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Hydrogeological Assessment of Mountainous Mhadei River Watershed –Western Ghats Region

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Abstract: Groundwater domains are often governed by the topographic configuration of a region in hilly areas. Thus, boundaries of river watersheds invariably coincide with that of groundwater domains. The present study comprises of groundwater assessment of an interstate river basin falling in Goa and Karnataka states located along the West coast of India. An attempt has been made to understand the groundwater occurrence, distribution and flow pattern in the Mhadei River mountainous watershed. An observation well network was established to monitor groundwater fluctuations in the lateritic aquifer of the Mhadei watershed. Pumping tests were carried out to estimate aquifer parameters like transmissivity, specific yield and specific capacity. The aquifer recharge has been estimated using rainfall infiltration method and water table fluctuation method. Well hydrograph analysis has been used to identify groundwater potential zones in the watershed.

Keywords: *Mhadei River, Western Ghats, Flow-net, Aquifer parameters, Recharge.*

Introduction:

The hydrogeological investigations are important facets of any groundwater management strategy. The groundwater potential of an area depends on the geological and geomorphologic setup, rainfall pattern, aquifer type, groundwater flow pattern, boundary conditions, aquifer properties, etc. Systematic hydrogeological studies in Goa have been carried out since last three decades by various workers. However, most of these studies were carried out on a regional scale with administrative boundaries as study units while others focused on the influence of open cast mining on the local ground water domains. The Department of Water Resources (WRD), Government of Goa and Central Ground Water Board (CGWB), have assessed the net annual groundwater availability of the State of Goa at 132 million cubic meters (MCM) and the annual groundwater draft is 43 MCM as on March 2009. The stage of groundwater development is 33% and the entire state has been categorised as safe (WRD & CGWB, 2011). Micro-watershed level studies carried out by Chachadi and Lobo Ferriera (2001) in the coastal areas and Chachadi (2003) in the mining belt have indicated moderate to severe water stress conditions in majority of the sub-watersheds. There are quite a few reported examples where groundwater and surface water have been seriously contaminated due to industrial effluent disposals, urban sewage and solid waste disposals (Chachadi, 2009). The exploitation of groundwater resource has increased manifold recently in the urban areas with random sinking of bore wells. The groundwater abstraction from shallow dug wells for irrigational purpose is also on rise in the rural areas.

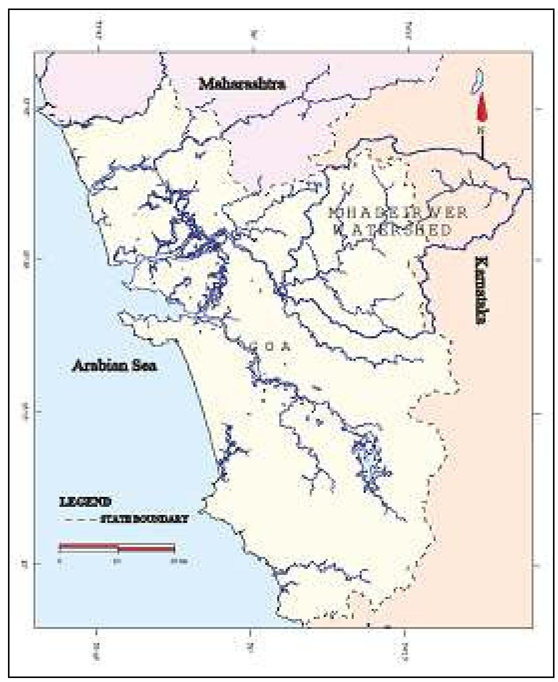

Figure 1: *Location Map of Mhadei River Watershed*

Objective of the Present Study:

The main objective of the present study is to bring out a comprehensive picture about the groundwater status of the Mhadei river watershed located in the States of Goa and Karnataka. This being a mountainous interstate watershed not studied before would constitute an interesting study to assist in understanding of impacts during interstate water sharing.

The Study Area:

The Mhadei River and the Khandepar River are the two major tributaries of the Mandovi River which drains into the Arabian Sea. The Mhadei watershed lies between latitudes N 15° 22' 14.85" and N 15° 42' 8.3" longitudes E 74° 02' 25.6" and E 74° 25' 00 covering a total area of 899 km^2 of which 573 km^2 (64%) lies in Goa and 326 km^2 (36%) lies in Karnataka (Fig. 1).

Topography:

The Mhadei watershed can be divided into three parts, viz., the western low lying region, the central Western Ghats escarpment and the eastern plateau region. The western region of the watershed lies in the central midland region of Goa, this region consists of elongated hills having elevations less than 400m above mean sea level (amsl) separated by the etch plain having elevation between 30m to 100m amsl. The central part of the watershed comprises of steep imposing hills of the Western Ghats ranging in elevation between 500m to 800m amsl while the eastern part of the watershed constitute the western fringe of the extensive Karnataka plateau (Fig 2). The highest elevation in the watershed is 1026m amsl in the Western Ghats while the lowest elevation is near zero at the mouth of the river near Usgao.

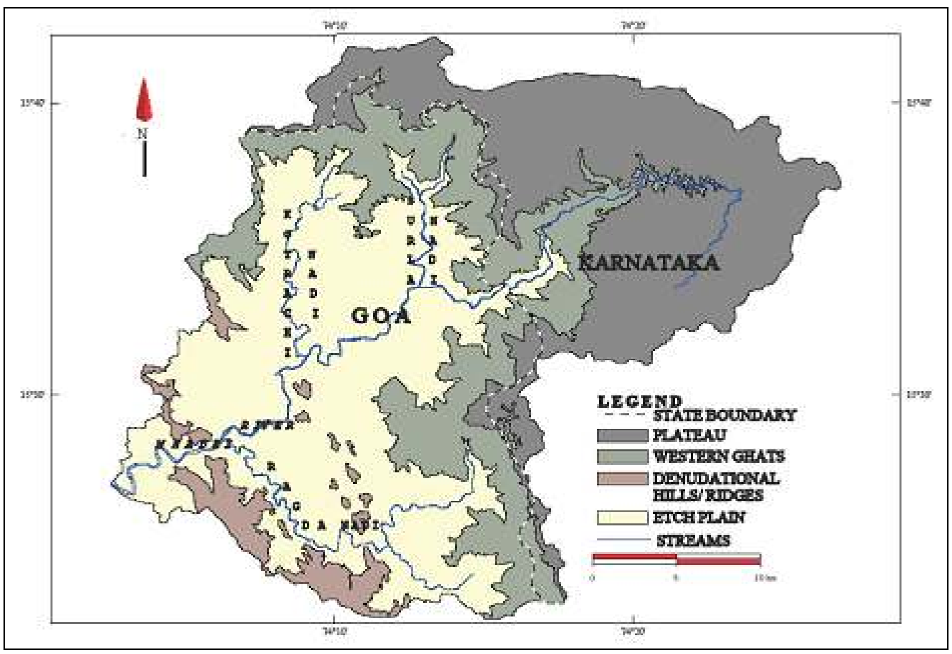

Figure 2: *Physiographic Map of Mhadei River Watershed*

Drainage:

The Mhadei River originates at Degaon village in Khanapur taluka of Belgaum district in Karnataka. Nanode nadi, Kotrachi nadi and Ragda nadi are the major tributaries of Mhadei River (Fig.2). A number of smaller streams like Bail nadi, Kotni nadi, Doli nadi and Bhandura nadi also join the Mhadei River. In general, the Mhadei River watershed exhibits dendritic drainage pattern. However, most of the streams of fourth and fifth order in the western part of the watershed 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 watershed. Also, the first and second order streams flowing on the Karnataka plateau show parallel drainage pattern in the north-eastern part of the watershed as they flow on the horizontally laid Deccan Traps.

Land use- Land Cover:

The surface runoff and infiltration capacity of land varies considerably with the land use - land cover pattern. In the present watershed more than 85% of the area is covered by forest and only about 3.5% is agricultural land.

Rainfall Pattern in the Watershed:

The Mhadei watershed receives abundant rainfall due to the southwest monsoon during the months of June to

September. Isohyetal and Thiessen polygon methods have been used to compute the average normal rainfall for the Mhadei watershed. The average annual rainfall using Thiessen polygon method for the Mhadei watershed is 4014mm whereas using Isohyetal method it is 3933mm. Since Isohyetal method gives consideration to orographic effects and storm morphology (Raghunath, 1992) and the Mhadei watershed is a mountainous watershed, therefore Isohyetal method has been adopted for further computations. The average annual rainfall for Goa region is 4160 mm while that for the Karnataka region is 3539mm. As a result of the orographic influence the rainfall increases progressively from the western boundary of the watershed towards the Western Ghats from about 3500mm to over 5000mm. However, further east it decreases rapidly to about 2500mm. Over 90% rainfall occurs during the monsoon months 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. Rainfall is the main source of groundwater recharge in the watershed.

Geology of the Watershed:

The study area dominantly comprises of the rocks of the Goa Group resting on the Peninsular Gneisses. 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 (Gokul et al, 1981). The rock types exposed in the study area includes gneiss, meta-basalt, quartz-sericite schist, quartz-chlorite schist, pink ferruginous phyllite, BIF with iron ore deposits, limestone and metagreywacke. The Bondla mafic-ultramafic complex represented by gabbro and peridotite is also exposed. The Deccan Traps (65 Ma) occur along the north-eastern margin of the study area comprising of horizontally laid basaltic flows (Fig 3). Most of these rocks have undergone weathering to varying extent and are covered by a thick layer of laterite and/or lateritic soil.

Hydrogeology of the Watershed:

Laterite and valley fill deposits are the important aquifers that occur in the Mhadei watershed. Ground water predominantly occurs in unconfined condition in these rocks. However, ground water occurs in semi-confined condition in the fractured and weathered metamorphic rocks at depths. Laterite occurs as an extensive layer capping the low lying area of the watershed that comprises of the etch-plain and the low elongated hills (Fig. 4). However, it is often absent on the higher hills and the denudational hills of the Western Ghats. Generally, the thickness of the laterite is maximum, reaching over 30m in the western region of the watershed and diminishes progressively towards the Western Ghats. Nevertheless, the thickness varies depending on the type of lithology over which it has developed. The phyllites and schists show maximum lateritisation.

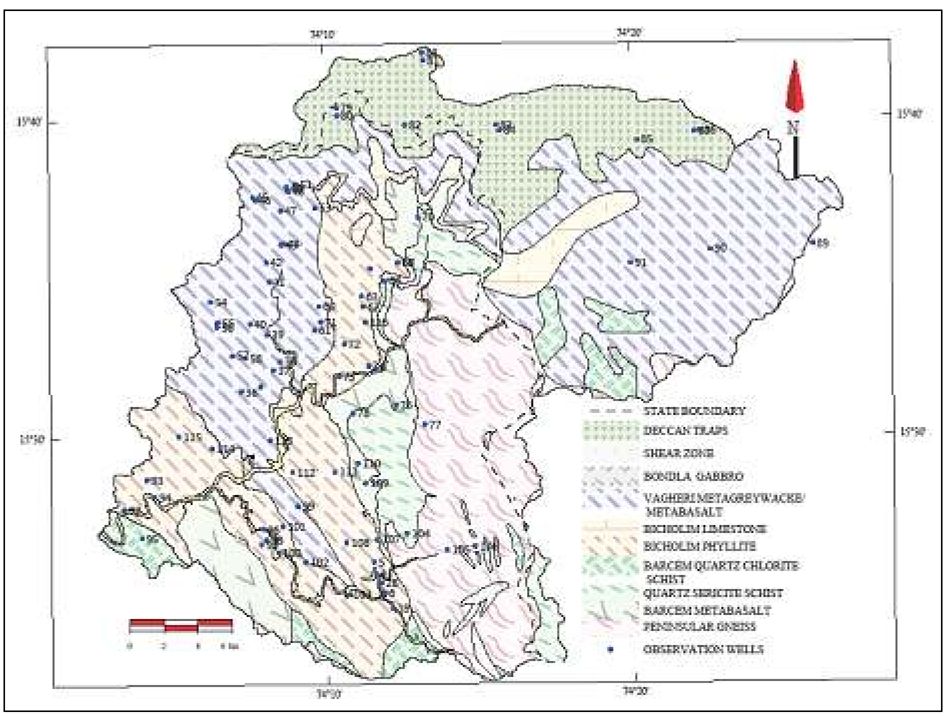

Figure 3: *Geological Map of Mhadei Watershed with Observation Well Network (Adopted from GSI, 1996)*

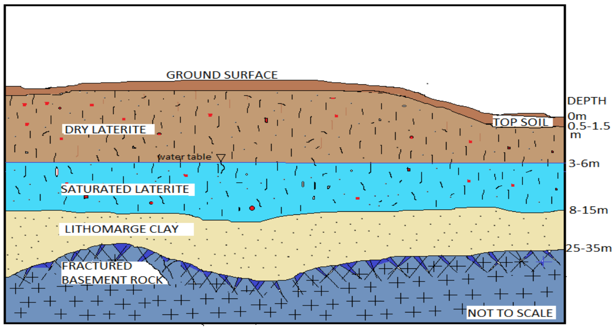

Figure 4: *A Schematic Vertical Section of an Unconfined Laterite Aquifer*

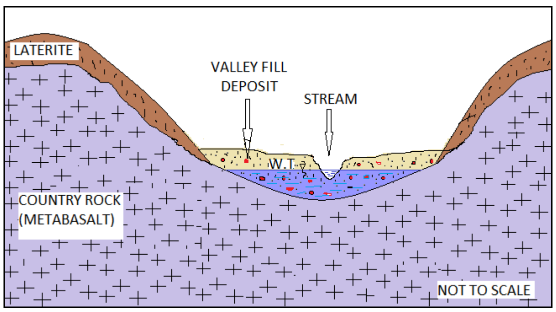

Figure 5: *A Schematic Vertical Section of an Unconfined Aquifer in Alluvial Valley Fills*

The intermountain valley fills consisting of alluvial and colluvial deposits also behave as important ground water reservoirs (Fig. 5). The narrow valleys occurring between the low denudational hills in the watershed are often filled by gravel mixed silty unconsolidated deposits. These deposits being unconsolidated and superficial have high porosity and thus store groundwater under unconfined condition.

Weathered basalts occurring on the Karnataka plateau also form an important aquifer. The Deccan basalts occupying a large area in the north-eastern region of the watershed consists of massive, vesicular and fractured lava flows. The fractured and vesicular flows are inherently porous in nature. The top flows that are subjected to tropical weathering are invariably altered to clays or even weakly lateritised. Groundwater occurring in the weathered basalts is under water table condition and is the only source of fresh water for the people living in this region.

Some wells dug on the hill slopes tap groundwater from the fractured and weathered schistose rocks. These aquifers are of semi-confined to confined nature depending on the thickness and nature of the overlying laterite cover and occurrence of the groundwater in fractures.

Few iron ore deposits occur in the western region of the watershed. The iron ore bodies occur in a typical geological setup composed of complex folds and embedded in clay layers all around (Fig 6). The ore bodies show considerable porosity and are saturated with fresh water. Invariably these confined ore bodies are laterally limited due to numerous altered dykes composed of impervious clays. During mining they are intersected and fresh water is drained out to provide dry working conditions. Sometimes these ore bodies get recharge from percolating rain water through overlying laterites (Pahala Kumar et al, 1994).

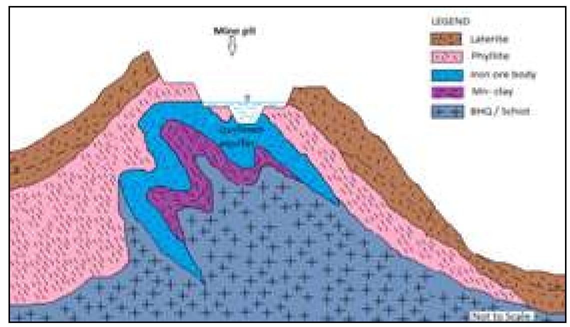

Figure 6: *A Generalised Vertical Section of a Confined Aquifer in Iron Ore Bodies*

Data Collection:

In the present study area of 899km^2, 82 observation wells were established to monitor ground water levels in the unconfined aquifers (Fig.3). The wells are open dug type mostly used for domestic and agricultural purposes. The groundwater levels were measured on seasonal basis from May 2007 till November 2009 in 69 observation wells located in the western low lying region of the watershed. 13 observation wells located on the Karnataka plateau in the eastern part of the watershed were also monitored for ground water fluctuation for three seasons of the year 2007.

Depth to Groundwater Level:

The average depth to groundwater levels have been computed using data of 2007, 2008 and 2009 for each season. The groundwater levels in most part of the area remain within 10m depth throughout the year. Contour map showing the average depth to groundwater levels below ground has been prepared for the pre-monsoon season (Fig. 7).

The average depth to groundwater level in the pre-monsoon season (May) is 5.53m. However, deeper groundwater levels of about 8 to 12m are noticed in around five regions of the watershed namely, Surla-Bolcornem, Poikul-Shail, Advai-Singne, Ambede-Dhave and Kankumbi village. The maximum depth to groundwater level does not exceed 13m in the watershed. The average depth to groundwater level in the monsoon season (August) is 2.37m. Major part of the watershed area shows more than 3m rise in groundwater levels as compared to the pre-monsoon levels due to the monsoon recharge. The average depth to groundwater level in the post-monsoon season (November) is 4.10m. However, deeper groundwater levels of about 8 to 10m are noticed in the same five regions of the watershed as was noticed in the pre-monsoon season. These regions show considerable fall in the post-monsoon water level.

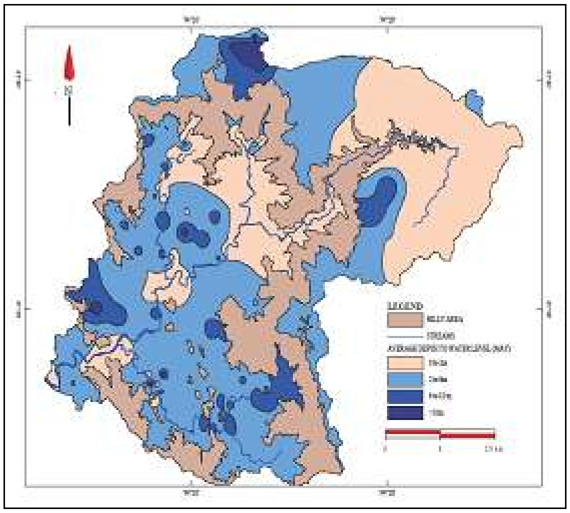

Figure 7: *Map Showing Average Depth to Groundwater Level in Pre-Monsoon Season*

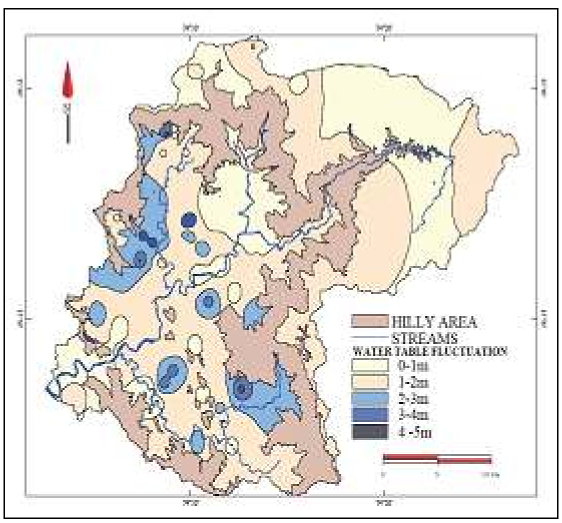

Figure 8: *Map Showing Average Water Table Fluctuation in the Watershed*

Water Table Fluctuation:

The difference between the pre-monsoon and post-monsoon season groundwater levels has been utilised to compute the water table fluctuation and is shown in Fig. 8. About 72% of the wells show water table fluctuations of less than 2m while the remaining 28% show water table fluctuation of more than 2m. The average groundwater fluctuation in the Mhadei watershed is 1.43m. However, higher groundwater fluctuation is seen around Koparde- Charavne, Ambede-Dhave, Kumtol-Karanzol, Myangne-Shail and Tarade-Dharge regions and Mauxi village.

Groundwater Flow:

The groundwater flow nets covering pre- monsoon, monsoon and post-monsoon seasons have been prepared to understand the groundwater flow pattern. Flow net for pre-monsoon season of the year 2007 is shown in Fig. 9.

Two domains of groundwater occurrence have been identified using the flow nets- one in the western low lying region of the watershed which lies in the midland region of Goa and other in the eastern part of the watershed situated on the western fringe of the Karnataka plateau. These two domains are separated by the steep Western Ghats escarpment. The ground-water domain in the Goa region has widely spaced equipotential lines indicating flat hydraulic gradient with uniform ground water flow. The area around village Dhave shows the presence of a groundwater mound indicating major recharge area. The groundwater flow lines are directed towards the river reaches indicating effluent nature of the rivers. The ground water domain in the Karnataka region, which is situated at higher topographic level compared to the domain in the Goa region, has closely spaced equipotential lines indicating steep hydraulic gradient. The pattern of groundwater flow regime in both the groundwater domains remains unchanged during monsoon and post-monsoon seasons except the magnitude of the mounds and troughs.

Aquifer Parameters:

Short duration pumping tests were conducted on ten open dug wells to compute the aquifer parameters: Transmissivity (T) and Storativity (S). Type curve methods developed by Papadopulos and Cooper (1967) and Mishra and Chachadi (1985) have been used for analysis of the pumping test data. The specific capacity (C) has been computed using Slitcher's method at 1 hour recovery. The details regarding the well locations, dimensions and pumping data are given in Table 1 and the results are tabulated in Table 2. It is seen from these tables that the T values vary from $4m^2$/day to $216m^2$/day with an average of $62m^2$/day by Papadopulos and Cooper method and $58m^2$/day by Mishra and Chachadi method. The specific yield values are within the range of values for unconfined aquifers (except for well no. 99 which is tapping a confined aquifer) and, therefore, are adopted for further calculations. The average specific yield is 0.05 or 5%.

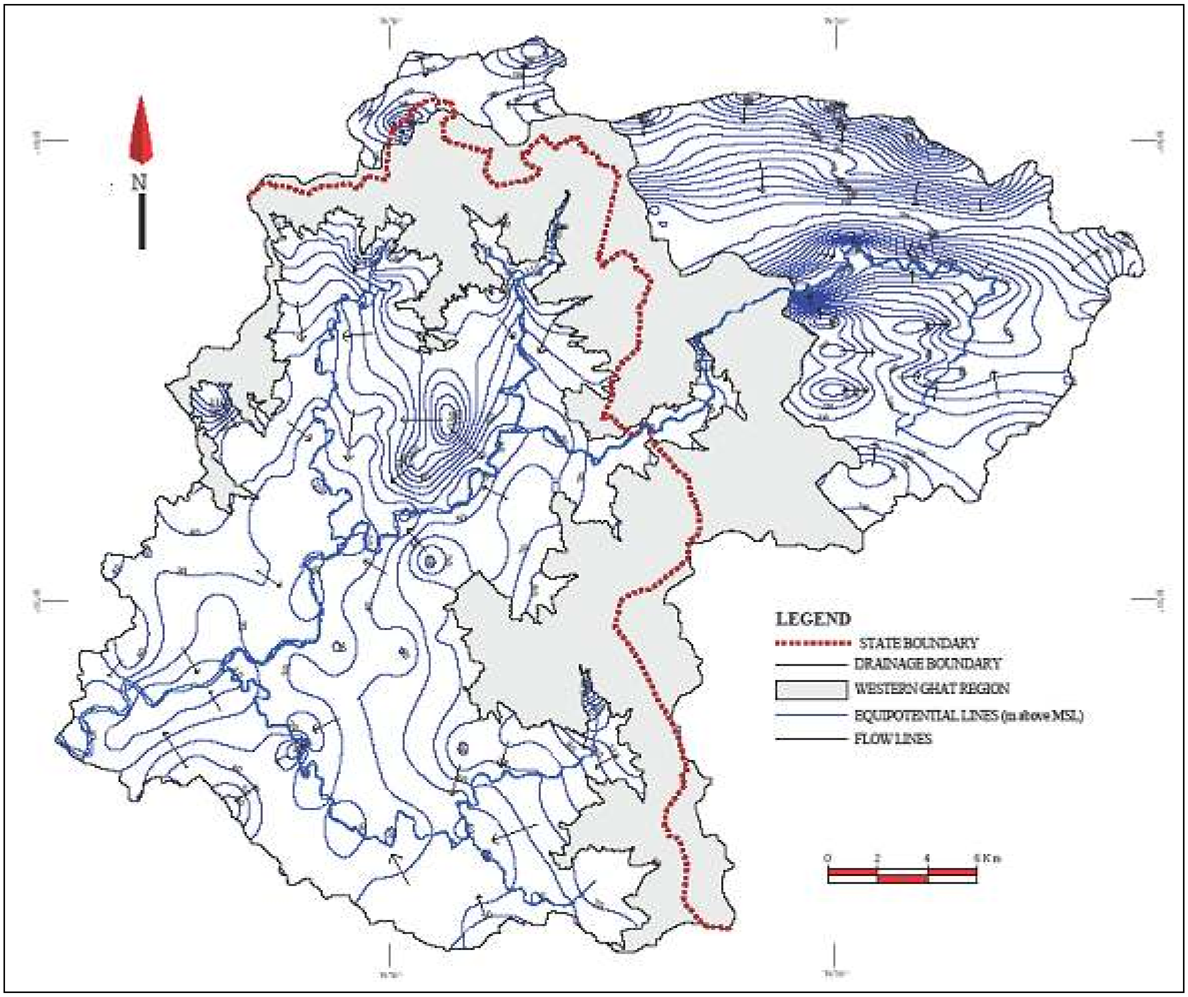

Figure 9: *Groundwater Flow Net Of Mhadei Watershed for Pre-Monsoon 2007*

Table 1: *Details of the Pumping Tests Conducted In the Mhadei Watershed*

Sr. No	Well No.	Well location	Well dep-th (m)	Well dia. (m)	Static water level (mbgl)	Pump-ing duration (min)	Draw-down (m)	Duratio of obs. Recovery (min)	Reco-very (m)	% Reco-very
1	36	Valpoi	5.39	2.76	3.35	124	1.02	1426	0.98	95
2	42	Pali	5.76	1.50	4.33	110	1.09	110	1.09	100
3	47	Hivre	3.61	3.50	2.86	27	0.75	470	0.68	90
4	48	HBudruk	6.50	2.06	4.09	127	0.79	225	0.15	19
5	95	Usgao	6.93	4.62	5.27	58	0.058	265	0.042	72
6	97	Paikul	4.79	2.44	4.08	58	0.064	260	0.036	56
7	99	Myangne	7.84	4.12	6.27	20	0.25	207	0.086	34
8	5	Bolcorne	9.40	3.16	7.59	15	0.052	185	0.014	27
9	107	Bother	6.62	2.60	4.42	60	0.146	540	0.124	85
10	103	Sancorde	8.50	3.32	4.09	40	0.13	40	0.105	81

Table 2: *Transmissivity (T), Storativity (S) and Specific Capacity of Aquifers*

Sr. No	Well No.	T (m^2/d) Papadopulos & Cooper Method	T (m^2/d) Mishra & Chachadi Method	'S' Papad-opulos & Cooper Method	'S' Mishra & Chachadi Method	Specific Capacity (m^2/d)	Aquifer
1	36	4	12	0.05	0.0001	26	Laterite
2	42	12	18	0.016	0.0012	39	Argillite
3	47	8	41	0.01	0.0001	115	Metagreywacke
4	48	7	4	0.19	0.11	4	Valley fill
5	95	25	24	0.06	0.1	102	Laterite
6	97	22	22	0.015	0.0015	23	Laterite
7	99	187	187	0.000015	0.000001	43	Schist
8	5	55	33	0.026	0.028	49	Laterite
9	107	91	92	0.11	0.11	133	Laterite
10	103	216	144	0.015	0.0003	513	Laterite

Groundwater Recharge:

The ground water recharge in the Mhadei watershed has been assessed as per methodology recommended by Groundwater Estimation Methodology Committee (GEMC)-1997. The recharge has been calculated using both Rainfall infiltration method and Water table fluctuation method (Table 3). The recharge has been calculated separately for each domain of groundwater in Goa and Karnataka.

Since the agricultural area in the watershed is merely 3.5% of the total watershed area and only about 25% of it is irrigated during non-monsoon season, the return seepage from irrigation during the non-monsoon season may be considered as negligible. Similarly, there are no tanks, ponds or canals in the watershed. Therefore, recharge from all other sources may be considered as negligible.

Table 3: *Computation of Groundwater Recharge in the Mhadei Watershed*

1	Total geographic area of Mhadei watershed (A)	89900 ha
2	Total area of the watershed in Goa (A_G)	57300 ha
3	Total area of the watershed in Karnataka (A_K)	32600 ha
4	Area not suitable for groundwater recharge in the watershed	23000 ha
5	Area suitable for groundwater recharge in Goa (A_{SG})	38100 ha
6	Area suitable for groundwater recharge in Karnataka (A_{SK})	28800 ha
7	Normal annual rainfall in watershed in Goa (NAR_G)	4.160 m
8	Normal annual rainfall in watershed in Karnataka (NAR_K)	3.539 m
9	Rainfall infiltration factor (RIF) adopted from GEMC,1997	0.06
10	Average water table fluctuation in Goa (ΔWTF_G)	1.57 m
11	Average water table fluctuation in Karnataka (ΔWTF_K)	0.83 m
12	Average Specific yield of aquifers (Sy)	0.05
13	**Groundwater recharge by rainfall infiltration method**	
a	Recharge from rainfall in Goa (R_{RG}) = NAR_G x A_{SG} x RIF	9510 ham
b	Recharge from rainfall in Karnataka (R_{RK}) = NAR_K x A_{SK} x RIF	6115 ham
c	Total recharge from rainfall in the watershed = a+b	15625 ham
14	**Groundwater recharge by water table fluctuation method**	
a	Total Recharge in Goa (R_G) = A_{SG} x ΔWTF_G x Sy	2991 ham
b	Total Recharge in Karnataka (R_K) = A_{SK} x ΔWTF_K x Sy	1195 ham
c	Total Recharge in the watershed = a+b	4186 ham

The total groundwater recharge in the watershed computed using water table fluctuation method is substantially lesser (4186 ham) as compared to the total recharge computed by rainfall infiltration method (15625 ham). This could be due to wrong values of rainfall infiltration factor adopted. Therefore, the rainfall infiltration factor should be taken as 0.02 or 2% for the watershed as computed using data from water table fluctuation method. The dynamic annual groundwater storage of the part of watershed lying in Goa is 2991 ham while that lying in Karnataka is 1195 ham.

Well Hydrograph Analysis:

The 69 observation wells located in the western low lying region of the watershed were monitored for variation in groundwater levels on seasonal basis from May 2007 till November 2009. These water levels were plotted as well hydrographs (Fig. 10) along with the monthly rainfall of the corresponding period. A linear fit to the groundwater levels is fitted on all hydrographs to ascertain their behaviour with time. The well hydrographs indicate that the water levels in the phreatic aquifers respond prominently to rainfall recharge. The steep slope of the rising limb of hydrograph indicate quick recharge to groundwater while the gentle slope of the falling limb of hydrograph indicate slow drainage of the aquifer which is considered good for the groundwater potential of the region (Chachadi and Choudri, 2004). All the well hydrographs were classified into three categories based on their hydrograph trends (Table 4).

Specific Recharge:

The rise in groundwater level from May to August divided by the amount of rainfall during the corresponding period has been used to compute a value named 'Specific Recharge' of a groundwater level. It is a dimensionless quantity defined as a ratio of groundwater level rise to the corresponding rainfall within a specified time. In other words, it is groundwater level rise per unit of rainfall. The value of specific recharge is a function of rainfall and also ground conditions. Based on the magnitude variation in the specific recharge, the aquifer potential has been categorised into three classes (Table 5).

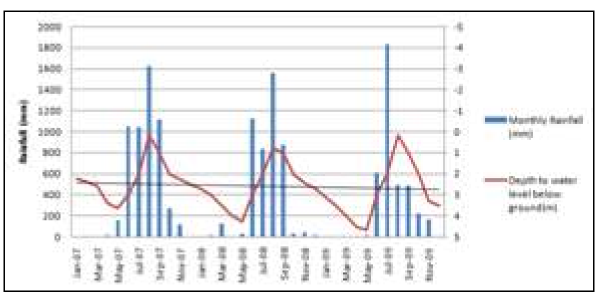

Figure 10: *Well Hydrograph and Monthly Rainfall for Observation Well No. 43*

Table 4: *Classification of Wells Based on Trend of Hydrographs*

No.	Hydrograph Trend	No. of wells	% of Total
1	Increasing	40	58
2	Decreasing	16	23
3	No change	13	19

Table 5: *Classification of the Aquifers Based on Specific Recharge*

No	Aquifer category	Specific recharge	No.of wells	% wells
1	Good	>1	41	50
2	Moderate	1 to 0.5	23	28
3	Poor	<0.5	18	22

Demarcation of Groundwater Potential Zones:

Based on the specific recharge, the groundwater potential zones in the watershed have been identified (Fig.11). It is evident from this map that the western regions of both Goa and Karnataka Plateau show higher groundwater potential and it decreases gradually towards the eastern region.

Conclusions:

Laterite is the most widespread aquifer in the Mhadei watershed. Groundwater occurs in water table condition in this aquifer and is extensively used for domestic and irrigation purposes. Valley fills and weathered basalts also constitute important unconfined aquifers locally. However, the confined aquifers of iron ore bodies and fractured schistose rocks are rarely utilised. The groundwater level in the unconfined aquifers is generally less than 6m bgl even during the dry season. The water table fluctuation is less than 2m over a large area of the watershed resulting in a small quantity of the dynamic groundwater resource in the watershed.

The Western Ghats separate the two domains of groundwater that occur in the watershed at two different topographic levels. The Mhadei River and its tributaries are effluent in nature and receive base flow from the two domains of groundwater throughout the year. The area around Dhave village is a major recharge zone in the watershed.

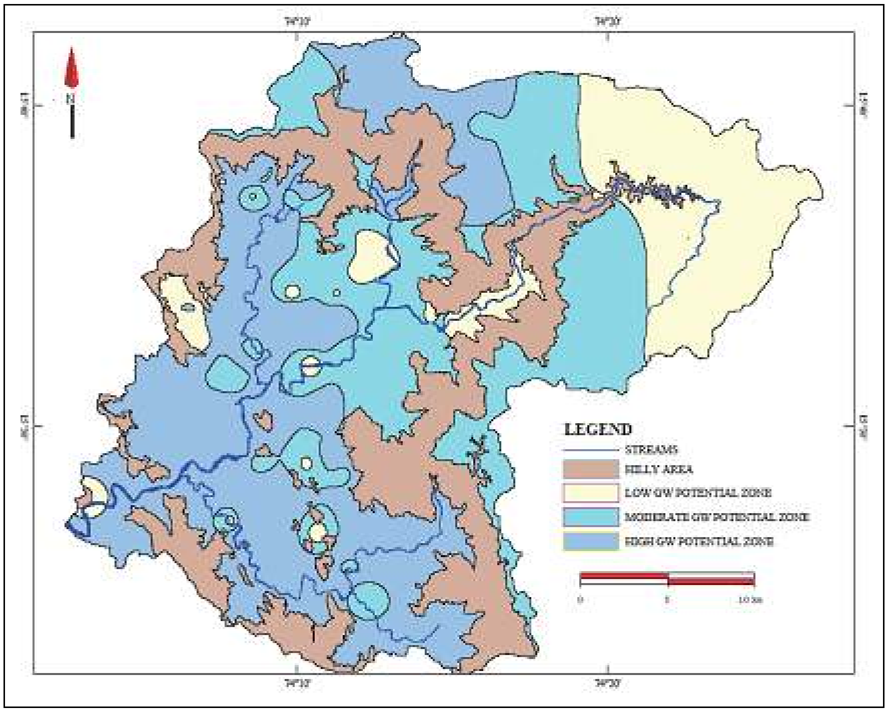

Figure 11: *Map Showing Groundwater Potential Zones in the Mhadei Watershed*

The groundwater recharge computed by water table fluctuation method is 4186 ham and the percent rainfall recharge is estimated to be 0.02 for the Mhadei watershed. The transmissivity values of the unconfined aquifers in the watershed vary from $4m^2$/day to $216m^2$/day and the average specific yield is 0.05. The western regions of both the groundwater domains have higher groundwater potential and it decreases gradually towards the eastern region. This is attributed to the decreasing thickness of the weathered mantle towards east.

References:

[1] Chachadi, A.G. and Lobo Ferriera J.P. (2001), GIS and mathematical modelling for the assessment of groundwater vulnerability to pollution: Application to an Indian case study area in Goa, IInd year report of DG Research programme INCO-DC, Ref.No.115/01-GIAS, pp 69.

[2] Chachadi, A.G. (2003), Technical report on groundwater balance studies in mining belt of Goa. Department of Earth Science, Goa University.

[3] Chachadi, A.G. (2009), Hydrogeology and water availability status in the State of Goa. In: Natural resources of Goa: A geological perspective, Geological Society of Goa, pp 119-147.

[4] Chachadi, A.G. and Choudri B.S. (2004), Well hydrographs as tools for impact assessment of open cast mining on groundwater regime in Goa. Journal of Applied Hydrology, vol. XVII, No. 2&3, pp 20-26.

[5] CGWB, (1998). Detailed guidelines for implementing the groundwater estimation methodology-1997.

[6] Gokul, A.R., Srinivasan, M.D., Gopalakrishnan,K., and Vishwanathan, L.S., (1981), Geology and stratigraphy of Goa. Proc: Earth Resources for Goa's Development, Panaji, Goa, pp 1-13.

[7] Mishra, G.C. and Chachadi, A.G. (1985), Analysis of flow to a large-diameter well during the recovery period. Ground Water, v.23(5), pp 646-651.

[8] Pahala Kumar, S., Shah, S.D., Venkataraman, G. and Pandalai, H.S. (1994), Evaluation and monitoring of ground water potential of Mandovi River sub-catchment area of North Goa using remote sensing and conventional data through GIS. Abst. Symposium: Mapping from space, XIV INCA congress, Dept. of Space, Bangalore, pp. 20-21.

[9] Papadopulos, I.S. and Cooper, H.H. (1967), Drawdown in a well of large diameter. Water Resources Res., v.3, pp 241-244.

[10] Raghunath, H. M. (1992), Ground Water, Wiley Eastern Limited, New Delhi, pp 25.

[11] WRD and CGWB (2011), Dynamic groundwater resources of Goa-March 2009. Report, Govt. of Goa.