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# Highlight

## Local and Sub-basin Level Impact of Watershed Development Projects:
### Hydrological and Socioeconomic Analysis for Two Sub-basins of Narmada

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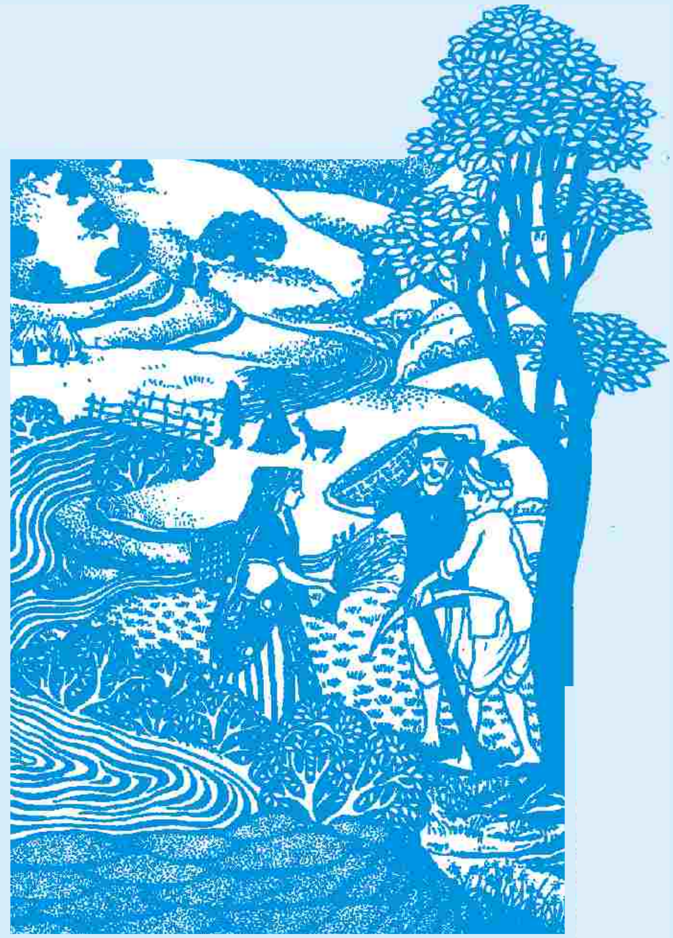

Intensive rainwater harvesting activities and groundwater development, which occur as an aftermath of watershed development program, have the potential to bring about socio-economic and hydrological changes at various levels in the basin.

Analyses shows that increased water harvesting and land treatment have resulted in improved groundwater recharge at the sub-basin and watershed level, thereby enabling cropping intensification. The activities also caused reduction in runoff downstream of the sub-basin, indicated by a lower estimated runoff coefficient.

There is a need to consider these socioeconomic and hydrological changes before planning and implementing new water resource development programs for ensuring sustainable resource use.

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# Local and Sub-basin Level Impact of Watershed Development Projects: Hydrological and Socioeconomic Analysis for Two Sub-basins of Narmada[1]

## Research Highlight Based on a Paper with the same Title

The Narmada basin is one of the water rich basins of India. The Narmada river originates from east of Madhya Pradesh (MP), enters into Gujarat and ends up in the Gulf of Cambay. Approximately, 90 percent of the basin falls in MP. Since mid 90s, the MP government has made concerted efforts in watershed development and water harvesting through decentralized administration and governance under the Rajiv Gandhi Watershed Mission (RGWM) and Rajiv Gandhi Rural Drinking Water Supply (RWSS) mission. Subsequently, intensive watershed development work was taken up in 1694 watersheds of the basin between 1995-96 and 2001-02. Besides this, many donor agencies have supported local NGOs who have implemented watershed development projects independently.

**Intensive rainwater harvesting activities, and groundwater development, which occur as an aftermath of watershed development programs, have the potential to cause major socio-economic and hydrological changes at various levels in the basin.**

Intensive rainwater harvesting activities and groundwater development, which occur as an aftermath of intensive watershed development programs (WDP), have the potential to cause major socio-economic and hydrological changes at various levels in the basin. Limited field observations from intervention areas have made many NGOs argue that local groundwater recharge improves as a result of watershed and water harvesting interventions. Improved hydrological regime not only helps people improve their socio-economic conditions through enhanced water use, but also increases the lean season flows in downstream areas and increases the local groundwater buffer for drought years. Notwithstanding the limitation induced by the neglect of change in local water demand patterns from induced supplies, the unit of such analysis is never extended beyond the village or the watershed selected for the project.

The hydrological effects of watershed-based catchment treatments on the basin were not considered when the Narmada valley development projects were originally planned. It was rather viewed as a complementary work for sustainable basin management, often limited to a few hilly watersheds. But, as some researchers have observed, since the days of conceptualization of the Narmada master plan, water management concerns and priorities in the basin have changed with changing socio-economic conditions. The focus of the studies has been entirely on watershed development, decentralized water harvesting, and groundwater use, which had

[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.

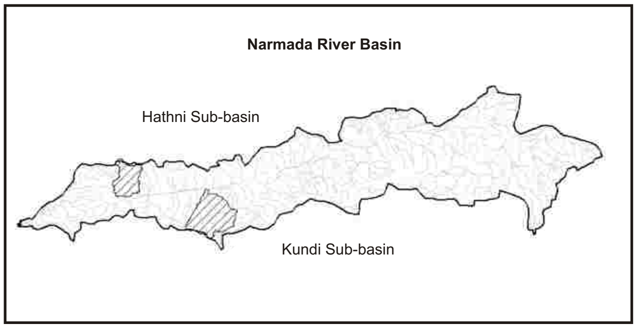
effects on the hydro-ecology in the form of reduced runoff generation, reduced stream flows, and faster groundwater drawdown. Researchers have used the recent hydrological records that show much lower basin yields to support their argument.

## Methodology

The study had two objectives: [1] to analyze the socioeconomic and hydrological impact of watershed development and water harvesting activities at the local level; and [2] to assess the effect of watershed development and water harvesting activities on the availability of flows at sub-basin and basin levels.

Data collected from RGWM show that intensive watershed development work was carried out in Khandva, Khargone and Jhabua. Among these leading watershed development districts, stream flow gauging stations have been set up in Kundi Sub-basin of Khargone district and the Hathni sub-basin of Jhabua district (Figure 1). Therefore, we purposively selected these two districts for the study. Since Khargone district falls in the Kundi sub-basin, we have used district level data as representing the sub-basin. In the case of Jhabua district which occupies only 66 percent of the Hathni sub-basin, we culled out sub-basin level data from district level data. From each district, one micro watershed, which is intensively treated, was chosen for rigorous study. These micro watersheds are those which have more than 90 percent their geographical area treated under the employment assurance scheme (EAS) during 1995-96 to 1999-2000. From both districts, a non-treated micro watershed, which is contiguous to the treated micro watershed, was selected for comparison.

**Figure 1: Study Area in Narmada Basin**




## Findings and Discussion

### Socio-Economic Changes

Analysis of socio-economic data shows that there is a remarkable growth in population at the sub-basin level during the study period in the Kundi and Hathni sub-basins, the annual compounded growth rate of population being 2.4 percent and 3.2 percent respectively. The treated watersheds show much lower growth in population compared to the control (untreated) watersheds in both basins: 3.45 percent against 4.5 percent in the Kundi watersheds and 0.39 percent against 4.49 percent in the Hathni watersheds, though their growth rates are higher than the aggregate sub-basin level growth rates. A marked increase in livestock population was also observed in the Kundi sub-basin during the study period; however much lower growth was observed in the micro watershed. But, the growth in the treated watershed (0.56 percent) was slightly higher than that in the untreated watershed (0.17 percent).

**There was a marked rise in livestock holding at both micro and macro levels. This has great implications in terms of increased water demand for cattle and animal feeding.**

Cross-sectional analysis brings out sharper differences. Livestock population per household is 4.10 and 6.29 animals in treated watersheds, in the Kundi and Hathni sub-basins respectively, compared to 2.56 and 5.56 animals per household in non treated watersheds of the respective basins.

This indicates more intensive livestock rearing activities in the treated watersheds. The rapid rise in livestock holding at micro and macro levels would lead to increased demand for water for domestic use, cattle drinking and animal feeding.

**Of the 244 respondents from the treated watersheds in the Hathni sub-basin, 115 reported getting temporary employment during implementation of WDP and reduction of migration period, as the two major benefits they realized so far.**

There is not so significant increase in the number of people engaged in different rural occupations such as agriculture, animal husbandry, and local employment for the watershed in the Kundi sub-basin. Sharp differences are observed when compared with the situation in non-treated watersheds. People in treated watersheds, viz. Bada Bhawta and Khedi remained engaged in agriculture for an average of 5.4 and 8.4 months compared to 4.1 and 6.6 months in non-treated watersheds- Bahedwa and Jaljyoti. In the Khedi watershed, there was a marginal rise in agricultural employment after the intervention from 8.3 months to 8.4 months. More people are engaged in animal husbandry in treated watersheds (11.75 and 24.4 percent respectively in Bada Bhawata and Khedi) compared to untreated watersheds (9.8 and 21.35 percent in Bahedwa and Jaljyoti respectively). This may be explained by larger livestock holdings in the treated watersheds which can be attributed to better availability of fodder.

There has been a sharp reduction in the number of family members migrating in treated and untreated watersheds; the reduction being higher in untreated watersheds (1.75 percent against 2.3 percent) of the Kundi sub-basin. One could argue that watershed interventions have helped contain the impact of consecutive droughts. Of the 244 respondents from the treated watersheds in the Hathni sub-basin, 115 reported that getting temporary employment during implementation of WDP and reduction of migration period are two major benefits they realized so far. However, informal discussions with stakeholders of WDP and interaction with watershed community during field work showed that the temporary nature of employment generation did not significantly affect the overall migration, except a little change in the period and pattern of migration.

The study did not show any marked difference in local employment generation potential in both basins. Increased agricultural production, improvement in soil condition, and introduction of income generation activity through self-help groups are other benefits reported by 8, 4, and 21 respondents respectively.

### Changes in Land Use

**While winter cropping is increasing with improved water availability in treated watersheds, the farmers are expanding the rainfed area to meet the increased food and fodder requirements in untreated watersheds.**

Land use data from the agricultural censuses, 1989-90 and 1995-2000, show a declining trend in land use between 1989-90 and 1999-2000 in the Kundi sub-basin. Data collected from district land records office of Jhabua also corroborated this finding for the Hathni basin. Total reported area came down from 1,349,000 to 1,019,000 ha in the Kundi basin and from 2,71,000 to 2,69,000 ha in the Hathni basin. Forest area has drastically shrunk from 34.85 to 9.75 percent in the Kundi sub-basin and from 3.22 to 2.75 percent in the Hathni sub-basin. Land that is not available for cultivation increased from 15.3 to 22 percent in the Kundi sub-basin and from 21.3 to 23.6 percent in the Hathni sub-basin. Cultivable wasteland increased from 2.3 to 3.6 percent and 2.3 to 2.6 percent in the Kundi and Hathni sub-basins respectively. Net sown area increased from 46.7 to 63.2 percent of the cultivable area in the Kundi sub-basin and did not change much in the Hathni sub-basin. Gross cropped area increased

**Table 1: Change in Cropped Area at Micro Watershed Level (area in acres)**

| Period | Cropped area | Kundi basin | | Hathni basin | |
|---|---|---|---|---|---|
| | | Treated-Khedi | Non Treated-Jaljyoti | Treated-Bada Bhawta | Non Treated-Bahedwa |
| Pre watershed | Geographical area | 1,092.00 | 1,331.00 | 1411.00 | 971.00 |
| | Reported area | 872.25 | 528.82 | | |
| | Cultivated area | 855.25 | 492.75 | | |
| | Irrigated area | 355.00 | 196.75 | | |
| | Kharif cropped area | 751.25 | 344.50 | | |
| | Rabi cropped area | 110.00 | 65.25 | | |
| | Cropping intensity | 114.64 | 118.94 | | |
| Post watershed | Reported area | 938.75 | 662.82 | | |
| | Cultivated area | 927.75 | 598.75 | 585.50 | 417.50 |
| | Irrigated area | 517.50 | 287.25 | 140.50 | 59.00 |
| | Kharif cropped area | 858.25 | 543.00 | 896.50 | 626.50 |
| | Rabi cropped area | 168.50 | 81.90 | 169.00 | 24.50 |
| | Cropping intensity | 119.63 | 115.08 | 118.85 | 103.91 |

Source: Primary survey, 2004

from 51.6 to 73.6 percent in the Kundi sub-basin, but marginally reduced from 70.9 to 68.8 percent in the Hathni sub-basin.

Kharif and winter cropped area show a declining trend in the Kundi sub-basin. This is mainly because of reduction in the reported area. Therefore, it is important to look at the changes in cropping intensity. Cropping intensity (expressed as a ratio of gross cropped area and net sown area) increased after watershed intervention from 114.64 percent to 119.63 percent. Agricultural statistics for the five year periods 1992-96 (pre-intervention) and 1996-2003 (post-intervention) show that average production and productivity of many of the crops also declined with decline in the cropped area. While reduction in crop production could be attributed to reduction in aggregate area under each crop, reduction in yield of some crops would have also contributed to reduced crop production. It is interesting to note that the yield of crops such as wheat and cotton increased after the intervention, while that of many rainfed crops reduced. Reduction in yield of rainfed crops could be because of the overall impact of consecutive poor monsoons for many years after the watershed interventions.

Cultivated area, irrigated area, kharif cropped area and winter cropped area increased by 8.5, 45.8, 14.2 and 53.2 percent in treated watersheds and increased by 21.5, 46, 57.6 and 25.6 percent respectively in non treated watersheds of the Kundi sub-basin (Table 1). One can argue that while winter cropping is increasing with improved water availability in treated watersheds, the farmers are expanding the rainfed area to meet the increased food and fodder requirements in untreated watersheds. Cropping intensity increased by 5 percent in treated watershed but decreased by 3.25 percent in untreated watersheds during the study period (Table 1). In the Hathni sub-basin, irrigated area and winter cropped area to geographical area is higher by 3.9 and 9.45 percent in treated watersheds compared to untreated watersheds. The percentage of kharif cropped area to geographical area remained the same for both watersheds.

Area under irrigation has increased in the Kundi sub-basin. Except for tanks, there was an increase in irrigated area under all other sources. The small water harvesting structures (WHS) may be functioning as alternative irrigation sources in treated watersheds. Drastic reduction in tank irrigated area is observed in the basin, from 11,200 to 1,200 ha. Area under well and tube well irrigation increased by 36 percent. Canal irrigated area has reasonably increased. All these clearly show that groundwater development took place at a greater speed in the basin during the last decade. While surface irrigation shows a mix trend because canal irrigation is increasing but tank irrigation is declining.

**The difference in recharge fraction between treated watershed and untreated watershed is larger at higher magnitudes of rainfall. At lower magnitudes of rainfall, the portion of rainwater that percolates down the soil is more or less same whether the watershed is treated or not.**

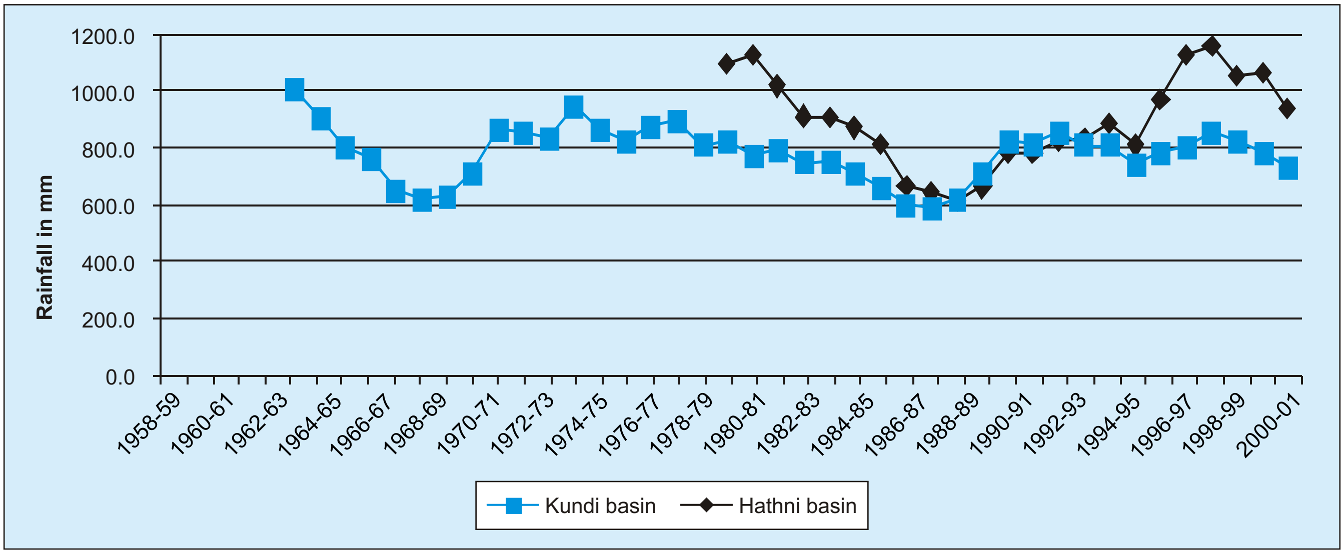
**Hydrological Changes**

Data on annual rainfall was collected from the district land record office of the study basins for 44 years for the Kundi sub-basin area and 28 years for the Hathni sub-basin. Moving average of these rainfalls at five year intervals are presented in Figure 2. In Kundi sub-basin, the moving averages indicate cycles of approximately 20 years with steep rise reflecting consecutive wet years, followed by steady decline reflecting consecutive dry years. The year corresponding to lowest moving average value is same for both the basins. In Hathni, steep decline and rise in moving average is found indicating a sharper difference between rainfall magnitudes of wet years and dry years. With a mean annual rainfall of 880mm, Hathni sub-basin receives higher rainfall as compared to Kundi which has a mean annual rainfall of 784mm.

**Though the number of wells and bore wells and well yields are nearly same for treated and untreated watersheds, annual pumping hours are remarkably higher in treated watersheds giving warning signals against future problems of groundwater overdevelopment.**

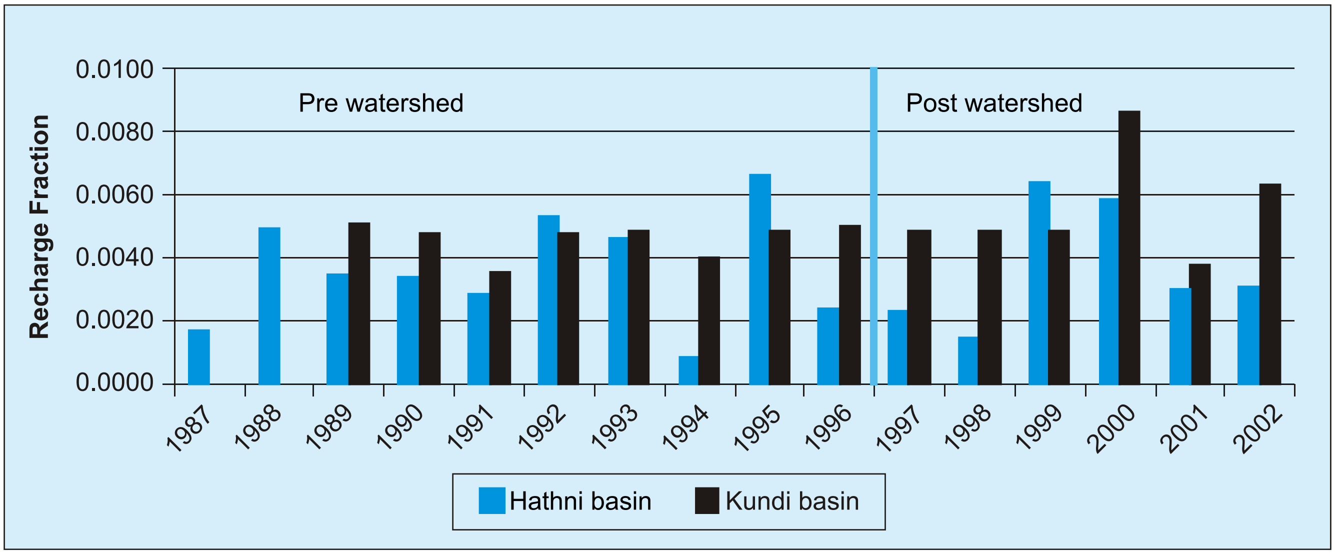
Both sub-basins have taken remarkable strides in groundwater development. The number of water harvesting structures created under WDP directly affects local level water availability. Data on pre- and post- monsoon water levels of 39 observation wells in the Kundi sub-basin and 51 observation wells in the Hathni sub-basin were obtained from the geo-hydrological survey units of the respective sub-basins and analyzed. From these figures, average annual rise/fall in well water level at the sub-basin level is worked out. To nullify the effect of yearly variations in rainfall on groundwater recharge, we worked out recharge fraction as a ratio of rise in well water level and average annual rainfall.

**Figure 2: Moving Average of Annual Rainfall in two Sub-basins**




(Source: Authors' analysis based on data from Office of Land Records, Khargone and Jhabua, MP).

**Figure 3: Effect of Watershed Interventions on Recharge Fraction**




Source: Geo-hydrological survey unit, Khargone and Jhabua, MP

The estimated values of the recharge fraction shows positive change after introduction of WDP at micro watershed and basin level (Figure 3). This shows a higher rate of percolation of water for the same quantum of rainfall. It is indicative of the positive effect of watershed interventions in terms of increasing opportunity time for runoff water to infiltrate. Therefore, we can argue that land treatment and WHS created under WDP might have contributed to increased ground recharge at the local level. Alternatively, one could also argue that the higher percentage of rainfall going underground is because of the effect of varying magnitudes of rainfall on the recharge process (that higher rainfall may not result in higher recharge rates but higher runoff) and because of any effect of land treatment on the recharge rate. Therefore, it is important to

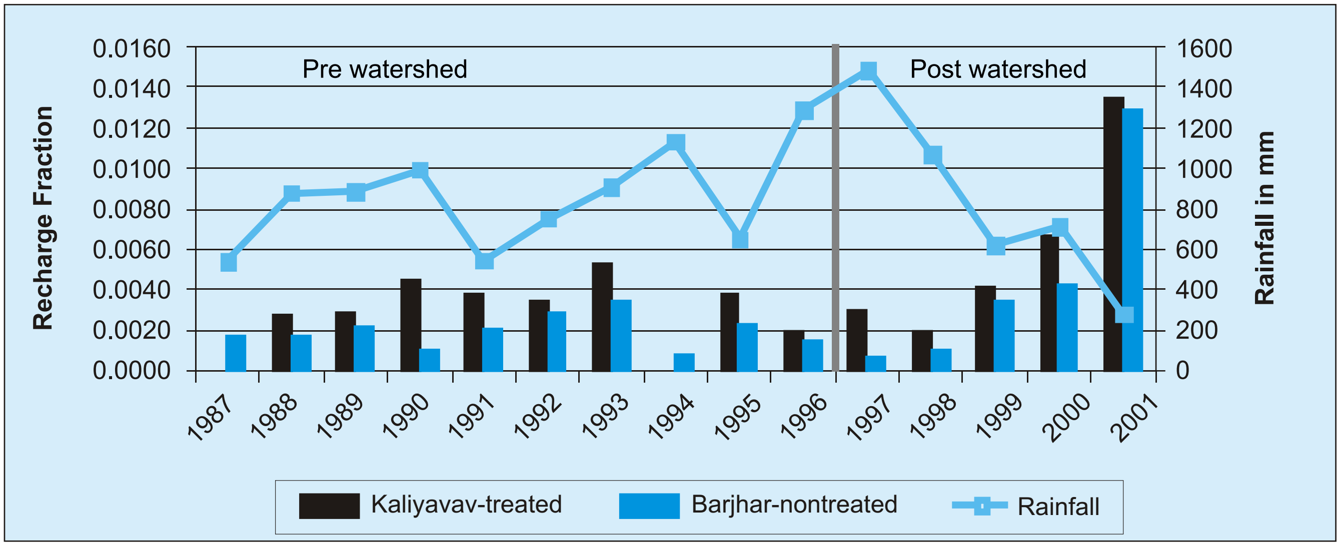
compare the recharge behavior for treated and untreated watersheds for the same magnitude of rainfall.

Detailed analysis was done for the treated and control watersheds. Like in the case of the sub-basins, the recharge fraction substantially increased. What is striking is the difference in recharge fraction between treated watersheds and untreated watersheds is larger at higher magnitudes of rainfall (Figure 4). At lower magnitudes of rainfall, the portion of rainwater that percolates down the soil is more or less same whether the watershed was treated or not.

**Water Balance at Micro Watershed Level**

Water balance at the micro watershed level is estimated on the basis of groundwater recharge and groundwater extraction for the year 2004 in the Kundi basin. Groundwater recharge and groundwater extraction were estimated using the estimated values of average water level fluctuations in wells during monsoon, the specific yield of the aquifer, and the geographical area of the watershed to arrive at the net recharge (=average water level fluctuation*specific yield*geographical area). To the net recharge figures, the estimated groundwater draft during

**Figure 4: Effect of Watershed Interventions on Recharge Fraction in Micro watersheds**



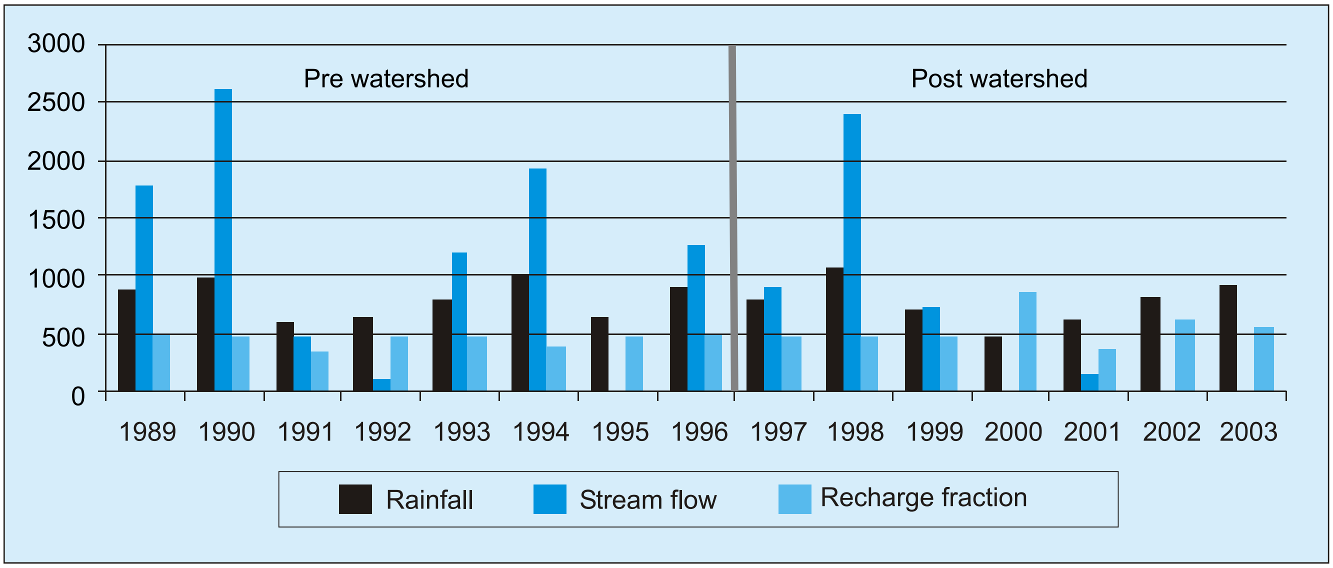

Source: Geo-hydrological survey unit, Jhabua

**Table 2: Water Balance at Micro Watershed Level in the Kundi Sub-basin**

| Details | Unit | Treated watershed | Non-treated watershed |
|---|---|---|---|
| Wells and bore wells | Number | 74 | 71 |
| Annual pumping per well | Hours. | 423 | 229 |
| Average well discharge | $m^3$ | 32 | 33 |
| Reported area | ha. | 376 | 265 |
| Rise in well water level during monsoon | m | 3.65 | 3.63 |
| Specific yield of the basalt aquifer | | 0.02 | 0.02 |
| Total groundwater recharge | ha. m | 102.30 | 59.50 |
| Groundwater abstraction | ha. m | 100.17 | 53.65 |
| Recharge rate | MCM/sq. km | 0.027 | 0.022 |
| Groundwater balance | ha. m | 2.11 | 5.89 |

Source: Primary survey, 2004

**Figure 5: Effect of Watershed Interventions on Streamflows**




Source: Authors' Analysis

kharif (=number of pumping wells* discharge* hours of pumping during kharif) was added to arrive at the actual monsoon recharge.

Estimates of water balance shown in Table 2 clearly indicate that not only the aggregate recharge is higher in treated watersheds compared to untreated ones (1,02,300 against 59,5 00 cubic metres), but the recharge rate is also higher (0.027 MCM/sq. km against 0.022 MCM/sq. km). On the other hand, ground water development is reaching a plateau in treated watersheds, in spite of high recharge owing to high rates of pumping. Though the number of wells and bore wells and well yields are nearly same for both watersheds, annual pumping hours are remarkably higher in treated watersheds which are giving warning signals against future problems of groundwater overdevelopment. The balance recharge in the treated watershed is only 2000 $m^3$. Moreover, the abstraction figures include only irrigation use. If we consider groundwater use in other sectors, especially, livestock, and domestic purposes, there would be hardly any water left as buffer. It means that the extra water made available at the local level through WDP is being utilized to its fullest potential by the watershed community. Therefore, unless measures are taken to increase groundwater recharge rates on a sustainable basis, communities should exercise precaution in further appropriation of the resources in areas where the abstraction levels are touching or even exceeding the recharge rates.

**Impact of WDP on Stream Flow at Sub-basin Level**

Though the recharge fraction is showing a slightly increasing trend stream flow in the Kundi sub-basin is showing a declining trend over a period of time (Figure 5). There are two possibilities: land treatment reduces runoff rate; and the WHS capture a portion of the runoff. Alternatively, one could argue that ideally the stream flows would be lower at lower magnitudes of rainfall. Such an argument gets strengthened when one looks at the annual rainfall figures during the post-WDP period. Therefore, to measure the real impact of watershed treatment on stream flow generation and the effect of water harvesting on downstream flows, we ran a regression between rainfall and stream flow for two time periods: pre-water harvesting period (15 years) and time period including the post-WDP period (20 years). The results of the regression analysis are presented in Table 3. The beta coefficient of the regression equation is slightly smaller for the period encompassing the post-WDP period, meaning the runoff corresponding to a unit rainfall (runoff coefficient) gets reduced after watershed treatment. Hence, this confirms the preliminary findings that the runoff rate has gone down in the post-project period.

**Table 3: Correlation between Average Annual Rainfall and Rise in Well Water Level and Annual Stream Flow**

| Variables | Period | a | b-coefficients | t value | $R^2$ |
|---|---|---|---|---|---|
| Rise in well water level | Pre (1989-1995) | -0.241 | -0.004922 | 4.730 | 0.789 |
| | Post (1989-2003) | 0.759 | -0.004036 | 3.611 | 0.501 |
| Stream flow | Pre (1980-1995) | -1883.727 | 3.988 | 8.427 | 0.845 |
| | Post (1980-2001) | -1913.545 | 3.974 | 10.358 | 0.863 |

Source: Authors' analysis

## Conclusions and Policy Implications

The study provides sufficient evidence of positive socio-economic impact of watershed development at the local level. The study also throws shows that WDP leads to increased land use with expanded winter cropping enabled by greater access to irrigation sources. Livestock keeping has gone up with greater access to water and biomass. Intensive treatment of land and extensive water harvesting structures lead to increased rate of recharge of precipitation into groundwater reserves at the sub-basin level. This is indicated by a high recharge fraction for the same runoff during the post-intervention period. Treated watersheds show higher recharge fraction than untreated watersheds with higher effect in high rainfall years. However, water balance estimates done for the treated micro-watershed show that groundwater recharge and extraction reached an equilibrium meaning almost all the recharged water gets used up within the watershed.

Analyses using limited hydrological data show that the availability of downstream runoff has reduced after the watershed and water harvesting interventions manifested by lower estimated runoff coefficients. This can be attributed to the increased local pumping for irrigated agriculture which follows the recharge. Hence, there is a need to consider these socio-economic and hydrological changes before planning and implementing new water resource development programs to ensure sustainable use of the resource. Also, it is desirable to design WDP and water harvesting projects keeping in view the committed flows for downstream development to reduce unintended effects.

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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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