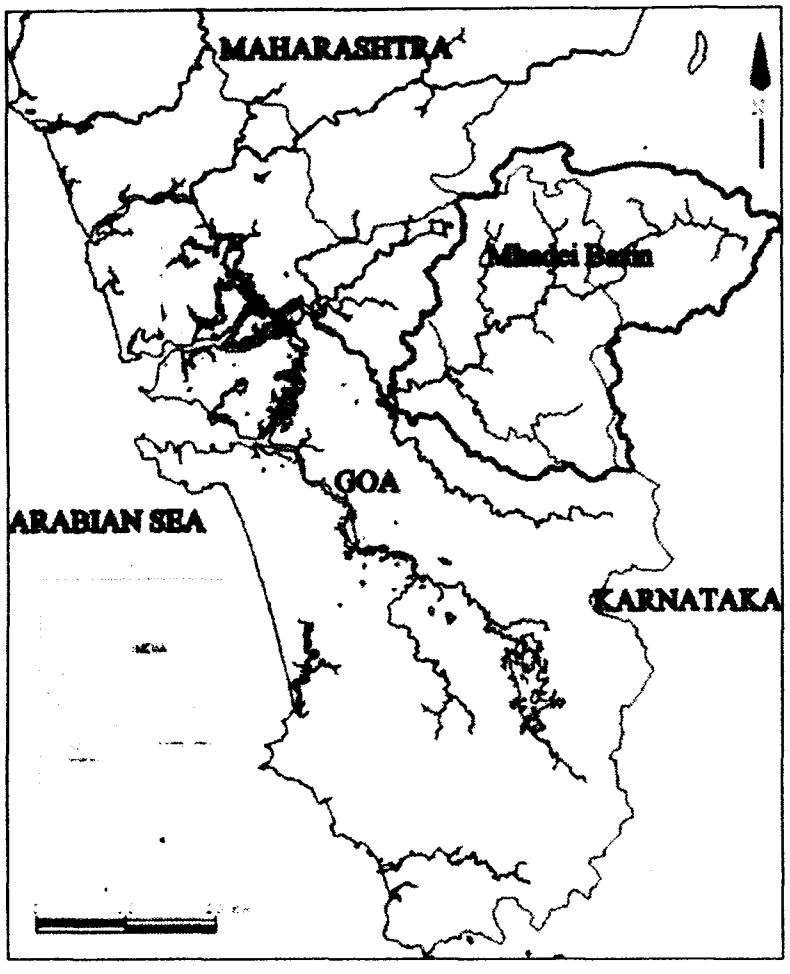

Fig.1. Location map of Mhadei River Basin

of Mandovi River, which drains into the Arabian Sea. The other minor tributaries of Mandovi River include the Valvanti River, the Mapusa River and the Sinquerim River. The Mhadei River Basin extends over a total area of 899 km^2 of which 573 km^2 lies in Goa and 326 km^2 lies in Karnataka (Fig. 1).

Topography

The drainage divide for the entire Peninsular India is located along the Western Ghats resulting in long sluggish easterly flowing rivers that drain into the Bay of Bengal and short, highly erosive westerly flowing rivers that discharge into the Arabian Sea. The Mhadei River is a short westerly flowing river that originates in the Western Ghats and drains into the Arabian Sea through Mandovi River. A special hydrological treatment is needed for mountainous watersheds of Western Ghats region because of their highly variable topography, thick vegetation and high rainfall. They posses rich biodiversity, land resources and water resources.

The Mhadei River Basin can be topographically divided into three parts, the western part of the basin lies in the Central midland region of Goa, this region consists of elongated hills having elevations below 400m amsl (above mean sea level), the central part of the basin comprises of the Western Ghats and the eastern part of the basin lies in the plateau region of Karnataka (Fig. 2).

Drainage

The Mhadei River originates at Degaon in Khanapur taluka of Belgaum district in Karnataka, at a height of 1026m amsl. The Nanode nadi, the Kotrachi nadi and the Ragda nadi are the major tributaries of Mhadei River. A number of smaller streams like Bail nadi, Kotni nadi, Doli nadi and Bhandura nadi also join the Mhadei River (Fig. 3). In general, the Mhadei River Basin exhibits dendritic drainage pattern. However, most of the streams of fourth and fifth order in the western part of the basin (the midland region of Goa) show a common NW-SE trend, suggesting a structural control, as the rocks in the region have a regional NW-SE trend. This results in a trellis type drainage pattern in some parts of the basin. Also, the first and second order streams flowing on the Karnataka plateau show parallel drainage pattern in the north-eastern part of the basin as they flow on the horizontally laid Deccan Traps.

Land use-Land cover

Knowledge of land use -land cover is very important for planning and management of water resources of a river

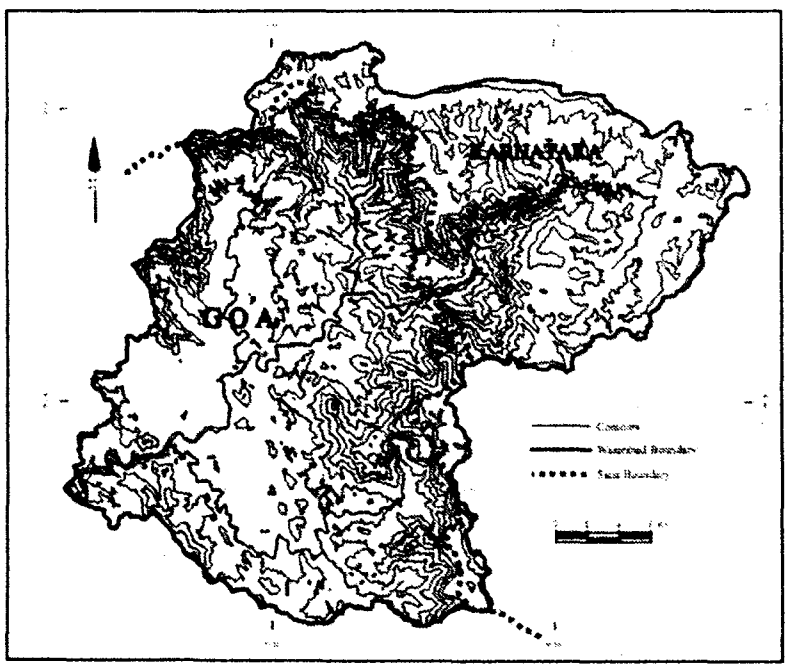

Fig.2. Topographic map of Mhadei River Basin

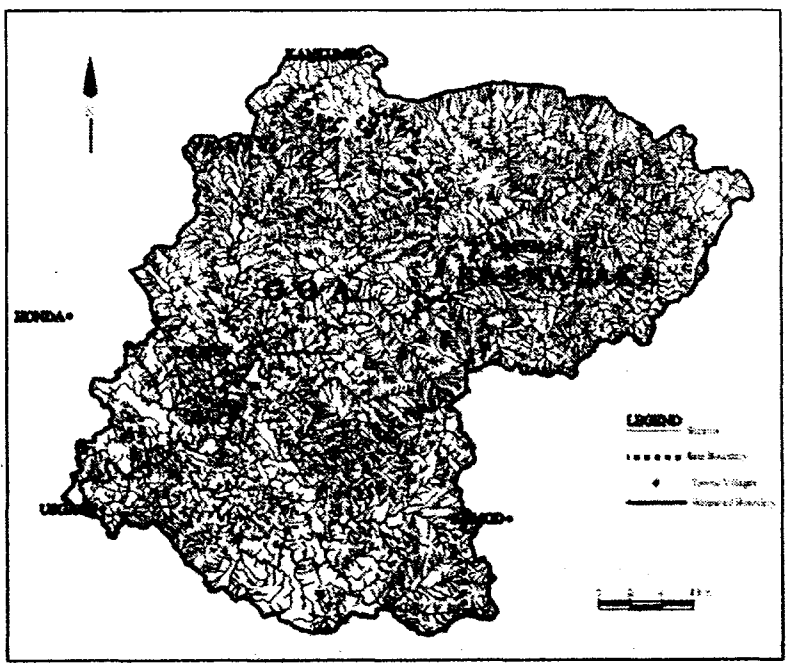

Fig.3. Drainage network of Mhadei River Basin

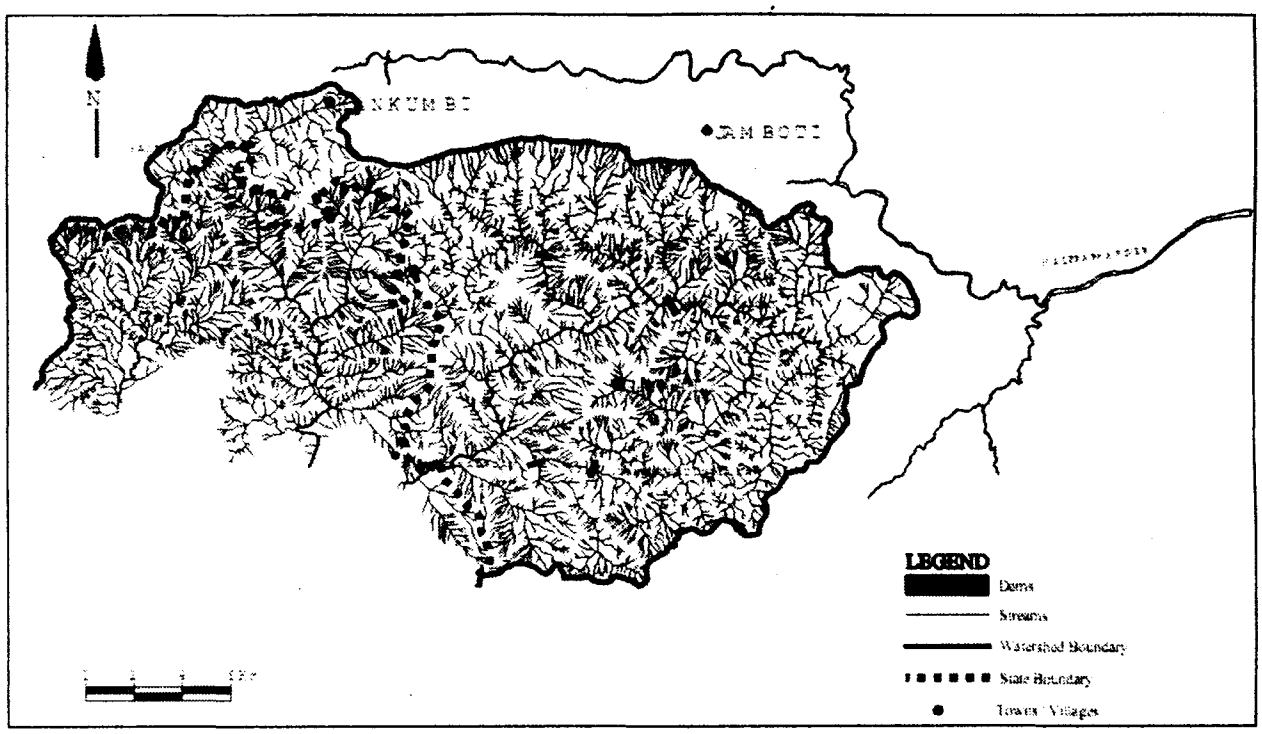

Fig.4. Location of proposed water retention structures in Mhadei River Basin

basin. The surface runoff and infiltration capacity of land varies considerably with the land use - land cover pattern. The land use- land cover pattern of the Mhadei River Basin has been studied using Survey of India toposheets and updated using Google Earth imageries of March 2009 in a GIS environment. The distribution of various land types in the Mhadei River Basin is presented in Table 1. It is evident from Table 1 that more than 85% of the area of the basin is covered by forest and only about 3.5% is agricultural land.

PROPOSED RIVER WATER RETENTION AND DIVERSION STRUCTURES

The Karnataka Government has proposed six water retention structures (dams/bandharas) in part of the watershed of Mhadei River Basin lying in Karnataka state (Fig. 4). The reservoirs of these water retention structures will be connected to the streams of Malprabha River through channels / water conduits. The main aim of this diversion is to augment drinking water supplies to major cities like Dharwad and Hubli through Malprabha dam at Saundatti built on Malprabha River. The data of the catchment area and water holding capacity of these structures have been procured from the Water Resources Department, Govt. of Goa and are also estimated during the present study and given in Table 2.

All the catchment areas reported by the Karnataka Government are in close agreement with the computed values except at Punsheer nala structure. This possible discrepancy could be due to inaccurate location of the proposed structure in the watershed map. For the computation of the run-off the higher values of the catchment area are considered to be on a safer side.

RAINFALL ANALYSIS

The Mhadei River Basin receives abundant rainfall due to the southwest monsoon during the months of June to September. The rain-gauge stations in and around the study area have been identified and normal monthly rainfall data (Table 3) has been computed and analysed. Isohyetal method and Thiessen polygon method have been used to compute the average rainfall for the Mhadei

Table 1: Distribution of various land use – land cover types in Mhadei River Basin

Land Type	Area (km^2)	Area %
Settlement area	16.40	1.82
Agricultural land	32.21	3.58
Mining area	4.77	0.53
Plantations	71.43	7.94
Water bodies	8.71	0.96
Forest area	765.97	85.16
Total	899.49	100

Table 2: Catchment areas of each proposed water retention structure in the Mhadei River Basin lying in Karnataka

Sr. No.	Name of the proposed structure	Stream Order	Catchment area (km^2)		
			As per Karnataka Govt. data	Estimated during present study	Area adopted for run-off computation
1	Kalsa nala	IV	24.0	20.25	24.0
2	Kotni nala	VI	124.43	125.33	125.33
3	Andher nala	III	4.8	4.8	4.8
4	Bail nala	IV	31.9	31.8	31.9
5	Punsheer nala	IV	4.5	9.17	9.17
6	Murudhahaul	III	3.3	3.05	3.3
	Total		192.93	194.40	198.5

Table 3: Normal monthly rainfall (mm) of the rain-gauge stations in and around Mhadei River Basin

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	Annual
Stations in Karnataka													
Amgao	590	996	825	189	92	0	0	1	1	1	3	11	2709
Castlerock	1040	2274	1671	543	159	3	4	0	0	1	1	1	5697
Chapoli	821	1249	157	198	106	23	0	0	0	0	0	9	2563
Gavali	832	1462	1268	320	78	8	0	0	0	0	0	4	3972
Jamagao	495	792	685	179	69	9	0	0	0	0	0	1	2230
Jamboti	318	595	416	104	55	9	0	1	2	2	5	13	1520
Kankumbi	937	1556	1207	290	141	21	0	0	0	2	11	21	4186
Khanapur	325	726	379	127	113	42	7	1	1	5	28	80	1834
Tilariwadi	1176	1545	1280	386	136	54	3	0	0	0	0	35	4615
Stations in Goa													
Bicholim	924	1284	674	325	187	42	3	1	0	0	10	80	3530
Colem	1018	1823	1122	529	255	52	10	1	0	1	18	111	4940
Ponda	853	1233	804	413	164	82	13	2	0	0	10	88	3662
Valpoi	965	1474	929	385	197	57	7	1	0	1	14	97	4127

After: NWDA report Index 76, August 1984

River Basin. The average rainfall for the Goa and Karnataka regions has been computed separately.

The average annual rainfall using Thiessen polygon method (Fig. 5) for the Mhadei River Basin is 4014mm whereas using Isohyetal method (Fig. 6) it is 3933mm. Since Isohyetal method gives consideration to orographic effects and storm morphology (Raghunath, 1992), and the Mhadei River Basin is a mountainous watershed, therefore Isohyetal method has been adopted for run-off computations. The average rainfall for Goa and Karnataka regions using Isohyetal method has been computed separately. Using the computed area between the Isohyetes and the corresponding average rainfall the volume of run-off has been computed and is shown in Table 4.

SURFACE WATER CONTRIBUTION

Out of total area of 899 km^2, 64% of the Mhadei River Basin lies in Goa while Karnataka state covers 36% area. The average rainfall in the entire Mhadei River Basin using isohyetal method is 3933 mm. The average rainfall in the Goa region of the Mhadei River Basin is 4160 mm while that in the Karnataka region of the Mhadei River Basin it is 3536 mm. Thus, 2383 Mcum *i.e.*, 67% of the surface water is contributed by the Goa region of the basin while 1155 Mcum *i.e.*, 33% of surface water is contributed by the Karnataka region of the basin. The total volume of rainwater in the Mhadei River Basin is 3538 Mcum.

UNIT AREA BASE FLOW

Stream base flow measurements were carried out on Mhadei River at the Goa- Karnataka state boundary in the month of December 2007 using velocity-area method. The discharge measured was 3.48 cumec. This is equal to 9 Mcum per month. The contributing area to the above measured discharge is 296 km^2 from the Karnataka region of the basin. Thus, the unit area base flow from the Karnataka region of the basin can be calculated as:

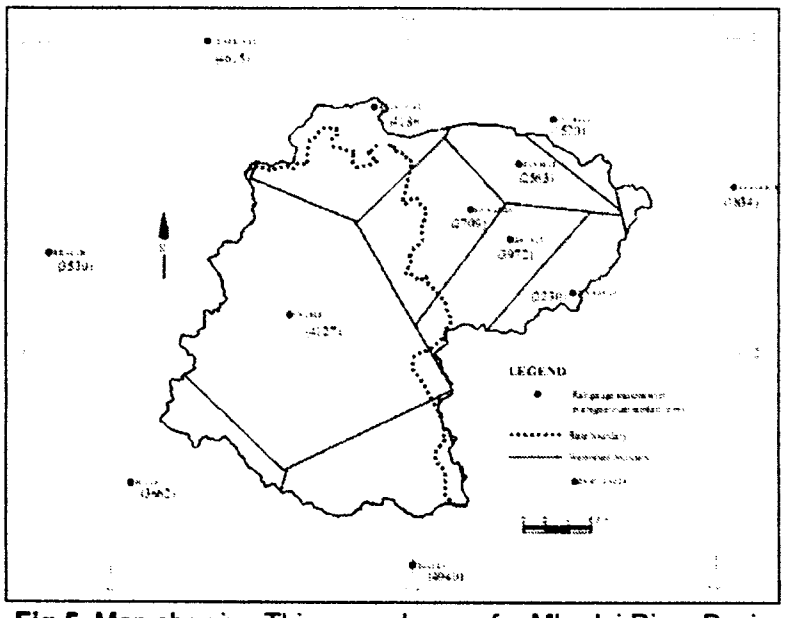

Fig.5. Map showing Thiesen polygons for Mhadei River Basin

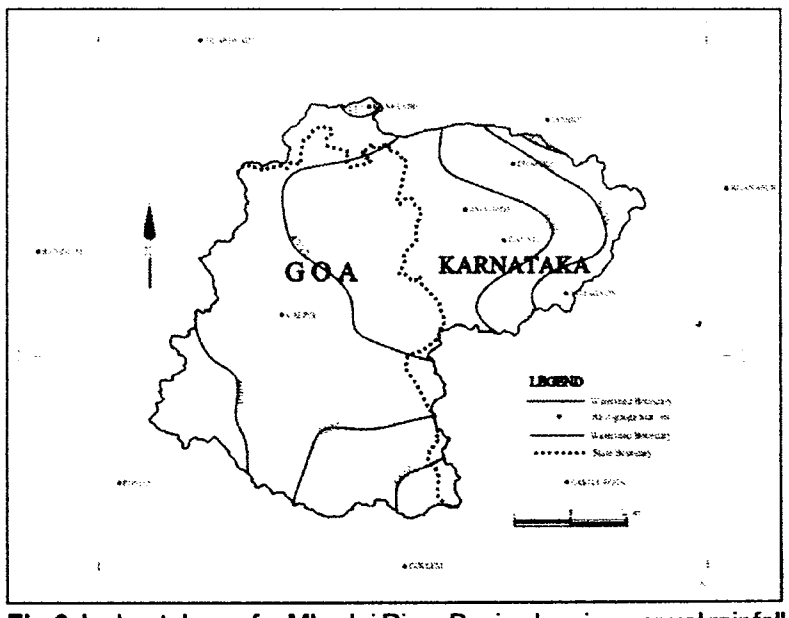

Fig.6. Isohyetal map for Mhadei River Basin showing annual rainfall

Table 4: State-wise average rainfall and volume of surface run-off using Isohyetal method

Isohyetal Interval (mm)	Av. Rainfall (mm)	Area in the Mhadei Basin (km^2)	Area in Goa (km^2)	Area in Karnataka (km^2)	Resulting volume of rainwater (Mcum)		
					In Mhadei River Basin	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	899.45	572.79	326.65	3538	2383	1155

Discharge/Area= 9 Mcum /296 km^2 = 0.0304 Mcum/ km^2/month

Since the total area of the Mhadei River Basin that lies in the Karnataka state is 326 km^2 therefore, the total base flow 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 Mcum/month

The average monthly river discharge data for 17 years measured at Ganje River-gauging station on the Mhadei River outlet is given in Table 5.

It is noted that the average discharge measured at Ganje River-gauging station for the month of December is 27 Mcum/month. The area contributing to the above measured discharge at Ganje station is 880 km^2 which is 98% of the entire Mhadei River Basin. Thus, the unit area base flow for the entire Mhadei River Basin for the month of December can be calculated as:

Discharge/Area= 27 Mcum / 880 km^2 = 0.0307 Mcum/ km^2/month

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

The base flow measured for the month of December from the Karnataka region of the basin (9.9 Mcum) is 37% of the base flow measured for the entire Mhadei River Basin (27 Mcum). The base flow contribution from Karnataka region has been computed for other non-monsoon months taking into account 37% of Ganje station base flow (Table 6).

As seen from Table 6, the base flow 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, settlements, industries, etc. which heavily depend on the available base flow.

The contribution of base flow from Karnataka region compared to the base flow measured at Ganje station for the non-monsoon months is shown graphically in Fig. 7. The unit area base flow from Karnataka region for each month of the non-monsoon season has been also computed in Table 6.

Table 5: Monthly average discharge data measured at Ganje River-gauging station on Mhadei River (*After* : Water Resource Department, Govt. of Goa)

Month	Discharge in Mcum
June	303.24
July	1333.36
August	1184.56
September	340.35
October	173.45
November	54.61
December	27.35
January	16.33
February	5.05
March	3.42
April	2.52
May	2.52
Total annual	3446.76

Table 6: Computed base flow during non-monsoon season from Karnataka area

Month	Average base flow measured at Ganje station (Mcum)	Base flow calculated from Karnataka area @ 37% of Ganje base flow (Mcum)	Unit area base flow from Karnataka for each month (Mcum/km^2)
October	173.45	64.2	0.1969
November	54.61	20.2	0.0620
December	27.35	9.9	0.0304
January	16.33	6.0	0.0184
February	5.05	1.9	0.0058
March	3.42	1.3	0.0040
April	2.52	0.9	0.0028
May	2.52	0.9	0.0028
Total	285.25	105.3	0.3231

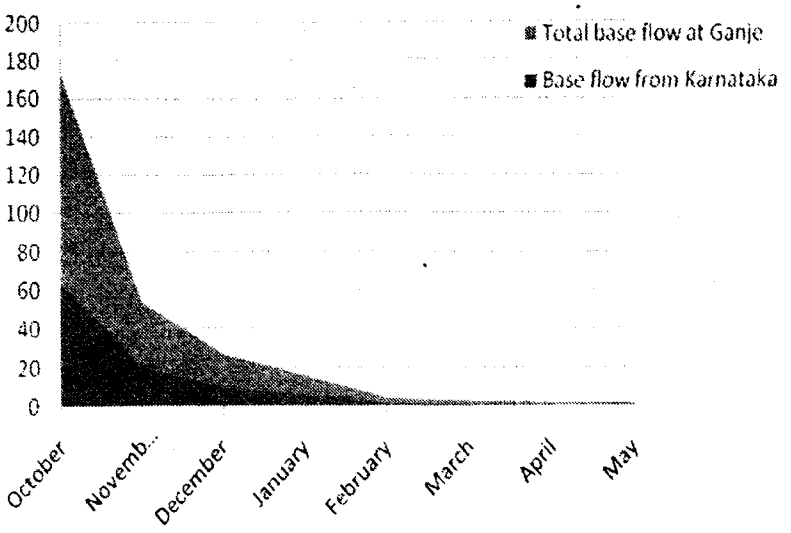

Fig.7. Comparison of base flow (in Mcum) from Goa with Karnataka

Table 7: Estimation of base flow for watersheds of proposed water retention structures in Karnataka

Name of the water retention structure	Catchment area (km^2)	Run-off volume (Mcum/yr)	% of runoff measured at Ganje station	Computed base flow for non-monsoon months (Mcum/yr)
Kalsa nala	24.0	84.94	2.46	7.75
Kotni nala	125.33	443.54	12.87	40.49
Andher nala	4.8	16.98	0.49	1.55
Bail nala	31.9	112.89	3.27	10.31
Punsheer nala	9.17	32.45	0.94	2.96
Murudhahaul	3.3	11.68	0.34	1.07
TOTAL	198.5	702.48	20.37	64.13

Estimation of Base Flow Contribution from the Watersheds of Proposed Water Retention Structures

The base flow generated from watershed of each water retention structure in Karnataka has been estimated by adopting the values of unit area base flow (Table 6) from the Karnataka region for each month of the non-monsoon season and multiplying them with the catchment area of each water retention structure. The volume of run-off generated from the catchment of each structure has been calculated by considering the average rainfall in the Karnataka area (Table 7).

It is evident from Table 7 that the maximum base flow comes from Kotni nala area which is 38% of all the base flow from Karnataka and 14% of the entire Mhadei River Basin.

CONCLUSIONS

The total area of catchments where all the proposed water retention structures are located in Karnataka is 198.5 km^2 which is 61% of the area of the Mhadei River Basin that lies in Karnataka and 22% of the total area of the Mhadei River Basin. The average annual discharge measured at the Ganje river-gauging station located on the Mhadei River outlet is 3447 Mcum/yr. The total volume of rainwater that will be captured in the catchments of the proposed water retention structures is 702.48 Mcum/yr which is 20.37% of the total annual discharge of the Mhadei River.

The average base flow measured for the Mhadei River at Ganje rain-gauging station for non-monsoon season is 285 Mcum/yr. The base flow contribution from Karnataka region for non-monsoon season is 105 Mcum/yr which is 37% of the total base flow. The total base flow generated from catchments of all the six water retention structures for non-monsoon season is 64 Mcum/yr. The above computed base flow contribution from catchments of all the structures is 61% of the base flow of the Karnataka region and 22% of the total base flow measured at Ganje station in Goa.

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