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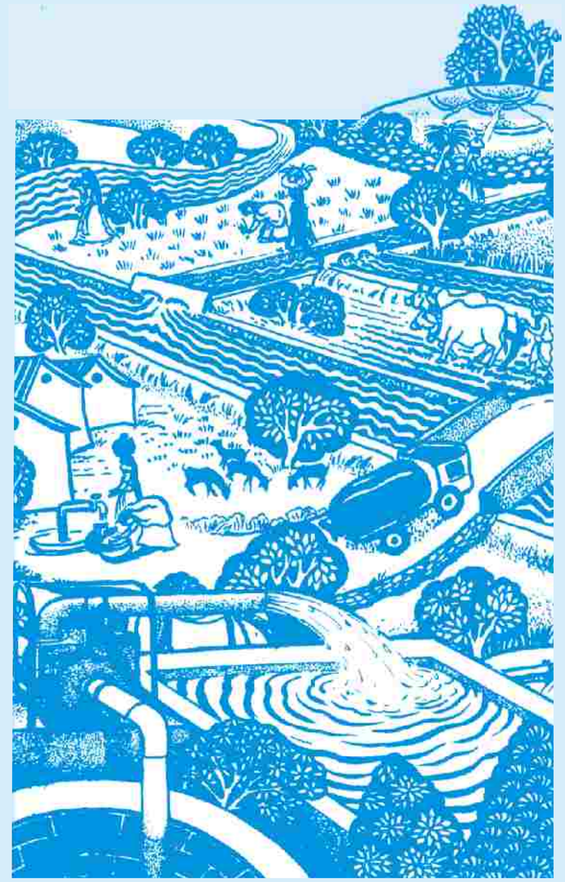

Changes in Groundwater Ecology and its Implication for Surface Flows:

Studies from Narmada River Basin, Madhya Pradesh, India

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Most of the discussion on enhancing the utilization of water resources in Narmada river basin, in its first master plan, had focused on its river flows. But, groundwater which is an integral component of the basin hydrology had not been taken into account by the Narmada Water Disputes Tribunal (NWDT) while deciding on the allocation norms for the four party states.

Based on analysis of long-term changes in groundwater balance and average annual groundwater level fluctuations, the authors make an empirical argument that increase in groundwater draft results in reduced outflows into the surface water stream. Therefore, any discussion on changes in hydrology of the river basin, its likely impacts on basin parties and compensation for such changes should focus on the overall changes in the basin's water resource system.

Changes in Groundwater Ecology and its Implication for Surface Flows: Studies from Narmada River Basin, Madhya Pradesh, India[1]

Research Highlight Based on a Paper with the Same Title

Narmada is one of the water rich river basins in India. The total amount of renewable water resources in Narmada basin is estimated to be 2,200 m^3/capita/annum. The recent Central Water Commission (CWC) finding that river flows in Narmada had reduced, particularly at the Sardar Sarovar dam, has raised concerns about the ability of water projects in Narmada valley and Sardar Sarovar Project (SSP) to realize the planned utilization of 28 Million Acre Feet (MAF). The NWDT had assessed the dependable yield of the basin as 28 MAF in 1979 for water allocation decisions among the four party states. Increase in wells and tubewells, and energisation of wells in the basin has resulted in a manifold increase in groundwater draft. The disputes over water sharing had totally missed out on aspects like the hydraulic inter-dependence between surface and groundwater and the probable effect that increased groundwater pumping could induce on surface flows, and therefore the need for re-allocation of water.

The NWDT had not taken into account this crucial factor while deciding on the allocation norms for the four party states. Instead, it provides for equally distributing the deficit in the event of reductions in surface flows in the basin. While at the conceptual level, such hydraulic interdependence is often understood and appreciated by water professionals, there are complex hydrological parameters involved in analyzing the “effect”, and integrating the same in water allocation decisions. There are problems in anticipating future growth in groundwater draft. Nevertheless, if these effects are significant, then the sanctity of the water allocation decisions would be questioned. Therefore, any discussion on changes in hydrology of the river basin, its likely impacts on basin parties and compensation for such changes should focus on the overall changes in the basin's water resource system as a whole.

Objectives

Present study is confined to Madhya Pradesh (MP) part of the Narmada river basin, which covers about 87 percent of the basin. The major objective of this paper is to analyze the changing dynamics of interaction between surface water and groundwater resources in Narmada basin on the basis of the changing hydro-ecology. The specific objectives are: [1] to analyze the long-term changes in surface flows in the basin; [2] to estimate the groundwater draft in the basin for different time period and analyze the long-term changes in the same; [3] to analyze the long-term changes in groundwater level trends in the basin; and, [4] compare the long-term changes in groundwater level trends in relation to the same in average annual groundwater draft

Hypothesis and Assumptions

The hypothesis is that: [1] increased groundwater draft in the basin is leading to increased infiltration and percolation, leading to increased recharge during both monsoon and non-monsoon periods; and [2] increased pumping of groundwater in upper catchment areas is causing reduction in groundwater outflow to rivers. These two processes lead to reduction in surface flows in

[1]The research covered by this IWMI-Tata Research Highlight was carried out with generous support from Sir Ratan Tata Trust, Mumbai under IWMI-Tata Water Policy Program. The research paper can be downloaded from the IWMI-Tata Website http://www.iwmi.org/iwmi-tata.

the basin. The argument in support of the hypothesis is that the groundwater draft in the basin had increased several times over the past few decades, but the same is not reflected in the long-term trend in groundwater levels. The effect of increased draft is being offset by increase in natural recharge induced by increased pumping. The assumptions are as follows: [1] there are no long-term changes in the basin rainfall, sufficient to alter the surface flows and natural recharge to groundwater; [2] there are no long-term trends in the pattern of rainfall; and [3] there are no major land use changes in the basin area sufficient to alter the natural rate of recharge to groundwater. On the other hand, the changing geo-hydrological environment changes the surface water-groundwater interaction.

The Water Resource System of Narmada Basin

Characteristics of the Drainage Basin

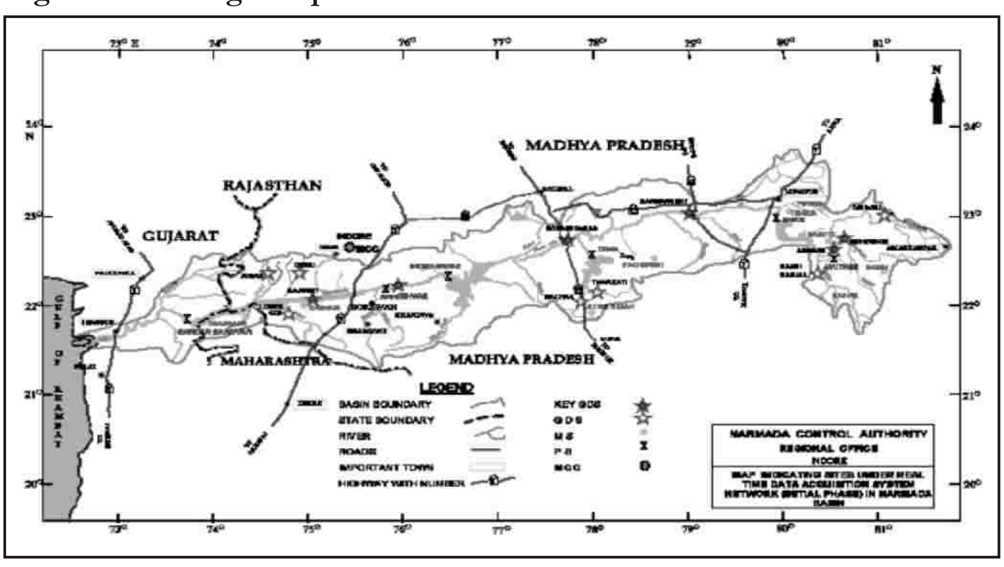
Narmada River is the fifth largest river in India and largest west flowing river of peninsular part. The net utilizable yield (at 75 percent dependability) of the basin is estimated to be 35.54 BCM. The Narmada river basin is one of the trans-boundary river basins with a total drainage area of approximately 100,000 sq. km., out of which nearly 87 percent of the basin area is in MP, 11 percent in Gujarat and 2 percent in Maharashtra (Figure 1). The Narmada River has 41 tributaries meeting the trunk river at various confluence points along its course.

Rainfall and Surface Hydrology

The annual rainfall in the basin occurs mainly during the monsoon period with 90 percent occurring during June to October. The normal rainfall varies from 800mm for Khandwa station to 1,623.2mm for Balaghat station. The average normal rainfall for the entire basin works out to be 1,230mm. From the source to Sardar Sarovar, the coefficient of deviation in rainfall varies from 19 percent to 37 percent.

The oldest estimate provided by NWDT (1979), which estimated the total surface water availability of Narmada basin is 40.95 BCM using 75 percent dependability factor. A committee headed by member (WP), CWC assessed surface water resources of Narmada basin in 1992 as 45.64 BCM based on estimated stream flows. The stream flow records at Garudeshwar obtained for the period from 1947 to 1979 shows that mean discharge is highest during the month of August (5,170.2 m^3/sec), immediately followed by September (4,857.6 m^3/sec). Runoff estimates based on monthly mean values of daily river discharge data obtained for 31 years show that 91.34 percent of the flow occurs during the four months starting from July. However, the flow pattern varies significantly depending on the type

Figure 1: Drainage Map of Narmada River Basin



Source : Website of Narmada Control Authority (NCA) of year; whether a dry year or a wet year. In wet years, a good percentage of the annual flows occur after the months of monsoon. Based on the historical data, the difference between maximum and minimum values of observed discharge for the month of September is 10.681m^3/sec. The difference between minimum observed discharge (86m^3/sec during the month of May) and maximum observed discharge (11,246m^3/sec during the month of September) is as high 11,160 m^3/sec.

Geology, Geo-hydrology and Groundwater in Narmada Basin

Narmada basin has heterogeneous geological profile. The major constituent litho-units are the sediments of Vindhyan and Gondwana Super Groups followed by Deccan Trap basalt. The Vindhyan Super group consists of flat Proterozoic sedimentary rocks exposed in the vast plateau mountains to the north of Narmada river in MP. The lower Vindhyans (Semri Group) are dominantly limestone whereas the upper parts of the succession are mostly sandstones.

The major part of the geological formations underlying Narmada basin is hard rock. Alluvial deposits cover only a small part.

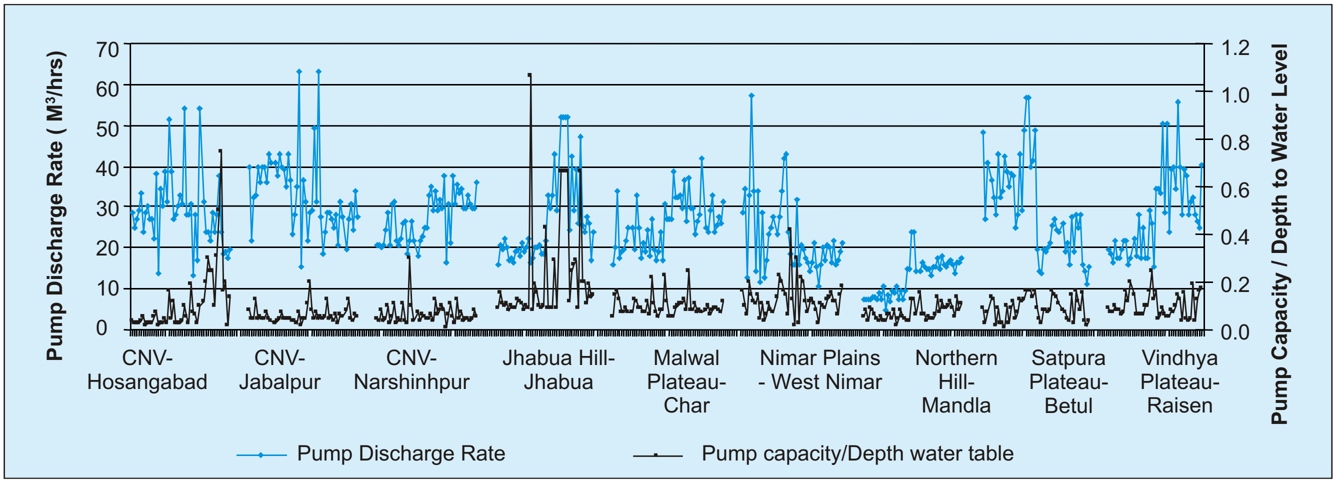
The major part of the geological formations underlying Narmada basin is hard rock. Alluvial deposits cover only a small part. In the hard rock areas, though groundwater occurs in fissures and weathered zones, due to the large vertical extent of these water containing geological formations, and the moderate to high rainfalls, groundwater potential is comparatively good.

Condition of Groundwater, Depth to Water Levels and Well Discharge

Farmers design their water abstraction systems in tune with the yield potential of the aquifer. The basic data on groundwater levels, well discharge and pump capacity were obtained from a primary survey of 420 farmers, across seven agro-climatic regions. We have plotted the values of well outputs and ratio of pump capacity and depth to water levels (P/L) of all the farmers across regions. The well outputs vary widely within, as well as, across regions from a lowest of 4.98 m^3/hour to a highest of 63.16 m^3/hour (Figure 2). Higher discharge rates are found for wells in Central Narmada Valley (CNV) districts. If we assume that the farmers take into account the efficiency factor in deciding the pumping capacity of the well, the variation in well output could be attributed to the variation in groundwater characteristics.

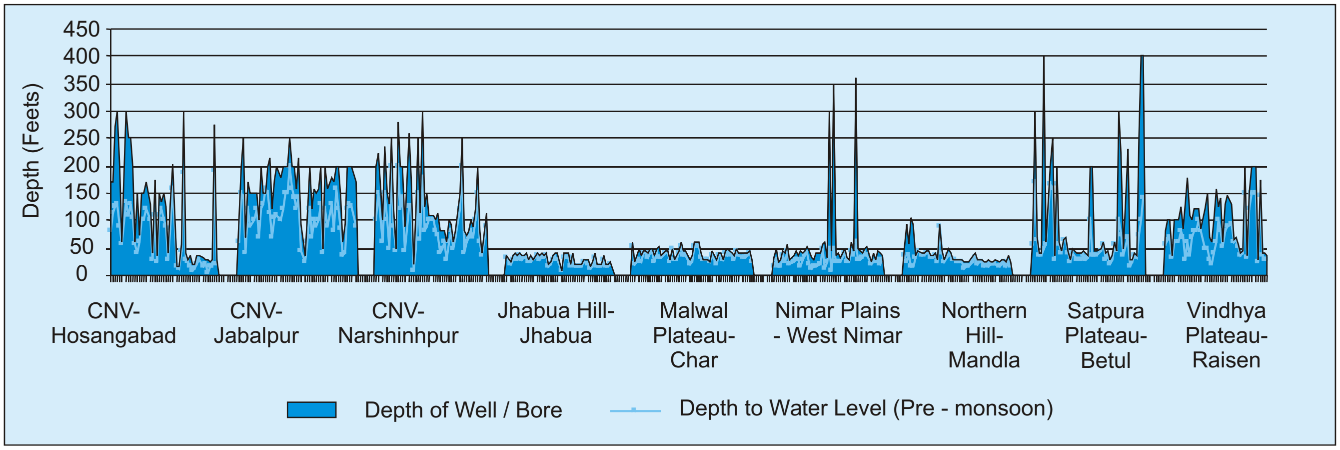
We have plotted the values of depth to water level in the wells and the depth of wells for all sample farmers (Figure 3). It can be seen that the depth to water level is very low in Jhabua hills, Nimar plains, Northern hills and Malwa plateau. The

Figure 2: Groundwater Yield Characteristics in Seven Regions of the Narmada River Basin, M.P.



Source: Authors' estimate based on primary survey, 2004

Figure 3: Depth of Well and Depth of Water Level in Different Regions of Narmada River Basin, M.P.



Source: Authors' estimate based on primary survey, 2004

Table 1: Average Gross Irrigated Area Commanded by a Well (Ha.)

Name of the agro-climatic region	Drought year (2002-03)	Normal rainfall year (2003-04)
Central Narmada Valley - Hoshangabad	4.95	5.06
Central Narmada Valley- Jhabalpur	5.55	5.54
Central Narmada Valley -Narsingpur	5.28	5.38
Jhabua Hill- Jhabua	0.07	1.01
Malwa Plateau- Dhar	1.59	2.65
Nimar Plains West-Nimar	3.41	5.10
Northern Hill Region of Chhattisgarh- Mandla	0.64	0.66
Satpura Plateau- Betul	4.06	4.23
Vindhyan Plateau- Raisen	5.86	6.78

Source: Authors' estimate based on primary survey, 2004

average depth to water level is slightly high in Vindhyan plateau. The highest depth to water level is found in the case of wells in three districts of CNV.

Irrigation Potential of Wells in Narmada Basin

We have seen that the characteristics of aquifers in terms of yield potential vary significantly in the basin. Such variations would also be reflected in the irrigation potential of wells, as farmers would be able to run the pumps for longer duration in case of better well yields, and bring larger area under irrigation. During the survey, we have collected data on the area irrigated by 420 wells across nine districts along with data on the crop economics (Table 1).

The difference in irrigated command area of wells could be understood when one examines the variation in average hours of pumping in a year. The wells in Central Narmada Valley (CNV) are run for a maximum hours (ranging from 460 to 869 per year), followed by those in Vindhyan Plateau (Table 2).

Rainfall, Characteristics and Long Term Trends

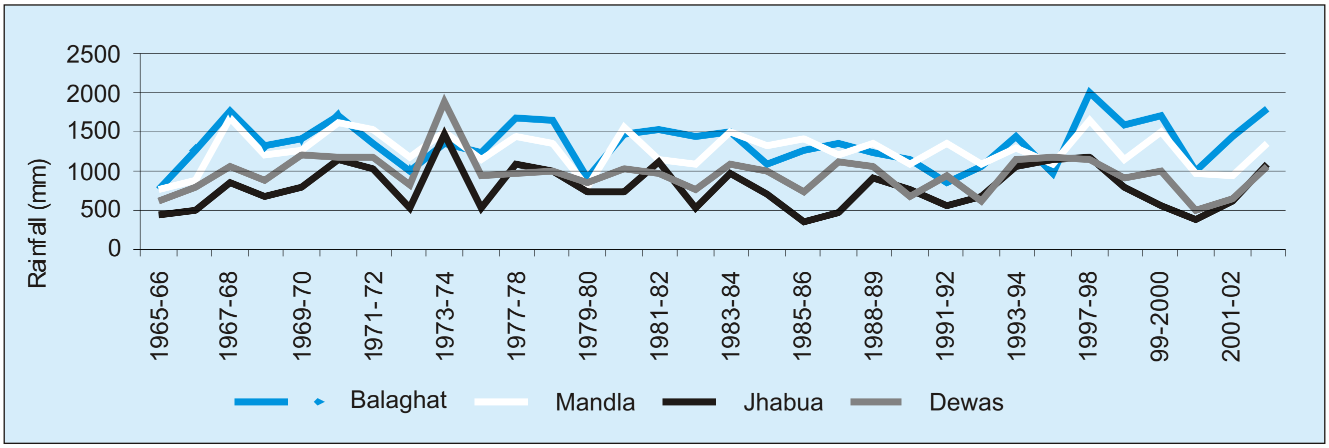
In the Narmada basin, the regions which record high mean annual rainfall experience low variability and vice versa, while the regions which receive higher magnitude of annual rainfall experience greater number of rainy days and vice versa. There are major spatial variations in mean annual rainy days in the basin.

Table 2: Average Annual Water pumping and Hours of Pump Running

Name of the agro-climatic Region	Average water pumped (m^3/year/well)		Average hours of pump running (Hrs/year/pump)	
	Drought year (2002-03)	Normal year (2003-04)	Drought year (2002-03)	Normal year (2003-04)
CNV- Hoshangabad	13027.4	13365.4	460.3	470.9
CNV- Jabalpur	27874.2	26772.2	740.2	729.6
CNV- Narsingpur	21181.0	22468.5	869.2	902.0
Jhabua Hill -Jhabua	180.0	3164.9	7.6	92.3
Malwa Plateau- Dhar	3132.2	5183.1	141.5	224.8
Nimar Plains- West Nimar	9295.6	17171.2	364.4	731.8
NHR of Chhattisgarh- Mandla	1536.2	1455.8	125.0	117.4
Satpura Plateau-Betul	11252.1	12016.8	482.1	502.2
Vindhyan Plateau - Raisen	11581.3	13459.6	469.9	533.3

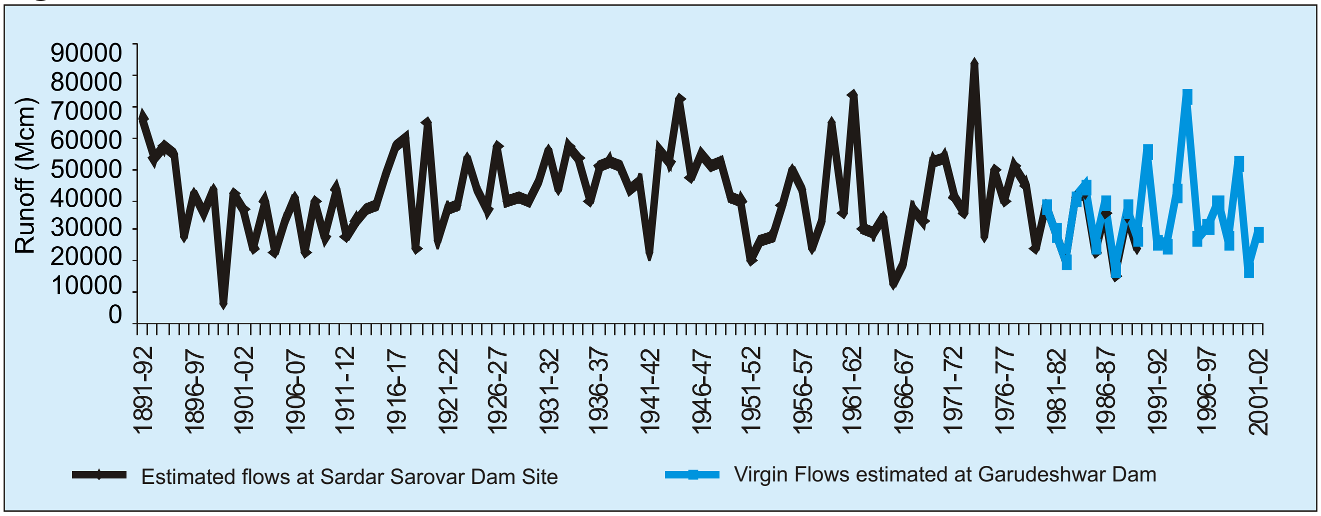
Source: Authors' estimates based on primary survey, 2004

Figure 4: Spatial and Temporal Variation in Rainfall, M.P.



Source: Government of Madhya Pradesh

Figure 5: Trends in Runoff in Narmada Basin



Source: NCA yearbook

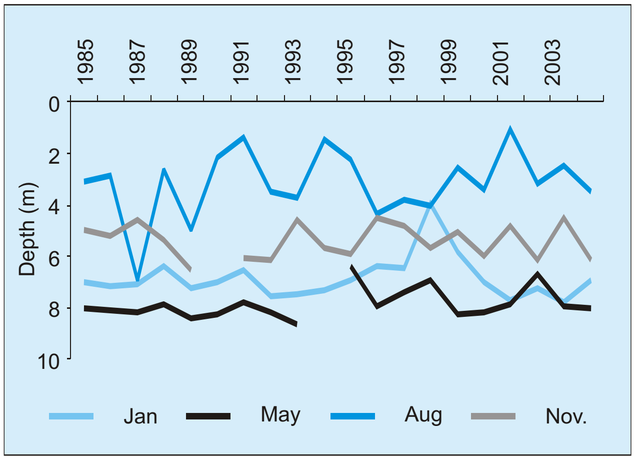
In order to examine whether there is any long-term trend in the region's rainfall, rainfall data for the period from 1965-2002 for four locations in the basin were analyzed (Figure 4). The analysis included locations with high rainfall (Balaghat and Mandla) as well as low rainfall (Dewas and Jhabua). The analyses did not show up any statistically significant trend in the rainfall, though the historical data show sufficient year to year variation in the annual rainfall magnitudes for all the four rain-gauge stations. The analysis did not show any long cycles of wet and dry years.

In the Narmada basin, the regions which record high mean annual rainfall experience low variability and vice versa, while the regions which receive higher magnitude of annual rainfall experience greater number of rainy days and vice versa.

Surface Water Flows and Long-term Trends

The estimated stream flows for Narmada basin for Garudeshwar for the period 1891-92 to 1989-90 and the estimated virgin flows for the period 1980-81 to 2000-2001 are presented in graphical form in Figure 5. First of all, the flow series estimated for 1891-1990 are based on historical flows observed at Garudeshwar. The estimated mean annual flow for this time period is 40.60 BCM and that for the second time period is 34.72 BCM. If the recent stream flow record is an indication, these datasets clearly show that the annual flows in Narmada are much less than what had been estimated for basin planning. The dependable runoff estimated for the first time period 1891-91 to 1989-90, is 34.5 BCM, whereas that on the basis of recent flow data is only 28.08 BCM.

Figure 6: Groundwater Fluctuation in Central Narmada Valley: Jabalpur



Source: Central Ground Water Board, Bhopal

The dependable runoff estimated for the period 1891-91 to 1989-90, is 34.5 BCM, whereas that on the basis of recent flow data is only 28.08 BCM.

Results and Discussion

Long-Term Trend in Groundwater in Narmada Basin

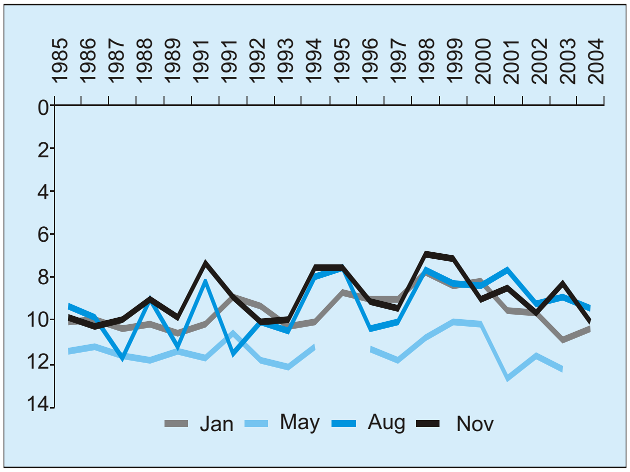
The long-term trends in groundwater in the basin were analyzed by examining the trend in depth of groundwater levels for 36 observation wells in the basin, which fall in different geo-hydrological settings. Data on one of the observation wells in Jabalpur falling in CNV (Figure 6) shows that there has been no significant decline or rise in water levels, from 1985 to 2004. While the pre-monsoon depth of water level remained more or less same, the water level fluctuation during monsoon (May to November), declined from 3.10m to 1.85 m.

This means, the net recharge during monsoon has reduced. The reduction in water level rise during monsoon could be attributed to pumping during the rainy season. The long term trends in water level in a well in Mandla of NHR of Chhattisgarh are presented in Figure 7. It shows that there has been slight increase in pre-monsoon depth to water levels (from 11.4 m to 12.25 m), while post-monsoon depth to water level had shown a marginal reduction from 9.81m to 8.31m. This means, the pre-post monsoon fluctuation in water level had risen.

What is the Long-Term Change in the Rate of Decline in Groundwater Levels?

The long-term trends in the annual fluctuations in groundwater levels in different locations in Narmada basin were analyzed by estimation of 3 to 4 year average annual change in water levels for

Figure 7: Groundwater Fluctuation in Northern Hill Region of Chhattisgarh: Mandla



Source: Central Ground Water Board, Bhopal

different time intervals; 1972-74, 1976-79, 1978-82, 1982-84, 1985-89, 1988-93, 1993-96, 1997-2000, and 2000-2004 using the data for the month of May or June. The data of groundwater level fluctuations from 36 locations can be classified into two groups: [1] wells in which the fluctuation was in terms of rise in water levels in the initial years; and [2] wells in which, the fluctuation was in terms of drop in water levels. In the case of first category, we would normally expect a reduction in "annual water level rise" over the long-term or reversal of annual fluctuation from "annual rise" to "annual drop" owing to increased abstraction and reversal of groundwater balance from positive to negative. In the second case, we would normally expect a rise in annual water level drops. A deviation from this expected trend would mean an upward trend in the annual groundwater recharge.

The mean values of average annual water level fluctuations in different time periods were estimated for the 36 observation wells. The results are presented in graphical form in Figure 8. It shows that the water levels are falling in the initial years. But, the estimated mean values of average annual drop in water levels reduced over a period of time, and towards the recent years, the average annual fluctuation have started showing reverse trends with water levels rising at the regional scale. Among those wells, which recorded annual rise in water levels in the initial years (11), the trend was found to be increasing over time in 9 cases, with increasing magnitude of fluctuation. Among the second category of wells (25 nos.), the average annual drop in water level was found to be reducing in 23 cases (Table 3). In the remaining two cases, the average annual drop increased. This is the trend we were expecting.

What is the Reduction in Surface Water Flows?

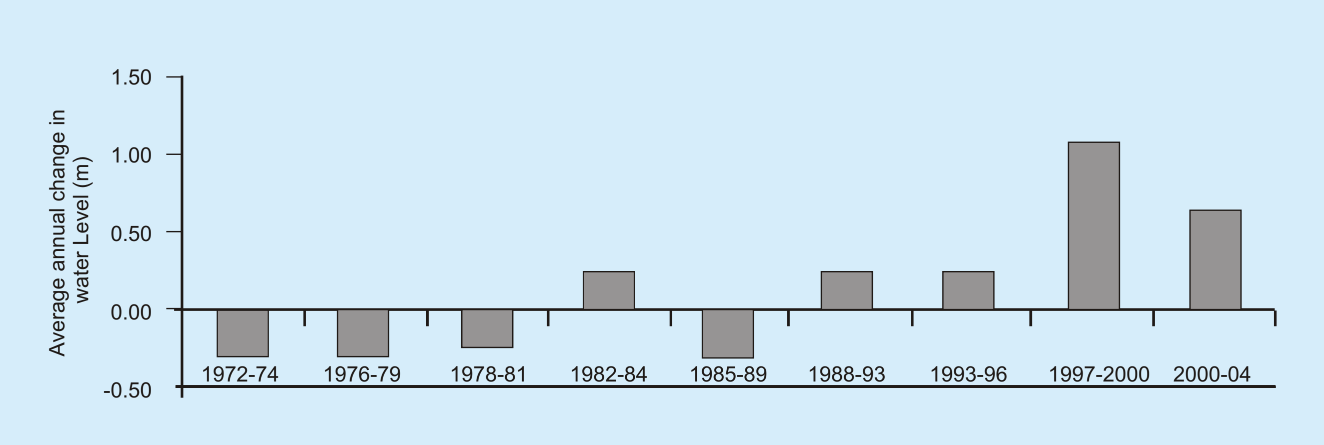
The regression models estimated with linear and exponential trends show that the rainfall-runoff relationship has changed over the years (Table 4). The estimated correlation coefficients suggest that the runoff corresponding to unit rainfall is less for the period 1980-2000 as compared to that during two time periods, viz. 1965-1990 and 1965-2000. This means that the runoff that a unit rainfall can generate had reduced over a period of time in the basin. Now, our earlier analysis had shown that there has not been any significant change in the rainfall over the years. Hence, one can safely conclude that the runoff had reduced, for reasons other than the rainfall. The runoff generated with different magnitudes of rainfall using the exponential regression for two regression models; one estimated for 1980-2000 and the other for 1965-1990 are plotted in Figure 9.

What is the Long-term Change in Groundwater Balance in the Basin?

The data on gross annual groundwater draft and recharge estimated for five year periods were obtained from the Central Ground Water Board (CGWB) for two years, viz. 1993 and 1998. The estimates for 1993 have separate component of recharge (return flow) from canals (1,080 MCM). However, the 1998-99 estimates do not have a separate component. We have used the tentative estimates available from Singh *et al.* (2005) for irrigation return flows (1,225 MCM) to arrive at the natural recharge. The estimates of natural recharge for 1993 and 1998-99 do not show major variations in recharge figures. Hence, we have used the figures of 1993 for the previous year i.e. 1985.

For estimating the total groundwater recharge from surface irrigation systems, we have used:[1] the total surface water allocation from Narmada river system for agriculture in these two years; and

Figure 8: Average Annual Groundwater Fluctuation at Different Time Periods



Source: Authors' estimates based on data from CGWB

Table 3: Changes in Groundwater level trends in Narmada Basin

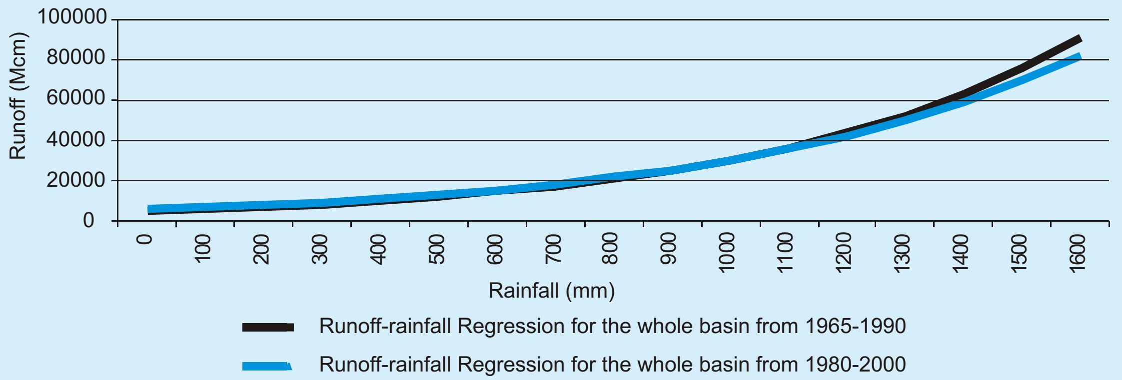
Name of the Region	Trends in water levels in wells recording rise in W.L in initial years			W. L trends in wells recording drop in water levels in initial years		
	Total number of wells	No. of wells showing declining trend in W. L rise	No. of wells showing rising trend in W. L. Rise	Total number of wells	No. of wells showing declining trend in W. L drop	No. of wells showing rising trend in W. L. drop
Balaghat	3	0	3	0	0	0
Betul	0	0	0	2	2	0
Chindwara	1	1	0	1	1	0
Dewas	0	0	0	1	1	0
Harda	0	0	0	1	1	0
Hoshangabad	1	0	1	1	1	0
Indore	1	0	1	0	0	0
Jabalpur	0	0	0	2	2	0
Jhabua	0	0	0	1	1	0
Khandwa	2	0	2	1	1	0
Khargone	1	0	1	4	4	0
Bharwani	0	0	0	2	2	0
Mandla	0	0	0	1	1	0
Dindori	0	0	0	2	0	2
Narsingpur	1	0	1	3	3	0
Raisen	0	0	0	1	1	0
Seoni	1	1	0	1	1	0
Sagar	0	0	0	1	1	0
Total	**11**	**2**	**9**	**25**	**23**	**2**

Source: Authors' estimates based on data from Central Ground Water Board

Table 4: Estimated Rainfall-Runoff Relationship for Narmada Basin at Garudeshwar

	Regression equation	F-statistic	Sig.	R^2
Runoff-rainfall regression for the whole basin from 1965-2000				
Linear	-31886.25+64.09*X=Y	139.17	0.00	0.826
Exponential	$4909.47*(e^{(0.0001811*X)})=Y$	170.47	0.00	0.853
Runoff-rainfall regression for the whole basin from 1965-1990				
	Regression equation	F-statistic	Sig.	R^2
Linear	-34530.31+66.98*X=Y	102.30	0.00	0.828
Exponential	$4817.60*(e^{(0.0018358X)})=Y$	110.40	0.00	0.838
Runoff-rainfall regression for the whole basin from 1980-2000				
	Regression equation	F-statistic	Sig.	R^2
Linear	-19981.28+51.38*X=Y	29.44	0.00	0.640
Exponential	$5611.31*(e^{(0.001678*X)})=Y$	34.26	0.00	0.675

Figure 9: Trend in Runoff-Rainfall Regression for Narmada Basin



[2] the estimated percentage return flow to groundwater (43 percent). These figures were added to the natural recharge figures available from official estimates of CGWB for two years to obtain the effective groundwater recharge. It shows that the groundwater balance at the aggregate level in the basin though had remained positive, had reduced over the year, significantly from 8,977.10 MCM in 1985-86 to 7,818 MCM in 1998-99 (Table 5). These figures do not take into account the natural outflow from the aquifers, but only consider the outflow through well pumping.

Conclusion and Policy Inferences

The groundwater system of Narmada river basin is complex, characterized by heterogeneous geology and geo-hydrology. Analysis shows significant variations in the characteristics of wells in terms of depth to water level, yield and irrigation potential. Even as per official estimates, the groundwater balance of the basin has undergone significant changes over the past 25-30 years, with increased groundwater draft for irrigation and other uses on the one hand and increased recharge to groundwater on the other, with additional recharge coming from surface irrigation systems.

The analysis carried out for the study had brought about several changes taking place in the hydrological system of the basin. First of all, the basin yields have reduced significantly during the past two decades (1980-2000) as indicated by the lower values of mean annual flows and

Table 5: Long term Trend in Groundwater Balance in Narmada Basin

Year	Total ground water draft (as per authors' estimate (MCM)	Natural ground water recharge (as per CGWB) (MCM)	Recharge from surface irrigation systems (MCM)	Total ground water recharge (including recharge from canals)	Estimated groundwater balance /deficit (5-2)
1985-86	1007.90	9200.00	785.00	9985.00	+8977.10
1991-92	1795.50	9200.00	1080.00	10280.00	+8074.50
1998-99	2582.00	9175.00	1225.00	10400.00	+7818.00

Source: Singh *et al*. (2005); CGWB (1995) and (2004).

dependable flows, as compared to that for the period 1965-1990. But, runoff could reduce due to reduction in rainfall too. However, our analysis shows that there has not been any long-term trend in the rainfall. In order to ascertain the effect of factors other than rainfall in reducing basin yields, we have estimated regression models for rainfall and runoff for different time periods. It showed that the observed runoff corresponding to a unit rainfall had reduced since 1980. While runoff could reduce due to reduction in runoff generation potential of the catchment resulting from changes in land use, it could also reduce due to influx of surface runoff into groundwater system.

Our analysis of well hydrographs showed that the long-term trend in average annual water level fluctuation does not conform to the rate of change in groundwater abstraction in different parts of the basin. While the average water level drops in certain locations had reduced over the past three decades or so, the average rise in water levels in wells had increased in certain other locations. This is in spite of major decrease in groundwater balance in the basin, estimated on the basis of gross abstraction and sum of natural recharge during monsoon and recharge from irrigation return flows. This significant change in water level fluctuations could then be attributed to: [1] increase in groundwater storage in the basin due to influx of surface water flows into the groundwater systems; or [2] reduction in annual outflow of groundwater from the aquifers to surface streams, both being directly linked to changes in hydro-dynamics of groundwater.

While a significant chunk of the potential induced recharge due to surface water flux into groundwater system is already captured in recharge estimation, the possibility of the first one could be ruled out. Therefore, the reduction in surface flows in the basin could be attributed to reduced outflow from aquifers into the surface streams.

The study had major implications for the management of the basin's water resources. Groundwater and surface water system within a basin are inter-dependent. As our study clearly illustrates, it is impossible to manage both the systems separately. As MP is likely to increase its groundwater pumping, it is likely to have significant effect on the groundwater outflows into the surface streams. This would reduce the lean season flows significantly in the short-run, while in the long-run the surface flows during the monsoon itself would get severely affected. Since groundwater system is not covered in the water allocation regime being monitored by the Narmada Control Authority, increase in groundwater draft in MP could threaten the sanctity of water allocations norms being enforced by the authority for the party states; as less water would be available as surface flows. The surface water-groundwater interactions in the basin need serious scientific studies for better management of the basin's water resources. Apart from its implications for protection of the downstream rights, the reduction in lean season flows would seriously threaten the ecology of the basin, and environmental management.

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IWMI-Tata Water Policy Program

The IWMI-Tata Water Policy Program was launched in 2000 with the support of Sir Ratan Tata Trust, Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations.

Through this program, IWMI collaborates with a range of partners across India to identify, analyse and document relevant water-management approaches and current practices. These practices are assessed and synthesised for maximum policy impact in the series on Water Policy Research Highlights and IWMI-Tata Comments.

The policy program's website promotes the exchange of knowledge on water-resources management, within the research community and between researchers and policy makers in India.

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