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Effects of Deforestation and Forest Degradation on Surface Waters and its Economic Implications: A Case Study of Drinking Water Supplies to Greater Mumbai, India

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27.1 INTRODUCTION

Forests are generally perceived to be good for water environment under all circumstances. Hence, conserving (or extending) forest cover in upstream watersheds was deemed the most effective measure to enhance water yield, regulate seasonal flows and ensure high water quality. However, while forest hydrology researches conducted during the last three decades confirm the role of upstream forest cover in ensuring the delivery of high-quality water, several studies (Bosch and Hewlett, 1982; Bruijnzeel, 1990; Hamilton and King, 1983; Nik 1988; Pierce *et al.*, 1970; Robinson, 1998; Scott and Lesch 1997; Sikka *et al.*, 2003; Trimble *et al.*, 1987; van Lill *et al.*, 1980) suggest that the hydrological benefits of forests in respect of increasing downstream water yield[1] and regulating dry season flow have been exaggerated. Many now agree that in comparison to shorter crops, forests decrease runoff and dry season flows on account of higher interception losses in wet conditions, and greater transpiration losses in dry (drought) conditions (Bruijnzeel, 2004; Calder *et al.*, 2004; Calder *et al.*, 2007; IUFRO, 2007; van Dijk and Keenan, 2007). Calder (2003, 2005) even questions the wisdom of having forest as land cover to increase downstream water yield in arid or semi-arid ecosystems.

However, Malmer *et al.* (2009) question such generalizations, particularly for tropics on account of the broad use of the terms 'forests', 'afforestation' and 'reforestation', and use of data generated mostly outside the tropics. Too often all forests are 'bulked' in a single group and distinctions like reforestation and afforestation; different vegetation types/age; climax and non-climax communities are rarely maintained. Terms such as 'secondary forests', 'regrowth forest', 'altered forests', 'disturbed forest' are perceived differently by different groups (Chokkalingam and Jong, 2001). Further, the hydrological research has largely concentrated on two extremes – undisturbed forests versus cleared forest land, whereas most tropical forest areas are now a mix of secondary vegetation, and old forest interspersed with patches cleared for agriculture or other non-forest use (Bruijnzeel, 2004; Giambelluca, 2002). For these reasons, this study through spatiotemporal analysis evaluates the impact of a varied mix of primary,[2] mature secondary[3] and disturbed[4] forest cover, on water yield and surface water quality in four and six watersheds, respectively, in the Western Ghats of Peninsular India. The economic implication of the forest loss on water supply was also estimated to better communicate the contributions of forests to societal goals. Except one, the studied watersheds are those of reservoirs supplying drinking water to Greater Mumbai. The wide gap between water demand and supply as also escalating treatment costs makes appropriate management of forests in these watersheds critically important.

27.2 STUDY AREA

Of six reservoirs supplying domestic water to Greater Mumbai, four reservoirs and their watersheds – Tulsi, Tansa, Upper Vaitarna and Bhatsa – having virgin flow were selected for the study on water yield while a cluster of four watersheds – Pise, Tansa, Lower Vaitarna and Manda – were selected for study on water quality. Within the Pise watershed, water samples were also collected at sites Bhatsa and Sapgaon thereby adding sub-watershed Bhatsa and Sapgaon (that are nested within Pise watershed)to the studied watersheds (Figure 27.1).

The study on deforestation induced costs focused on the Panjrapur treatment plant (PTP) which collects water from the Bhatsai River that flows through Pise watershed. These watersheds lies in two clusters between longitudes 73.23°E and 73.65°E and latitude 19.50°N and 19.92°N, and longitude 73.127°E and 73.65°E and latitude 19.28°N and 19.70°N. The salient features of the catchments are listed in Table 27.1. Systematic working of the forests, illicit cutting, lopping of trees for fuel wood and slash-and-burn cultivation, clearing of land for shifting cultivation/encroachments, fires for hunting and

[1] Water Yield: Total quantity of surface water that can be expected in a given period from a stream at the outlet of its catchment (Subramanya, 2008).

[2] Primary Forests: Old forests with no or inconsequential human disturbance.

[3] Secondary Forests: Forests regenerating largely through natural processes after significant human and/or natural disturbance of the original forest vegetation at a single point in time or over an extended period, and displaying a major difference in forest structure and/or canopy species composition with respect to nearby primary forests on similar sites (Chokkalingam and Jong, 2001).

[4] Disturbed Forests: Forests that have been exploited on moderate to large scale for timber, fuel wood, fodder, shifting cultivation and other tangible benefits. Reforestation activities may or may not have been undertaken in them.

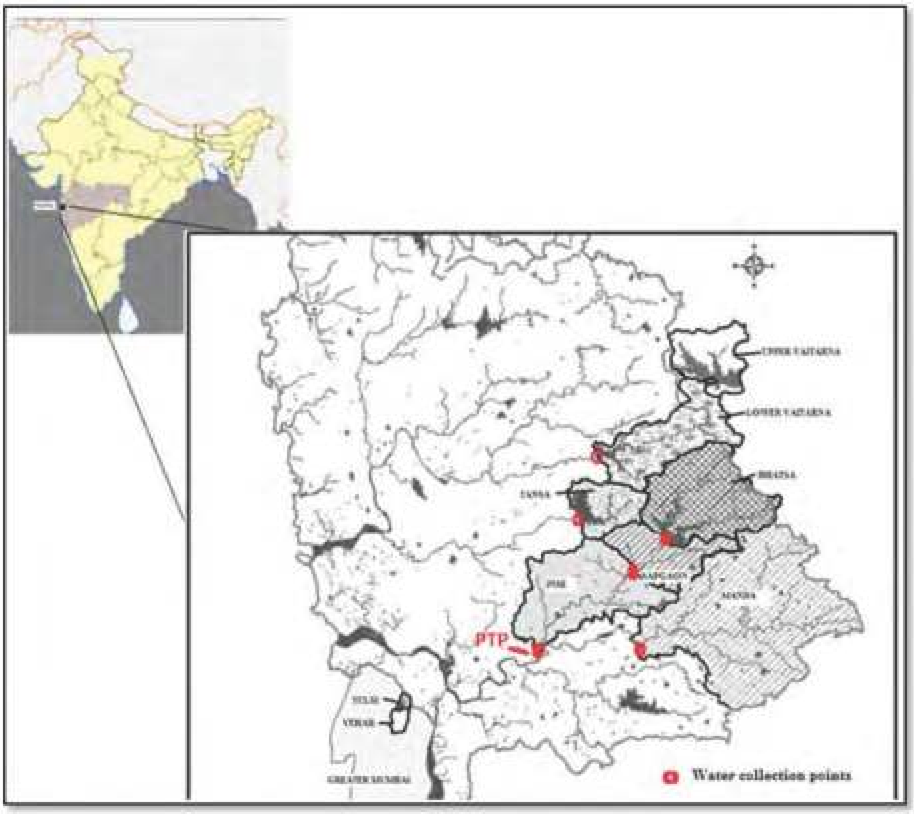

Figure 27.1: Location of the study area, the hydrometric region of Mumbai Metropolitan Region and the selected watersheds and treatment plant

(Source – *MMRDA*)

cultivation, and uncontrolled grazing have reduced forest cover and opened up the canopy considerably in the Upper Vaitarna, Lower Vaitarna, Pise and Manda. As a result, there is a mix of disturbed and degraded patches in the vicinity of villages while distant and inaccessible slopes are still covered with primary forests and mature tree cover. Such undisturbed/less disturbed patches constitute approximately 30 per cent to 40 per cent of the forest area in these watersheds. In Tulsi, effective protection and seclusion measures have resulted in thick, lush and undisturbed forests in over 80 per cent of the watershed area. Situation in Tansa is a mix of the above two as about 52 per cent of the forest cover in the Tansa is a mix of primary forest and mature secondary forests, while remaining 48 per cent mainly comprises disturbed forests with occasional patches of naturally open forests. The watersheds have no industry or urban settlements. All except Tulsi are well served with all-weather and fair weather roads.

The treatment process at the Panjrapur treatment plant is of conventional type i.e., consisting of flocculation, sedimentation, filtration, and disinfection activities. Drinking water standards formulated by the Bureau of Indian Standards – I.S. (10500:1991) – and guidelines of the Central Public Health and Environmental Engineering Organization are followed.

27.3 METHODOLOGY

The forest cover in the watersheds over the years was interpreted from the orthorectified satellite images for years 1972, 1973, 1989 and 1992 downloaded from Landsat.org; geo-rectified satellite images for 1985 acquired from the National Remote Sensing Centre (NRSC), Hyderabad; digitized land use/ land cover maps (LULC) for year 1994, and 2004 acquired from the NRSC, Hyderabad; and digitized forest cover maps for years 2000, 2004 and 2007 acquired from the Forest Survey of India (FSI), Dehradun. Watershed boundaries were demarcated with the help of digitized watershed/micro-watershed maps acquired from the Maharashtra Remote Sensing Applications Centre (MRSAC), Nagpur and toposheets. Methodology followed by Singh and Mishra (2012) was adopted for classification and accuracy assessment of the satellite images, segregation of forest cover into old forests (primary forest, mature secondary forest and undisturbed mature plantations) and the mixed forests (disturbed forests and to a lesser extent naturally occurring open forest) and calculation of forest cover in the watersheds on year to year basis. Monthly forest cover in a year was estimated assuming a linear change in forest cover over the months. Model specification and data processing are detailed in Singh and Mishra (2012). The analysis conducted was as follows:

27.3.1 Impact on water yield

Spatiotemporal analysis of historical data and satellite images from1974-2009 for Tulsi and Tansa; 1977-2009 for Upper Vaitarna and 1990-2009 for Bhatsa were used to study the effects of forest cover on water yield. Monthly runoff (surface runoff + basal flow)

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Table 27.1: Salient features of the studied watersheds

Features		Tansa	Pise	Sapgaon	Lower Vaitarna	Manda	Bhatsa	Upper Vaitarna	Tulsi
District		Thane	Thane	Thane	Thane	Thane	Thane	Nashik	Thane
Catchment Area (Sq km)		135.975	991.94	595.58	290	954.57	388.5	160.8	6.7
Av. Weighted Annual Rainfall (mm)		2687	2862	2871	2532	1985.5	2872	2540	2500
Land use (as percent of the catchment area)	Area legally defined as Forest	**65.12**	**31.27**	**32.53**	**45.33**	**20.41**	**36.1**	**21.72**	**85.51**
	Agriculture	12.66	49.25	47.39	34.55	49.26	45.16	45.86	
	Grassland	2.6	3.55	3.39	0.14	3.32	1.85	0	
	Wastelands	3.7	10.16	10.05	13.07	23.16	8.83	9.22	
	Built up	0.07	1.11	0.65	0.87	1.06	0.12	0.58	
	Water bodies	15.85	4.66	5.99	6.04	2.79	7.94	22.62	14.49
Forest subtype		Southern Tropical Moist Deciduous type							
Geomorphology		Mix of hills and plateau							Hills
Soil texture		Gravelly sandy clayey loam and Gravelly sandy loam							
Soil depth		Very shallow (< 10 cm) to Shallow (10-25 cm)							

Source: Digital thematic maps – MRSAC, Nagpur; Management plans of Forest Department, District Gazetteer.

to the reservoirs was estimated through the following water budget equation (following Fetter,1994, Güntner *et al.*, 2004):

$$(R + PD) - (O + ED) = \pm \Delta S \quad (28.1)$$

where,

R = Total runoff to the reservoir during the month,
PD = Direct precipitation over reservoir during the month,
O = Surface outflow of water from the reservoir during the month,
ED = Evaporation from the reservoir during the month, and
Δ S = Change in water stored in the reservoir during the month.

The runoff coefficient was taken as a measure of water yield as it removes the impact of precipitation on water yield and following regression was run on STATA SE independently for each watershed.

$$RO = \gamma R \quad (28.2)$$

where,

RO = monthly runoff;
R = monthly weighted rainfall, and
γ = regression coefficient (predicted runoff coefficient).

Comparisons were drawn between predicted runoff coefficients of Tansa and Upper Vaitarna where factors like watershed size, annual rainfall and slope (i.e., factors that tend to influence runoff coefficient) are similar, but land use pattern was markedly different (in Upper Vaitarna, agriculture and grasslands have occupied 60-70 per cent area over the years as compared to Tansa where forests covered nearly 75 per cent of area in initial years that has subsequently reduced to 43 per cent).0

To analyze the impact of forest cover on water yield over time an array of the runoff coefficient; forest cover as percentage of watershed area; catchment area; weighted rainfall and rainy days for each water year was constructed as panel[3] data. Following regressions were run on STATA SE

$$RC = \alpha + \beta_1 FC + \beta_2 CA + \beta_3 wR + \beta_4 Rd \quad (28.3)$$
$$RC = \alpha + \beta_5 OF + \beta_6 MF + \beta_2 CA + \beta_3 wR + \beta_4 Rd \quad (28.4)$$

where,

α = Constant,
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ = Regression coefficients for respective variables,
RC= Runoff coefficient,
FC = Total forest cover,
OF= Old forest cover,
MF = Mixed forest cover,
CA = Catchment area
wR = weighted rainfall as depth,
Rd = number of rainy days for a water year, and
FC = OF + MF.

27.3.2 Impact on water quality

Monthly water quality data of six stations over a horizon of 13 years (1998-2010) were evaluated through multilevel mixed-effects linear model (broadly following Figueiredo *et al.*, 2010) with following form. The maximum likelihood regressions were conducted with STATA SE.

$$\mathrm{Ln}(Q)_{itjk} = \gamma + \gamma_1 \mathrm{Ln}(FC)_{itjk} + \gamma_2 \mathrm{Ln}(R)_{itjk} + \gamma_3 Dre_j + \gamma_4 Drp_j + u_{t(i)} + u_{j(i),t(i)} + u_{k(i),j(i),t(i)} + e_{itjk} \quad (28.5)$$

$$\mathrm{Ln}(Q)_{itjk} = \gamma + \gamma_5 \mathrm{Ln}(OF)_{itjk} + \gamma_6 \mathrm{Ln}(MF)_{itjk} + \gamma_2 \mathrm{Ln}(R)_{itjk} + \gamma_3 Dre_j + \gamma_4 Drp_j + u_{t(i)} + u_{j(i),t(i)} + u_{k(i),j(i),t(i)} + e_{itjk} \quad (28.6)$$

[3] Dataset having both cross-sectional and time series dimension.

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where,

Q_{itjk} = Water quality parameter in month *i* for year *t* at station *j* in watershed *k*,

FC_{itjk} = Forest cover as percentage of watershed area in month *i* for year *t* at station *j* in watershed *k*,

R_{itjk} = Monthly average weighted rainfall (in mm),

Dre_j = Dummy for site which measures water quality at outflow of the reservoir,

Drp_j = Dummy for site which have presence of riparian forests,

$u_{t(i)}$, $u_{j(i),t(i)}$, $u_{k(i),j(i),t(i)}$ = Random effects of year *t* , site *j* and watershed *k*

e_{itjk} = Error term with distribution $N(0, \sigma^2)$,

γ = Constant, and

$\gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, \gamma_6$ = Regression coefficients of respective variables.

27.3.3 Deforestation induced costs on water supply

The study estimated the economic relationship between the forest cover and (a) 'treatment costs (C_t)', (b) 'water losses due to backwash[6] and desludging[7] (V_{BW})', and (c) decrease in 'water yield (V_{WY})') and the cost implications of deforestation on the drinking water supplies to Greater Mumbai. Turbidity was taken as measure of raw water quality because it is considered a reasonably accurate measure of overall water quality. The forest cover–treatment cost relationship was estimated in two stages through the forest cover–turbidity and the turbidity–treatment cost relationships. The forest cover–turbidity relationship was taken from Eq. 28.5 while the turbidity–treatment cost relationship was characterized through monthly time series data (January 1998-December 2010) of the Panjrapur treatment plant using the following Cobb Douglas cost function:

$$Ln\,(C_t) = \alpha' + \beta'_1 Ln\,(T) + \beta'_2 Ln\,(V_t) + \beta'_3 Ln\,(C_{t-1}) \qquad (28.7)$$

$$Ln\,(V_{BW}) = \alpha^* + \beta^*_1 Ln\,(T) + \beta^*_2 Ln\,(V_t) + \beta^*_3 Ln\,(V_{BW-1}) \qquad (28.8)$$

where,

C_t = Monthly operating costs (chemical, electrical, repairs and maintenance, establishment and transport costs) in Indian rupee per ML[8],

T = Monthly average turbidity of raw water (in NTU),

V_t = Volume of treated water during the month (in ML),

V_{BW} = Monthly volume of water lost due to backwash and desludging (in ML),

C_{t-1}, V_{BW-1} = Lagged dependent variables,

α', α^* = Constants,

$\beta'_1, \beta'_2, \beta'_3, \beta^*_1, \beta^*_2, \beta^*_3$ = Regression coefficients of the respective variables, and

Total water drawn for treatment = treated water (V_t) + water losses due to backwash & desludging (V_{BW}) + other miscellaneous water losses (like losses during transportation

[6] Backwash refers to the process of restoring functionality of clogged filter beds through air and water under pressure. Its frequency depends on incoming water quality.

[7] Desludging refers to the process of sludge removal from the settling tanks. The frequency desludging depends on incoming water quality.

[8] ML – Million Litre

The forest cover–water losses due to backwash and desludging relationship was similarly worked out in two stages from Eqs. 27.5 and 27.8. The forest cover–water yield relationship was taken from Eq. 27.3. The marginal effects of the forest cover on the treatment cost and water losses due to backwash and turbidity were obtained by multiplying the regression coefficient of FC in Eq. 28.5 with the regression coefficients of T in Eqs. 27.7 and 28.8, respectively (in line with Holmes,1988). Marginal effects were expressed in per ha terms through following calculations:

$$V_{BW-h} = (\gamma_1 \times \beta_1^*) \times / \qquad (27.9)$$

$$C_{t\_h} = (\gamma_1 \times \beta_1') \times C_t^* / \qquad (27.10)$$

where,

V_{BW-h}, C_{t_h} = Effects on V_{BW}, C_t induced by a ha change in the forest cover,

= Mean values of V_{BW} for the study period

= Mean forest cover,

C_t^* = C_t at 2010-11 prices, and

γ_1, β_1', β_1^*, = Regression coefficients from Eqs. (27.5), (27.8) and (27.9), respectively

Economic value estimate of V_{BW-h} (C_{BW_h}) was obtained as V_{BW-h} x P, where P is the market price of raw water. The price of water derived from unit volume expense of building reservoirs (Singh and Mishra, under review) was considered a better estimate than the subsidized price of INR1,188 per million litre being paid by the Municipal Corporation. Hence, C_{BW_h} was estimated taking the price of water to be INR 1,363.07 per million litre (following the replacement cost approach).

Effects on water yield induced by a ha change in the forest cover was estimated from Eq. 27.3 at mean values of runoff coefficient ($\overline{RC}$), forest cover ($\overline{FC}$) and weighted annual rainfall in million litre () as:

$$V_{WY\_h} = [(\overline{RC} - 0.0013) \times (\overline{RC} \times \overline{R})] / \overline{FC} \qquad (27.11)$$

From Eq. 27.11, it emerged that every 1 per cent decrease in the forest cover would reduce the water yield (V_{WY_h}) by 1.72 million cubic metre per year for the Bhatsa watershed. Assuming 80 per cent of V_{WY_h} is available for drinking water supply, the economic value estimate of change in water yield (C_{WY_h}) was worked out in same manner as C_{BW_h}.

The total economic value of the impacts induced by loss of one ha of the forest cover (C_p) is taken as the follows

$$C_p = C_{t\_h} + C_{BW\_h} + C_{WY\_h} \qquad (27.12)$$

Cost towards upgradation of infrastructure in the near future was not considered as the water treatment process used is conventional filtration which is stable over a wide range of water quality.

27.4 RESULTS AND DISCUSSIONS

It is generally observed that the watersheds with good forest/vegetal cover give lower water yield as compared to the watersheds with lesser vegetation and similar soils (Subramanya, 2008). Similarly, in comparison to grasses, crops and other shorter rotation vegetation, lower water yield is recorded from forests on account of higher interception and transpiration losses (Calder *et al.*, 2004; Hamiltion, 1985, Vinnikov and Robock, 1996). In

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Table 27.2: Regression analysis for water yield

Watershed	Forest cover		Av. Forest cover (% CA)			Current annual rate of change in forest cover (%)			Slope (Wt. ccount)	Av. Rainfall (mm)	Y (Eq. 2)	Regression Analysis (Eqs.3 & 4)
	OF	MF	FC	OF	MF	FC	OF	MF				
Tulsi	Primary Forest	Primary forest with less tree cover	84.48	68.5	15.9	0	0	0	15.88°	2790	0.63 (N = 385)	RC = 0.43 + 0.001 FC** + 0.00004 wR**+ 0.0006Rd** - 0.0001CA Prob > chi2 = 0.000 R^2 within = 0.116 between = 0.89 overall = 0.24 (N = 112)
Tansa	Primary & mature secondary forest	Primary forest with less tree cover & disturbed forest	56	29	27.3	-0.008	-0.017	0.0018	7.86°	2400	0.58 (N = 367)	
Upper Vaitarna	Primary & mature secondary forest, mature plantations	Disturbed forest reforested with exotics & indigenous species in patches	15.89	4.9	10.7	-0.001	-0.021	0.0085	10.43°	2540	0.59 (N = 396)	RC = 0.43+ 0.002 (OF)***- 0.0013 MF + 0.00004wR**+ 0.0005Rd*** + 0.00006CA Prob > chi2 = 0.00 R^2 within = 0.122 between = 0.99 overall = 0.26 (N = 112)
Bhatsa	Primary & mature secondary forest	Disturbed forest with very limited reforestation activities	34.4	14.2	20.3	-0.004	-0.028	0.013	9.81°	3404	0.71 (N = 240)	

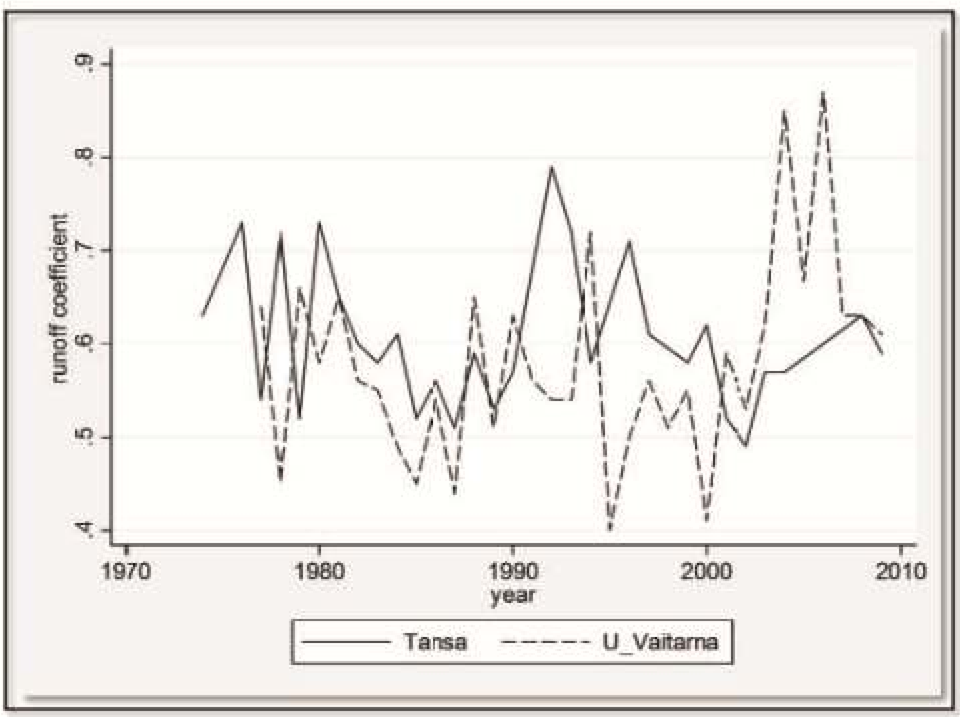

Figure 27.2: Yearly Runoff Coefficient for the watersheds Tansa and Upper Vaitarna

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Table 27.3a: Regression coefficients and estimates of variance for random parameter for total forest cover (Eq. 27.5)

	Total Forest Cover	Rain	D_reservoir	D_riparian	intercept	Var_j	Var_k	Var_t	N
Turbidity	-8.41***	0.23***	-0.82**	-0.72***	30.36***	8.57×10^{-21}	1.8	0.29	378
pH	0.056*	-0.001	0.019*	-0.006	1.82***	9.19×10^{-25}	8.94×10^{-22}	0.0003	381
TDS	0.27	0.02**	-0.12	0.04	3.53	7.28×10^{-19}	0.48	0.006	346
TSS	-4.17**	0.15***	-0.57**	-0.16	15.77***	7.21×10^{-15}	0.51	0.07	346
Total Hardness	0.29	0.03***	-0.16**	0.07	3.00	3.07×10^{-24}	0.46	1.71×10^{-24}	376
Ca Hardness	0.49***	0.02***	-0.17***	0.08**	1,46***	1.21×10^{-18}	4.37×10^{-17}	3.26×10^{-18}	360
Ca	0.35	0.01*	=0.19***	0.12**	1.34	4.26×10^{-23}	0.24	1.65×10^{-24}	360
Total Coliforms	-1.72	0.19***	-1.3**	-0.25	11.23	4.26×10^{-23}	4.26×10^{-23}	4.26×10^{-23}	293
E.coli	-3.91***	0.19***	-0.9**	-0.39	17.42	6.19×10^{-16}	2.65×10^{-13}	0.41	293
Total Chloride	Non-significant								
Mg	Non-significant								
Fe	Non-significant								

Vartvarj , vark = Variation of random effect parameters,

*** = p <= 0.001,

** = 0.01 <p <=0.05,

* =0.05 <p <0.10

Table 27.3b: Regression coefficients of segregated forest cover (Eq. 6)

	Old forest (OF)	Open & disturbed forest (MF)
Turbidity	- 6.63 ***	- 2.96**
pH	+ 0.05	+ 0.02
TDS	- 2.21*	+ 0.87*
TSS	- 3.42**	- 1.25
Total Hardness	- 1.57**	+ 0.48*
Calcium hardness	-0.49	+0.43***
Ca	-1.5**	+0.44*
Total Coliforms	- 5.39*	+0.64
E. coli	- 6.6**	-0.35

this study, however, the watersheds having fairly high percentage of forest cover viz. Tulsi and Tansa (on average 84 per cent and 56 per cent, respectively), had fairly high predicted runoff coefficient, i.e., 0.63 and 0.58, respectively (Eq. 27.2, Table 27.2). Further, despite having a much larger area under forest cover and more permeable soil, predicted runoff coefficient for Tansa was practically the same as that of Upper Vaitarna (Table 27.2).

At the beginning of the study period (i.e., during the 1970s) when the forest cover in the Tansa was as high as 75 per cent while grasslands and agriculture occupied practically 60 per cent of the catchment area of Upper Vaitarna (forest cover – 29 per cent), a higher runoff coefficient for Tansa was observed (Figure 27.2). Regression between the runoff coefficient, total forest cover and other variables (Eq. 27.3) confirmed significant ($0.01 < p < 0.05$) and positive relationship between total forest cover and runoff coefficient, i.e., unit loss of the forest cover was observed to reduce runoff coefficient by 0.001 and, thus, reduce the water yield (Table 27.2). When total forest cover was segregated into old forestsand mixed forests (Eq. 27.4), then old forests were observed to positively and highly significantly($p < 0.01$) influence runoff coefficient which is largely in line with the findings of Kagawa *et al.* (2009), Kuczera (1987), Langford (1976), and Wang *et al.* (2011) for Northeast China. In contrast mixed forests exhibited a negative trend that was not statistically significant.

Every 1 per cent decrease in forest cover was similarly observed to increase turbidity, total suspended solids and E. Coli by 8.41 per cent, 4.71 per cent and 3.91 per cent, respectively, as also decrease calcium hardness by 0.49 per cent (Table 27.3a). But on segregation, the old forests were observed to improve water quality significantly while the mixed forests exhibited significant positive correlation with many water quality parameters like total dissolved solids, total hardness, calcium hardness and calcium (Table 27.3b).

It was also apparent from the forest cover maps that the reduction in old forests has occurred by its conversions to mixed forests and to a lesser extent by its conversions to such non-forest landscapes as agriculture or grasslands/bare land (due to heavy erosion following tree removal). Such conversions have occurred because of "provisioning" ecosystem services like timber, livestock grazing, fuel wood, fodder, leaf-manure extended by the forests to the local communities and sustaining livelihoods. Thus, tradeoffs between the provisioning services and water quality services of forests were apparent.

The aforesaid results could be explained by the fact that the old forests because the dense root mat and organic matter in the topmost soil layers encourages high infiltration and soil retention. The infiltered water moves through layers of soil before it is available as sub-surface flow or ground water. In the process water is filtered naturally. Annual erosion rates from closed tropical forests too are small in comparison with disturbed landscapes (Chappell *et al.*, 2005; Douglas and Guyot, 2005). Hence, old and dense forests help keep streams clean and water quality high by promoting soils that provide natural filtration and vegetative cover that minimizes soil erosion and sediment runoff. Further, the undisturbed plant nutrient cycle in the old forests ensures rapid recycling and thus fixation of cations like calcium in the nutrient cycle (Brinkmann and Santos, 1973). In mixed forests, this cycle is likely to be disturbed resulting in leaching of nutrients to the streams.

The difference in response between the forest covers on water yield is largely attributed to the different evaporative characteristics of old/mature tropical forest and regrowth forest/young secondary or planted vegetation, and to a much lesser extent increases in storm runoff (Bruijnzeel, 2004). Young/regenerating forests consume more water on account of higher interception losses in wet conditions (because of increased atmospheric transport of water vapour from their aerodynamically rough surfaces), and greater transpiration losses in dry (drought) conditions (because of the generally increased rooting depth of trees, and consequently greater access to soil water), respectively (Calder *et al.* 2007). In contrast, old forests use three times lesser water on account of their structural and functional complexities (Bond *et al.* 2008). Increase in height of trees results in a longer hydraulic path length which has an inverse relationship with stomatal conductance and, therefore, transpiration. Similarly, lower sapwood basal area, complex branching pattern and other such age-related changes in the hydraulic architecture of older trees often decrease transpiration. Older forests are dense as well as structurally more complex both vertically and horizontally. The understory experiences a relatively sheltered environment with lower radiation and higher relative humidity which reduces its transpiration. Further, the bryophytes and lichens found in abundance in older forests in most humid regions, the organic layers and the large woody debris serve as water reserves for roots and mycorrhizal hyphae of shade tolerant trees.

Deforestation induced costs at the Panjrapur treatment plant of the Mumbai Municipal Corporation were estimated (Table 27.4) to be INR 64.96 per m^3 treated water/ha/year (USD 1.32 per m^3 treated water/ha/year) which translated to INR 3.73 million per year (USD 0.075 million per year) in 2010-11 prices. Nearly 99 per cent of the increase in the deforestation induced costs was on account of increases in the treatment costs. Assuming the annual rate of change in forest cover to be -0.0088 per cent (average annual rate of change in forest cover between the years 1994-2007), the deforestation induced costs translated to INR 3.73 million per year (USD 0.075 million per year) in 2010-11 prices for the Panjrapur treatment plant.

Thus, if deforestation is avoided the Municipal Corporation can save significant amount towards recurring costs of water treatment and to some extent mitigate the costs for a new source development. However, the Municipal Corporation practically does not make any investment towards source protection and nor is it involved in the decisions of forest management. On the other hand, the Forest Department is guided by its own priorities and the sources of grants which generally promote plantations of fast growing species. Such plantations along with regular hacking and lopping of trees and shrubs by the local communities for their sustenance and energy needs are likely to lead to a landscape

Table 27.4: Impact of the Forest Cover on the Panjrapur Treatment Plant (in 2010-11 prices)

	Costs induced by loss of one Ha of FC	Price (at 2010-11 prices) in Indian rupee ($)	Increased annual costs per m^3 treated water in Indian rupee ($)*	Taking treated water as 1310 million litre per day increased annual cost in Indian rupee ($)
1	Chemical cost (C_{ch_h})	204.12 (41.44) per million litre treated water	12.38 (0.25)	5920.18 (120.18)
2	Treatment cost (C_{t_h})	1142.12 (231.86) per million litre treated water	64.16 (1.30)	30679.58 (622.79)
3	Value-water losses due to backwash & desludging (C_{BW_h})	1363.07 (276.70) per million litre raw water	0.51 (0.010)	241.17 (4.89)
4	Value- losses in water yield (C_{wl_h})	1363.07 (276.70) per million litre raw water	0.29 (0.006)	138.77 (2.817)
	Total deforestation induced costs $C_t = C_{t\_h} + C_{BW\_h} + C_{wl\_h}$		**64.96 (1.32)**	**31059.53 (630.51)**

* 1 Indian rupee = $ 0.0203

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that competes for water resources (Calder *et al.*, 2007; Farley *et al.*, 2005; Fritzsche *et al.*, 2006). In addition, many activities for plantations – trenches, pits, trench-cum-mound fencing around the plantation area for protection from cattle – disturb the soil cover and accelerate sedimentation resulting in less than optimal water treatment and water storage services, and thus, adversely impact the finances of the Municipal Corporation. So inclusion of forests in the decision-making process (like cost benefit or cost effective analysis) of water treatment and water source development would help the Municipal Corporation to make appropriate choices between source protection, and infrastructure development and treatment processes. It can also ensure integration of water concerns with forest management and vice versa.

27.5 CONCLUSIONS

The study supports age-old perceptions about forests with respect to their responses to water yield (in the sense that the forests during the times of our ancestors were climax/old forests and hence their perceptions were with respect to such forests and not the new kinds that have come up because of biotic interferences). It also brings out contrasting responses of old forests vis-à-vis mixed forests on local hydrological processes and a trade-offs between the provisioning services and hydrologic functions and services of old forests. Further, in a mixed scenario, catchment hydrology appears to be the net result of the individual influences of different forest cover. Hence, there is a need to maintain distinctions like reforestation and afforestation; different vegetation types/age; climax and non-climax communities in hydrological researches.

The study also establishes the need for municipalities to include the forests in their decision-making, planning and operations. The tradeoffs between the provisioning services and the hydrological services of the forests also indicate the need to conserve the old/mature forests in the critical watersheds. Disturbed forests as well as plantations in the upstream should similarly be conserved so that with age, they are able to extend better hydrological services. Research studies that explore the impact of spatial distribution of forests and model the optimal undisturbed vis-a-vis disturbed forest cover within a catchment for extending the hydrological and the provisioning services, respectively, may also be in order.

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28

Climate Change Impacts on Water Resources and Livelihoods: A Case Study of Takoli Watershed, Garhwal Himalaya, Uttarakhand

R.S. Negi and M.K. Parmar

28.1 INTRODUCTION

While the unprecedented rate of global warming in recent times is conclusively established, scientific capacity to predict future climate scenarios is limited, with projected warming rates reported in the range of 1°C to 5.8°C on a global scale and 0.4°C to 2°C in India largely because of an upward trend in maximum temperature (Hingane, 1985). Some scientists considered likely warming by 2°C in temperature together with a 7 per cent increase in precipitation as the 'best guess' (IPCC, 2001). Climate change projections may vary depending on analytical tools used for making predictions. A trend of warming in the 20th century in the Himalaya unravelled by mathematical modeling and trend analysis of long-term climate data is not supported by the tree ring width data. Nesting of high resolution local/regional models within the low resolution global models can improve precision of predictions. While monsoon rainfall has been considered trendless over a long period of time by many workers, concluded a decline in rainfall by 6-8 per cent per hundred years over the north-eastern but an increase by 10-12 per cent per 100 over the western part of the country. Prediction of sporadic extreme climate events is much more difficult compared to changes in climate on annual or seasonal scale. An uncertainty in the projected rates of climate change implies an uncertainty of the predictions about its consequences or the outcomes of the mitigation or adaptation measures identified based on an imperfect knowledge. Enhancement of scientific knowledge must be an integral component of all climates.

28.2 STUDY AREA

Geographically, the Takoli Gad watershed lies between 300°14' to 300°23'N latitude and 780°37' to 780°46'E longitudes in the Survey of India toposheet nos. 53J/11, 53J/12 and 53J/15 (Figure 28.1). The watershed has an area of about 131.43 sq. km and comes under jurisdiction of district Tehri Garhwal,

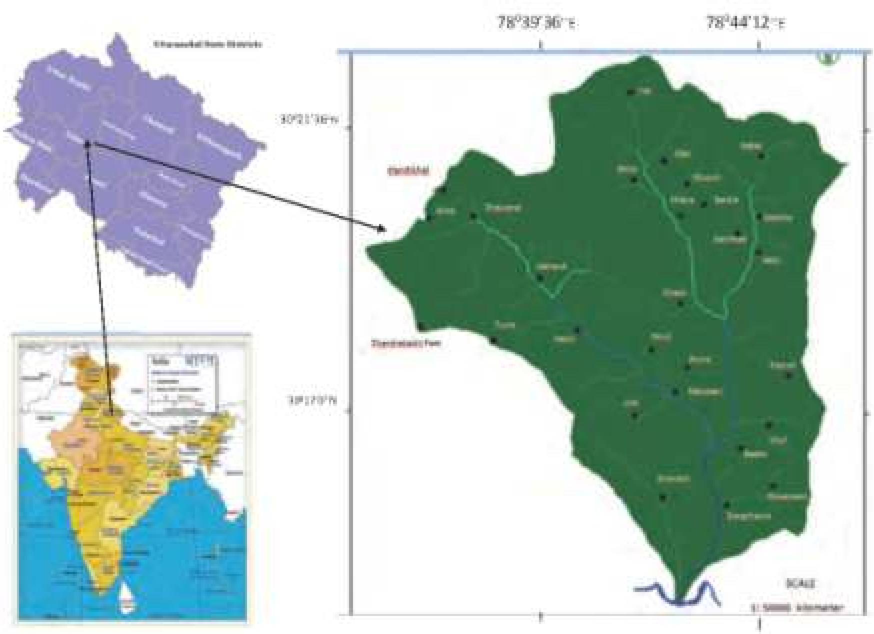

Figure 28.1: Location Map of the Sturdy Area

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Uttarakhand. The area is approached by Kirtinagar-Tehri and Kirtinagar-Chauki all-weather roads. The area falls in the inner Garhwal lesser Himalaya and is characterized by gentle and mature topography. The Takoli Gad originates from the Eastern slope of the Chandrabadni Peak (2,278 metres) and joins the Alaknanda at Juyal Garh (605 metres). Jakhand and Dagar Gad are the two main sub-streams/tributaries of the Takoli Gad.

28.3 MATERIAL AND METHODOLOGY

- We have categorised the whole Takoli Gad watershed into three parts on the basis of altitudinal zone between 500 to 1,000 metres (lowest zone), 1,000 to 1,500 metres (middle zone) and 1,500 to 2,000 metres (higher zone). All three vertical zones governing watershed hydrology include resource utilization, livelihoods, and food security pattern. Then we selected one sample village from each altitudinal zone for case study. Thus, we have three sample villages for case study in Takoli Gad watershed.
- Data was collected through field survey, through primary and secondary data sources, Secondary data collected from district/block administration, reports, journals, research articles/papers, etc.
- Field survey was undertaken in the three sample villages, namely Takoli (lower elevation zone), Dhaulangi (middle elevation zone) and Machchiyari (higher elevation zone).
- Semi-structured questionnaire survey was conducted in the villages and some key respondents interviewed for collection of information on the indigenous system of livelihoods and resource utilization pattern.
- Information was also gathered on the effects of changing climate on livelihood and food security of local inhabitants in the watershed. The indigenous uses of water resources, agriculture and plant species were also recorded.
- Group discussion was also conducted with farmers for understanding the problems and prospects with the water resources, agriculture system in the area along with the perception of local people on climate change and indigenous agro forestry system. The information was also acquired through field inspections, field observations, participation in the social life of local people/ farmers and their cultural events.
- Agriculture land, water bodies (natural springs and streams) and forests was also surveyed to document the impact of climate change on different crops and their compositions.
- After collection of primary and secondary data, we analyzed the data using various statistical techniques and maps of the area prepared using various cartographic techniques LISS IV data used on ERDAS 9.3, ARC GIS 9.3 software.

28.4 RESULT AND DISCUSSIONS

28.4.1 People's perceptions on climate change

By 'good climate year', local people mean sporadic low rainfall events during March-May, peak monsoon rainfall during July-August, moderate rainfall/heavy snowfall during December-January and absence of cloud burst events, with highest degree of uncertainty attached to the onset of monsoon and time of abnormally high rainfall events. Thus, farmers attach more importance to precipitation than temperature. One of the major

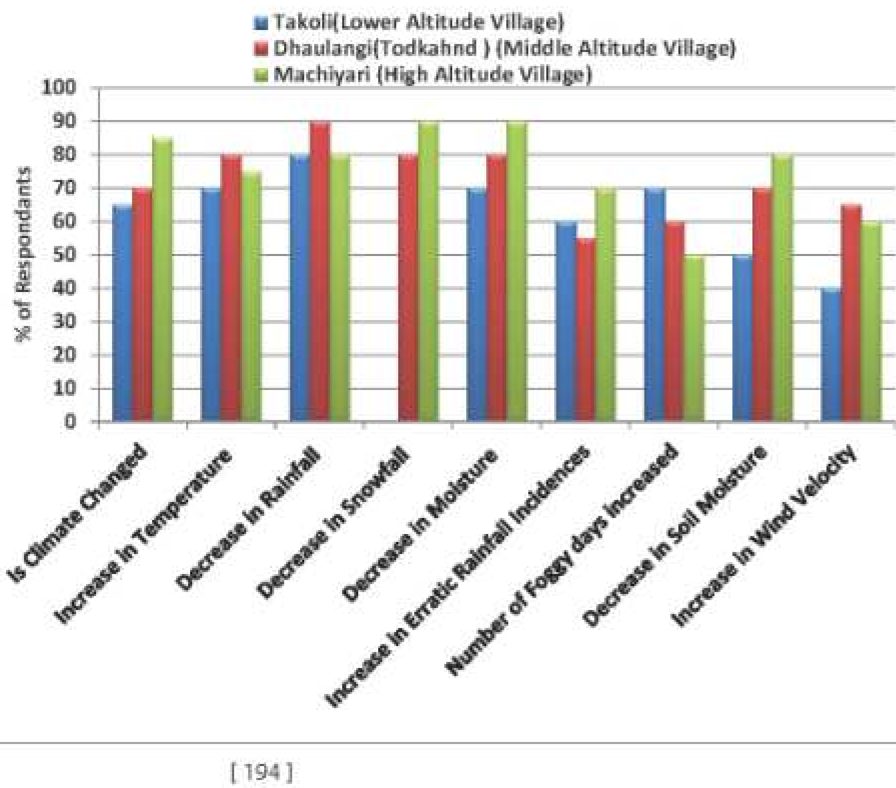

Figure 28.2: Climatic Parameters to Assess Climate Change (2000-2010) (People Perceptions)

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Table 28.1: Climate Change impacts on different resources and livelihood

Sr. No.	Statements	Responses (in %)		
		Takoli	Dhaulangi	Machiyari
1	Due to climate change food grain production has decreased.	75	70	64
2.	Climate change has increased the risk of crop failure.	70	60	62
3.	Water bodies have dried up due to change in climate.	58	62	76
4.	Due to climate change, level of ground water has decreased.	65	75	61
5.	Climate change has caused scarcity of fodder in the area.	54	48	42
6.	Climate change has increased the rate of outmigration	52	37	45
7.	Due to climate change, attack of insect-pest and diseases has increased, thus resulting in reducing crop yield.	49	67	52
8.	Change in climate has increased the frequency of rainfall.	75	57	80
9.	Because of climate change, the incidences of untimely rainfall have increased.	72	62	79
10	Change in climate has decreased soil moisture level.	57	63	67
11	Soil erosion has increased due to climate change.	55	47	65

impacts cited (85 per cent of respondents) was that the average annual rainfall had declined in the past decade. According to the majority of respondents, the total number of days of rainfall had perhaps come down, leading to an overall decrease in the total rainfall. Also, 75 per cent of people surveyed also talked about changing rainfall patterns. The failure of the winter rains had led to a drastic decline in winter crops.

Farmers from Dhaulangi village said that last winter, their entire winter crop was ruined due to lack of adequate rainfall. "Last winter, due to lack of rainfall, the winter crops were so poor that we were not even able to recover the cost of the seed," said Chandra Dev Singh Rana, a farmer from Dhaulangi (Todkhand) village in Takoli watershed. Farmers mentioned that spells of unusually heavy rainfall during the rainy season were more frequently experienced than previously. This was considered detrimental to soil health and farmers complained of heavy soil erosion during this period. Communities said that heavy soil erosion had led to a considerable decline in crop productivity during subsequent cropping seasons. About 53 per cent of respondents said that the availability of water in the streams had declined significantly during summer and that very little water was available for irrigation through *guhls*.

It was also perceived by the communities that the overall frequency and quantity of snowfall had declined considerably. The village residents also reported an increase in temperatures resulting in hotter summers and warmer winters, with 76 per cent respondents saying that the temperature had increased over the last 8-10 years (Table 28.1). It has been observed by the people that they are experiencing extreme climatic events like, in 2009, the village experienced snowfall in the month of February, without any dip in temperature and no rain, which is very unusual. Such snowfall has been witnessed after some 9 or 10 years, which earlier used to be a regular annual feature. There has been less or negligible winter rains in the village for the last 4 or 5 years and the rain cycle has also shifted by 2 to 3 months. This basically means that it has resulted in low/loss of production of the winter crops and erratic rainfall during the monsoon period. These persistent changes in weather have resulted in the overall decrease of water quantity across all water sources.

28.4.2 Land-use and land cover change (LULCC)

Land-use and land cover change (LULCC) affects climate through alteration of near surface energy and moisture exchange, as the physical characteristics of the land surface such as albedo, soil moisture, and roughness are changed (the biogeophysical pathway). LULCC also affects climate through changes in atmospheric concentrations of greenhouse gases (GHGs) such as CO_2, CH_4, and N_2O resulting from alteration the land-atmosphere fluxes (the biogeochemical pathway, Arora and Boer 2010; Canadell *et al.*, 2007; Houghton 2003; House *et al.*, 2002; Pongratz *et al.*, 2009; Shevliakova *et al.*, 2009). LULCC has been shown to result in seasonal changes in temperature, precipitation patterns, snow cover in high latitude regions, and atmospheric dynamics (e.g., Bala *et al.*, 2006; Chase *et al.*, 2000; Claussen *et al.*, 2004; Feddema *et al.*, 2005).The land-use study of the investigated area shows four main land-use patterns, i.e forest land (68.31 sq.km), not available for cultivation (3.88 sq.km), other uncultivated land (35.40 sq.km) and cultivated area (23.83 sq.km). In 2010, the forest area of Takoli Gad was 51.97 per cent of the total geographical area of the watershed. The mixed forest in the region has a variety of trees depending on the different physiographic features like climate, soil, physiography and slope. The land-use area of year 2010 in Takoli Gad watershed differs from the land-use area of year 2000. The forest area is 0.03 sq.km less as against the year 2000. The land area not available for cultivation is 0.023 sq.km more in Takoli Gad watershed as against the year 2000. The area under other cultivation is 0.045 sq.km more while cultivated land is 0.03 sq.km less as compared to the year 2000.

The change in land-use statistics between 2000 and 2010 reveals that the forest area in the Takoli Gad watershed has been reduced by 0.03 per cent and wasteland increased by 0.04

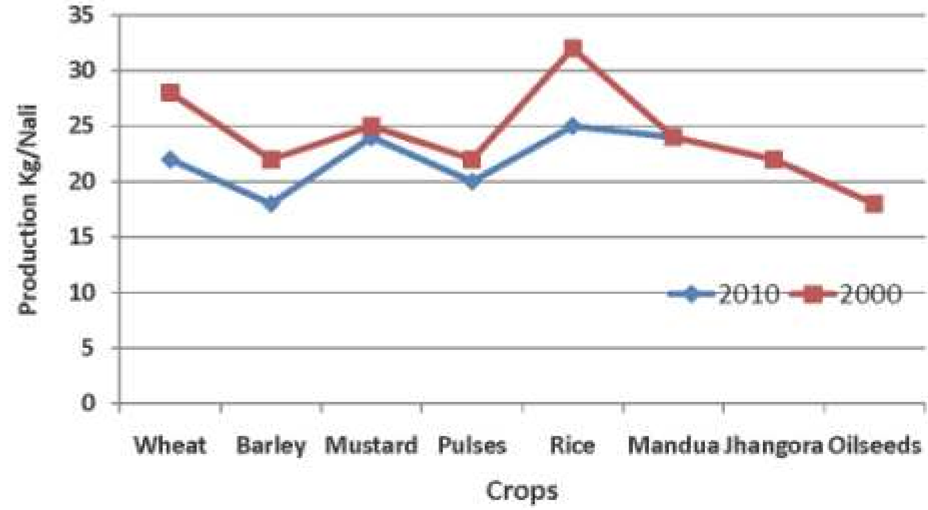

Figure 28.2: Changes in Crop Productivity between 2000-2010

per cent. This has certain implication on the hydrology of Takoli Gad watershed.

28.4.3 Impacts on Agriculture

The respondents were also asked to quantify the estimated annual decline in productivity of agriculture in the past two to five years. This led to some interesting observations with about 70 per cent of the farmers surveyed mentioning that agricultural productivity had declined by about 10 to 25 per cent, with only 20 per cent noting very little change (Figure 28.2). The major crops being produced are wheat, paddy, manduwa, barley, jhangura, different pulses like gahat, urad, soyabean, and matar. In addition, they also produce cash crops like different vegetables– capsicum, cabbage, tomato, potato, onion, brinjal, beans and carrot. Agriculture has seen a tremendous decrease in production over the last 10-15 years.

Agriculture in the Takoli watershed is mostly rainfed, and only small proportions of agricultural land are irrigated through traditional water channels (guhls), which are used to channel the water from nearby streams and rivulets to the fields. The fields irrigated through guhls have the best productivity in the village. However, about 65 per cent of respondents said that the availability of water in the streams had declined significantly during summer and that very little water was available for irrigation through guhls. Takoli village, which is located on both sides of a local stream called the 'Takoli gad', the people said that, for the past several years, the runoff in the stream had declined drastically, adversely affecting irrigation. A few farmers (20 per cent) also said that, in recent times, their crops had been subjected to more frequent pest attacks. "Generally we do not experience a lot of pest attacks, but the past few years have been different," said a farmer from Takoli village. Another concern of the village community in general was that warm and dry summers, as experienced in the past few years, were causing a major decline in the productivity of vegetables.

Generally, hill farmers cultivate a number of vegetables during the months from May to July, but late monsoons, high

Photo 1: Water Scarcity Affected cash crops

Photo 2: Canal (Guhl) network is useless due to absence of water availability

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temperatures, and an overall decline in irrigation(through guhls) were having an adverse impact on productivity levels. In less than a decade, some of the crops cultivated previously have become locally extinct from the villages of Takoli watershed. Koni (*Setaria italica*) was such a crop, which is no more cultivated now but 10 years ago each family had produced about 10 kg *koni* per year. The dishes prepared from *koni* had a high nutritive value. Jundla (*Sorghum vulgare*) was also cultivated by the villagers in the past, about two decades ago, but now its cultivation has also stopped. There are problems of new diseases destroying large chunks of crops every year, like wheat plant turning black, small red ant-like insects destroying cash crops like potatoes, tomatoes, etc. An insect, locally known as *Kurmula*, is damaging paddy, potatoes and chillies. Pulses are also affected and their leaves have numerous holes in them.

There has been a widespread growth of wild weeds in agricultural land; weeds like tipatia and gajar ghas. These weeds are responsible for decreasing the productivity of crops, as they take up all the available soil nutrients. The presence of the weeds in the fields also means that it requires additional time, and effort, from the women to clean them from the fields. Villagers are also facing a continuous failure of winter crops for the last two years. This is happening due to absolute lack of rains during critical winter period. This is a recent phenomenon seen in the village forcing people to look for other options for their survival. There has been a positive change observed by villagers in terms of ripening period of crops. The total number of months required for the cultivation of the crops, especially wheat, has reduced by 15 to 20 days. This is happening due to the rise in temperature, which has resulted in suitable climatic conditions for the crops to ripen. Damage caused by large animal pests viz., wild boar, bear, porcupine and monkey is one of major problems in the villages of Takoli watershed. It is believed that population of these animals has increased in the recent past as result of food scarcity and drinking water (in forest area), and so these wild animals have changed their traditional habitats and now are damaging crops and livestock. People expect compensation for damage caused by them from the government. Loss of crop yields could be as high as 50 per cent of total economic yield in some high altitudinal villages of watershed (Figures 28.3a and b).

28.4.4 Impacts on Water Resource

Water scarcity was a common problem of all the villages in the study area. The water quantity has either decreased several times or the water sources have completely dried up in the area over the years. It was hard to get even drinking water. Due to scarcity of water, people were forced to drink dirty polluted water stored for several days, which was very unhygienic. During summer, the villagers were mainly dependent on the water supplied by tankers. But it was difficult to supply even drinking water to villagers living away from the roadside.

Dhara (Spring) and Gadera (Rivulet) are the main traditional sources of water for drinking and irrigation purposes. There are 20, [(2^{nd}, 3^{rd} and 4^{th} order streams) (Gaderas)] in Takoli watershed. There were four main perennial streams which have changed into seasonal streams in the last 10 years (2000-2010). During the survey in the villages of Takoli watershed, 65 per cent respondents observed that the water discharge in local streams (Gaderas) is continuously decreasing. Also 70 per cent respondents observed that the level of groundwater has decreased and local springs are now drying up (Table 28.2). Thus, in the whole watershed area there is considerable decrease in the water levels across all the water sources. About 10-15 years back, there were Gharat (water mill) in the village, but now it has stopped working due to depletion in the quantity of water. Most of the water mills of the area have stopped working due to less water in the streams.

Table 28.2: Status of Springs in Takoli Watershed

Name	Altitude (a.m.s.l) (Mt.)	Status in 2000	Existing Status (2010)
Dhaulangi	1234	Perennial	Dry
Jakhand	1077	Perennial	Seasonal
Banjela	1201	Seasonal	Dry
Kaphald	1122	Perennial	Seasonal
Malupani	914	Perennial	Perennial
Lusi	818	Perennial	Seasonal
Amroli	1088	Perennial	Seasonal
Semisemla	1180	Perennial	Seasonal
Neuli	1239	Perennial	Seasonal
Tiuna	1613	Seasonal	Dry
Silod	1710	Perennial	Dry

28.4.5: Impacts of Climate Change: A case of Dhaulangi (Todkhand) Village

Table 28.3: General Profile of Dhaulangi village (Todkhand)

No.	Description	
1	Height	1200 mt. (amsl)
2	Climate	Subtropical
3	Main Horticulture crops	Orange, mango, guava, banana
4	Main crops	Paddy, wheat, Barley pulses, Jhangora, Manduva, Oilseed
5	Main species of fuel from forest	Miscellaneous
6	Distance from road	3 Km
7	Main source of water	Springs, hand pump, pipe line
8	Distance from market	
	Local market (Dugadda)	12 Km
	Main market (Srinagar)	38 Km
9	Area Under Agriculture	15 Acre
10	Electrification	Yes
11	Post office	No
12	Primary health centre	No
13	Primary school	Yes
14	Area of the village	50 Acre
15	No. of total families	21
16	Total population	130 (women 75 & men 65)
17	Literacy	47%

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28.4.6 Impacts on Animal Husbandry

There is fodder scarcity in the village and the people feel that buffaloes need more fodder and require stalled feeding. Cows can be sent off for open and free grazing and require less fodder compared to buffaloes. So, people are replacing their buffaloes with cows.There is another perception that buffaloes give more milk than cows, i.e. 5 kg/ day on average whereas local cows give only 2 kg/day on average. This affected their income because some families (12) getting cash income (Rs 2,000/HH/Month on average) from the sale of milk and milk products (butter, ghee, etc.) in Dhaulangi (Todkhand) village. Now they have a little amount of milk and they use it only to fulfill their domestic need. It affects their cash income as well as their livelihood.

28.4.7 Impacts on Horticultural Crops

There are some mango trees in Dhaulangi (Todkhand) village. These trees were giving fruit regularly till 2004-05. According to Kamla Devi, a resident of Dhaulangi village, "we have 25 mango trees in the village which have been giving fruit in every period regularly since 15-20 years. But for the last five years there is no fruit in these mango trees".

These mango trees were the source of cash income for some families, as they sold the fruit in the local market (Duggada, Kirtinagar and Srinagar) and got a good amount of cash (Rs 1,000/HH/period) from it.

Papaya is another important fruit which provide cash income to the villagers of Dhaulangi (Todkhand), but rise in temperature affected the quality of papaya and it also affected adversely the final price of papaya as well as its marketing. Since the last 8-10 years, wild animals and diseases have been damaging cash crops as potato, ginger and turmeric. Hence, farmers are getting a comparatively low income from such crops.

28.4.8 Coping Mechanism

People of Takoli watershed are the victim of climate change but now they have adapted some coping mechanism to face climate change problem: Traditionally farmers were cultivating five different varieties of paddy, namely *Bauniya, Bankuli, Rasia, Khwida, Lal Satti and Pasaru*, in irrigated and non-irrigated land. *Bauniya* which was extensively cultivated in irrigated land is being gradually replaced by *Bankuli* which requires less water. This crop has been introduced in both irrigated and non-irrigated land. Similarly, they have started sowing Red wheat (requires less water) instead of White wheat (requires more water), in non-irrigated land. *Tor*, a pulse variety, has been introduced in those areas where moisture in the soil is comparatively less. *Tor*, known as a drought resistance crop requires less water to grow. There has been a subsequent increase in the area under cash crops, like tomato, onion, potato, etc., because of less productivity of traditional crops like wheat, paddy, and mandua. Cash crops require less area and generate more output than traditional crops in relatively less time. People are replacing their buffaloes with cows, as buffaloes need more fodder and require stalled feeding. Cows can be sent off for open and free grazing and they require less fodder compared to buffaloes. Poor people have largely resorted to milk selling, as they largely own less cultivated land with limited irrigation facilities. Traditional cropping pattern which known as Baranaja system is the prevailing practice in the area. There is a realization of the negative consequences of high yielding varieties, viz., dependency on external agencies for seeds, fertilizers, irrigation and pesticides, drastic yield losses under unfavourable climatic conditions and low input management and lower fodder production compared to traditional varieties, hence traditional agriculture system is better to face climate change problems.

28.5 RECOMMENDATIONS

Water, soil and forest are the basic requirements of the community residing in mountain regions. The availability of these resources determines the sustainability of livelihood. Here, the requirement is to protect the catchment of water sources by planting more trees, especially those species having broad cuticle leaves like Oak, Rhododendron, Kafal, Utis, etc. Villagers have identified degraded land in the Van Panchayat and civil forests where plantation activities can be undertaken. Pine, which is a major cause of forest fires, should be replaced with the species that will aid water conservation. Khals (small ponds), are being constructed in catchment areas under different government programmes (MNREGA)/ schemes, for storage and conservation of rain water, but these Khals are being created unscientifically. As a result, they are unable to capture rain water, informed most of the villagers. A technical training should be organized and conducted for the community members, to help them select appropriate locations for the construction of the Khals and the adoption of appropriate construction methods. The Van Panchayat which is responsible for effective management of the forest at the community level is not fully trained and equipped to control forest fires. Only regular training and capacity building of Van Panchayats will ensure forest fires are effectively controlled. Rooftop rainwater harvesting should be implemented at the household level to deal with the water crisis. Villagers have identified a place where a small dam can be built to capture stream water as well as rainwater. Water stored in the reservoir will address the problem of irrigation and more land area can be brought under irrigation. Such activities can be replicated in other parts of hill villages. In order to address drought situations and instances of less rain during cropping seasons, drought resistance crop varieties should be promoted. Setting up of a seed bank would greatly help farmers procure seeds. Since traditional agricultural (agroforestry) system is the best mechanism to cope with climate change problems, there should be some promotion programmes for traditional mix farming. Poly house techniques is best to meet climate change problem; there is urgent need to promote this technique in Takoli watershed area.

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29

Taming the Climate Dynamics and its Influence in Forest Hydrology: Assessment of Transformation in Forest Ecosystems - A Case Study in Western Ghats, Tamil Nadu

Dr. N. Kavithaand M. S.Vaidyanathan

29.1 INTRODUCTION

The world's water crisis is compounded by climate change, dwindling fresh water resources, pollution and growing population. Forests which occupy over one-third of earth's land surface have been increasingly recognized as a key player in global climate moderation, stream flow regulation and purification, erosion control, carbon sequestration and many other ecosystem services that humans need indeed; human civilizations originate from forests and water. Forests have been the source of water and livelihood for millions of flora, fauna and people living in the river basins and beyond. Studies of the effects of climate change on forests have focused on the ability of species to tolerate temperature and moisture changes and to disperse, but they have ignored the effects of disturbances caused by climate change (Ojima *et.al.*, 1991). Yet modeling studies indicate the importance of climate effects on disturbance regimes (He *et.al.*, 1999). Local, regional, and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent, and intensity of disturbances (Baker, 1995; Turner *et.al.*, 1998). Because trees can survive from decades to centuries and take years to become established, climate-change impacts are expressed in forests, in part, through alterations in disturbance regimes (Franklin *et.al.*, 1992; Dale *et.al.*, 2000).

29.1.1 Impact of Climate Dynamics on Forest Ecosystem

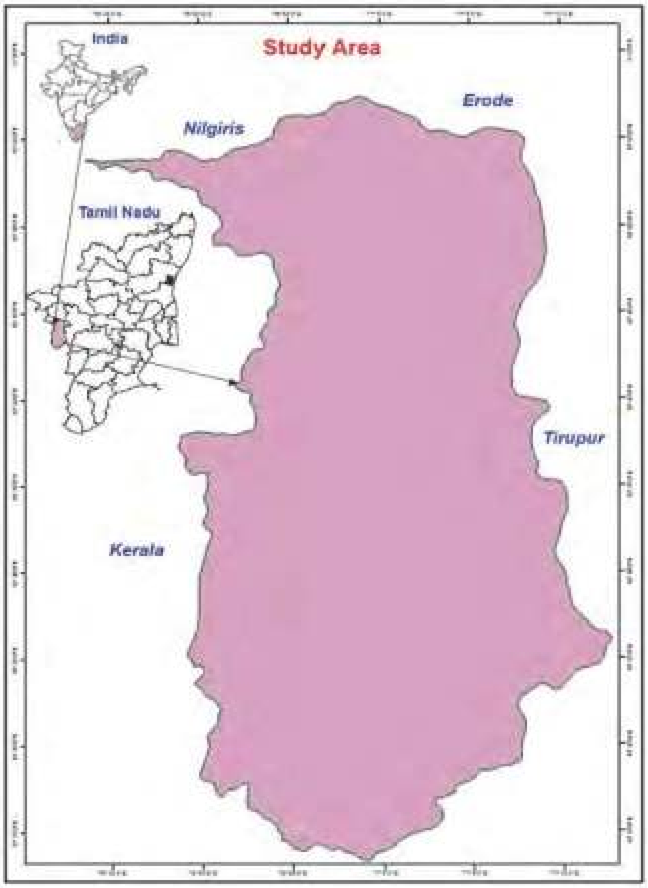
Forest and fresh water resources are increasingly threatened by ongoing global climate and land cover changes. Fresh water scarcity is becoming more problematic across the planet due to increasing population growth, land use change such as deforestation, and climate change variability. Disturbances, both human-induced and natural, shape forest systems by influencing their composition, structure, and functional processes (Virginia *et.al.*, 2001). Global change has resulted in a series of chain reactions in both natural ecosystems and human dominated systems. Growing concerns over watershed degradation, water scarcity, poverty, and social sustainability due to global change require new approaches to manage forests and water resources. Currently, there is little science-based guidance for resource managers and policy makers to adapt to the novel and ever changing environment in the 21st century. Understanding the interactions among forests, climate, water resources, and human activities is essential in advancing actionable sciences and developing robust climate change mitigation and adaptation strategies and methodologies.

Assessing the transformation of forest resources through traditional techniques is complicated, time consuming and uneconomical. Modern technologies like Geoinformatics enable simple, accurate, economical monitoring even for vast and inaccessible areas during a short period of time. For the study of climate dynamics and its influence in forest hydrology, a part of the Western Ghats was chosen which is located in Tamil Nadu, India. The Western Ghats represent an age-old ecosystem rich in biodiversity and is one of the eight global hotspots of biodiversity and a UNESCO World Heritage site. The Anamalai Hill Range in the Western Ghats of Tamil Nadu is a habitat to many reservoirs, wildlife sanctuaries and rich in bioreserves.

29.2 STUDY AREA

For the study of climate dynamics and its influence in forest hydrology, a part of the Western Ghats was chosen which is located in Coimbatore district, Tamil Nadu, India with an latitude and longitude of 10°14' to 10°55'N and 76°45' to 77°15'E with an area of 241,514.8 ha (Figure 29.1). Coimbatore is surrounded by mountains on the west, and reserve forests on the northern side. The entire western and northern part of the district borders the Western Ghats with the Nilgiri biosphere as well as the Anaimalai and Munnar ranges. The Western Ghats represent an age-old ecosystem rich in biodiversity and is one of the eight global hotspots of biodiversity and a UNESCO World Heritage site. Because of its close proximity to the Western Ghats, the district is rich in fauna. The Anaimalai Hill Range in the Western Ghats of Tamil Nadu is a habitat to many reservoirs, wildlife sanctuaries and rich in bioreserves. All the rivers, which have its source in the Anaimalai range, are served by the South-West Monsoon. The major portion of the dams and tunnels are located in the scenic surrounding of the Anaimalai range and the reservoirs are located amongst picturesque and natural surroundings in the reserved forest areas and tea estates. The forests are responsible for the cool weather, the green landscape and clean air of the district.

Figure 29.1: Location map of the Study area



29.3 METHODOLOGY

The transformation of forest ecosystem and hydrological assessment was analyzed using remote sensing images, enhanced thematic mapper (ETM) for the year 2000, IRS 1D LISS III data for the year 2010 and SRTM data for the year 2000. For the classification of the land cover, particularly vegetative cover, NDVI classification index technique was employed and NDVI classification map for the year 2000 and 2010 was prepared using Erdas Imagine 9.3 software. The normalized difference vegetation index (NDVI) is representative of the various spectral vegetation indices (Rouse *et.al*, 1974). NDVI is the traditional vegetation index used by researchers for extracting vegetation abundance from remotely sensed data. It divides the difference between reflectance values in the visible red and near-infrared wavelengths by the overall reflectance in those wavelengths to give an estimate of green vegetation abundance (Tucker, 1979). In essence, the algorithm isolates the dramatic increase in reflectance over the visible red to near infrared wavelengths, and normalizes it by dividing by the overall brightness of each pixel in those wavelengths. It is computed as;

$$NDVI = (NIR-Red)/ (NIR+Red)$$

Generally NDVI measurements range between -1.0 and +1.0. However, in practice the measurements generally range between -0.1 and +0.7. Clouds, water, snow and ice give negative NDVI values. Bare soils and other background materials produce NDVI values between -0.1 and +0.1. Larger NDVI values occur as the amount of green vegetation in the observed area increases (Rahman *et.al*, 2009).

To assess the changes in rainfall pattern of the study area, annual rainfall data was collected for the year 2000 and 2010 and Isohyet maps were prepared using Arc GIS 10 and Spatial analyst software. Morphometric characteristics like linear, aerial, geometry and drainage of the watershed were assessed

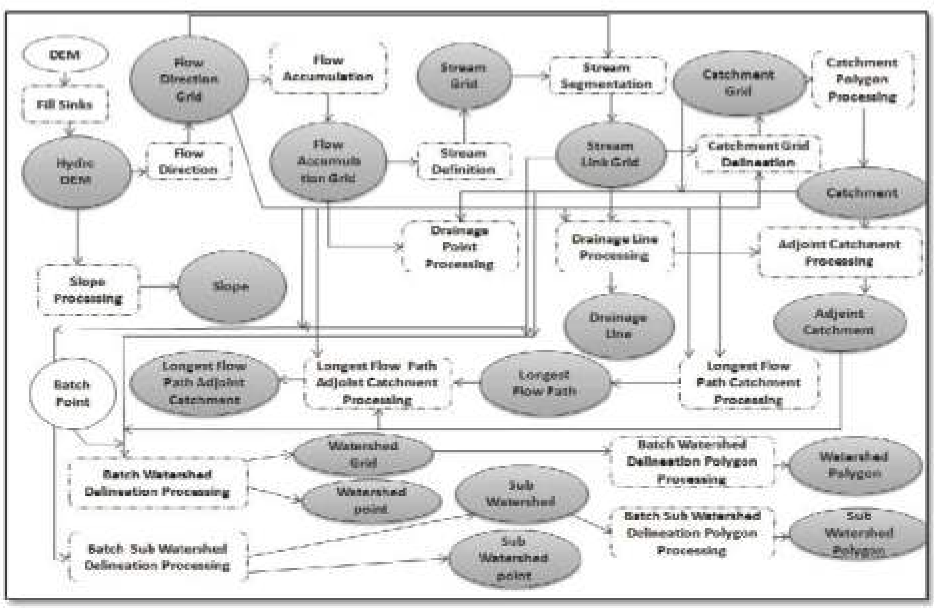


Figure 30.2: Methodology adopted for Watershed Delineation

Table 29.1: NDVI Classification Matrix for the year 2000-2010

Classification	2000 (ha)	2010 (ha) Water Bodies	Very sparse Veg. /Build up area	Sparse Veg.	Moderate Veg.	Dense Veg.
Water Bodies	1653.2	1653.2	4.2	0	0	0
Very sparse Veg./Build up area	6798.3	-4.2	6798.3	0	0	-327.3
Sparse Veg.	86211.7	0	0	86211.7	-1594.9	-1516.1
Moderate Veg.	89830.1	0	0	1594.9	89830.1	-400.0
Dense Veg.	57021.5	0	327.3	1516.1	400.0	57021.5
Total	**241514.8**	**1649.0**	**7129.8**	**89322.7**	**88635.2**	**54778.1**

Veg.-Vegetation

using the Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission (SRTM) of 90m resolution data (GLCF, 2000). Arc GIS 10, spatial analyst tools and Arc hydro tools were used for the sub basin delineation and further analysis of the morphometric parameters of the sub-basin like linear, topographic, relief and aerial aspects (Figure 29.2). Strahler stream ordering technique was followed for stream ordering and other mathematical formulae were followed for further analysis using various methods.

29.4 RESULTS AND DISCUSSIONS

29.4.1 Assessment of NDVI Classification (2000-2010)

The results of the study establish the relationship between the vegetative cover and the surface runoff, base flow and water availability. Periodical analysis with Geoinformatics techniques lends scope for a sentinel watch over the forest ecosystem and its hydrology which helps to address the problems with proper solutions. The climate has a major impact on land-use changes, which has a direct bearing on the hydrology, and results in a slow and steady degradation process of forest as well as hydrology. The NDVI is a simple graphical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not. Figure 29.3 represents the NDVI classification map for the year 2000 and 2010 and Rainfall Isohyets map for the year 2000 and 2010 for the study area. The southern part of the study area is rich in forest resources compared to the northern part which is known as Western Ghats which is home of rivers such as Bhavani, Noyall, Aliyar, Siruvani which provide the drinking water and irrigation water for the people and farmers of Coimbatore. The forests of Coimbatore district are spread over an area of 693.48 sq.km (www.coimbatoreforests.org). Study area NDVI values vary from -0.25 to +0.5. The positive values represent different types of vegetation classes (Dense to very sparse), whereas near zero and negative values indicate non-vegetation classes, such as water, build-up area and barren land.

NDVI classification area matrix for the year 2000 to 2010 (Table 29.1) reveals that there was a reduction in water bodies (4.2 ha), moderate vegetation (1,194.9 ha) and dense vegetation (2,243.4 ha) and there was a increase in very sparse vegetation/build-up area/barren land (331.5 ha) and sparse vegetation (3,111 ha). Reduced water body area of 4.2 ha was converted as very sparse vegetation/build-up area; moderate vegetation was converted as sparse vegetation (1,594.9 ha) and dense vegetation (400 ha); and dense vegetation was converted as sparse vegetation/build-up area (327.3ha), sparse vegetation as (1,516.1 ha) and moderate vegetation (400ha). Increasing trend of very sparse vegetation/build-up area was mainly converted from dense vegetation (327.3ha) and sparse vegetation converted from moderate vegetation (1,594.9 ha) and dense vegetation (1,516.1ha). The greater part of the Coimbatore forest division is situated in the southward extending Western Gnats, with the north-western parts forming the lower ranges of the Nilgiris. The Coimbatore forest division is part of the Nilgiri Biosphere Reserve (NBR) and also forms part of the Core Zone of the NBR. The forest of Coimbatore district is administered by two forest divisions. South of the Palghat Gap lies the Anaimalai Wildlife Sanctuary, which has been designated as a Tiger Reserve during 2008. North of Palghat lies the Coimbatore forest division. This division is bounded on the North and North-West by Sathiyamangalam, Erode, Nilgiris North and Nilgiris South Forest Divisions and on the West and South-west by Palghat Forest division of Kerala State (www.coimbatoreforests.org).

29.4.2 Assessment of Rainfall using Isohyets (2000-2010)

Of all the natural conditions, rainfall should be regarded as the fundamentals so for as progress of the society is concerned. It is always been treated as a fundamental sector for the total development of society (Sadhukan, 1987). Rainfall is a crucial agroclimatological factor in the seasonally arid parts of the world and its analysis an important perquisite for agricultural planning in India (Gadgil, 1986). India is a tropical country: its agricultural planning and utilization water depends on monsoon rainfall, more than 75 per cent of rainfall accruing during the monsoon season. The monsoon rainfall is uneven both in time and space, so it is important to undertake rainfall analysis. The mean annual rainfall of the Coimbatore district is 1,242 mm. The district is characterized with unique aerial topography in quantum of rainfall due to Western Ghats, Anaimalai and Nilgiri hills. Figure

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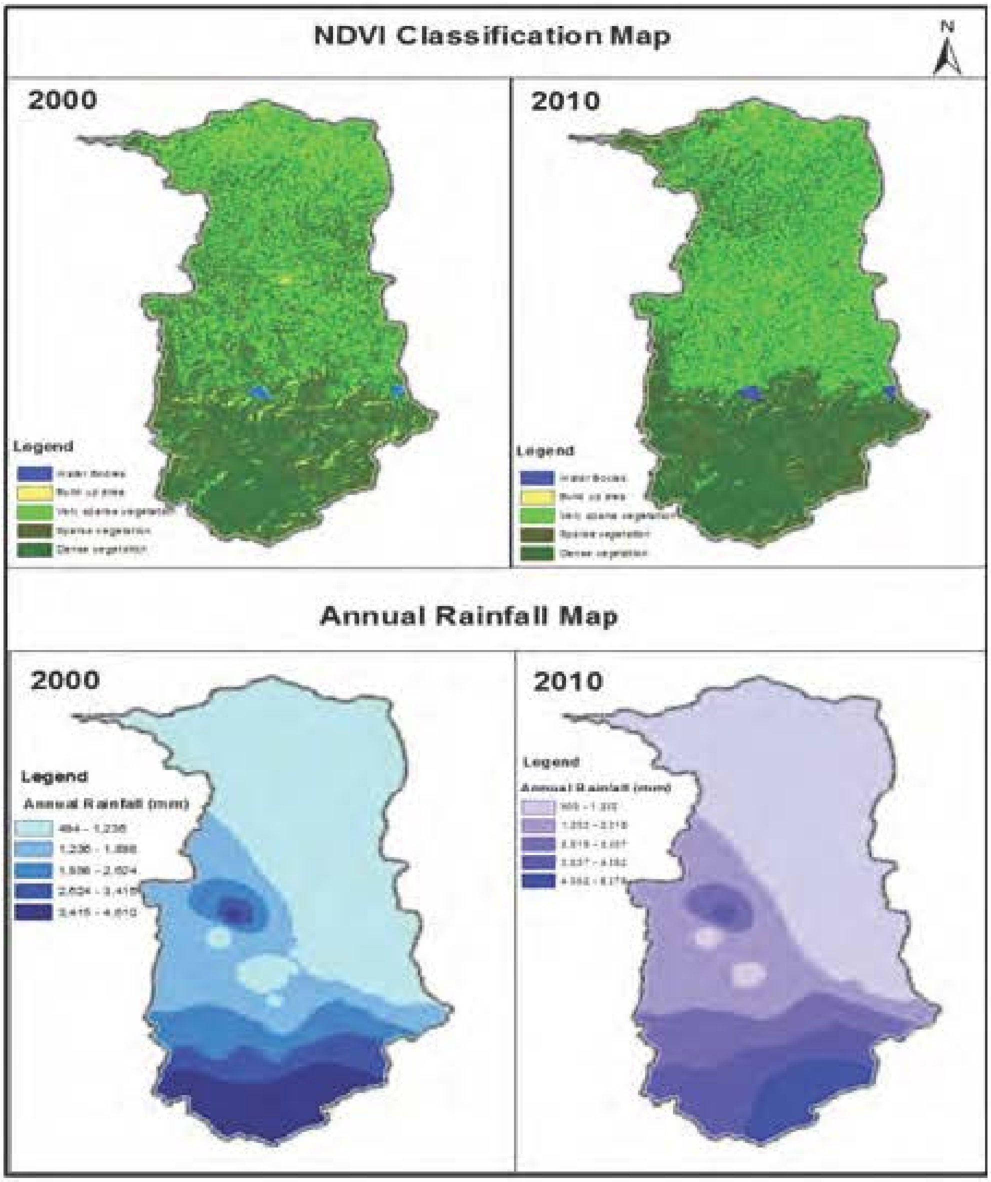

Figure 29.3: NDVI Classification and Isohyte maps for the year 2000 & 2010

Table 29.2: Morphometric analyses - Linear aspects

Stream Order S_u	No of Streams N_u	Length of stream (km) L_u	Log N_u	Log L_u	Bifurcation ratio R_b	Stream Length Ratio R_l	No of streams used in ratio
I Order	882	1160.7	2.945	3.065	4.324	0.475	
II Order	204	552.1	2.310	2.742	4.250	0.544	1086
III Order	48	301.4	1.681	2.479	4.000	0.645	252
IV Order	12	195.4	1.079	2.291	6.000	0.347	60
V Order	2	68.8	0.301	1.837			14
Total	**1148**	**2278.4**	**8.317**	**12.41**	**18.574**	**2.011**	**1412**
Mean	**191.33**	**379.7**			**3.71**	**0.40**	

Table 29.3: Morphometric analysis – Geometric aspects

No	Geometric - Parameters	Formula	Method	Result
1	Area (km^2) A	GIS output	Arc GIS 10	2415.01
2	Perimeter (km) P	GIS output	Arc GIS 10	276.76
3	Length (km) L_b	GIS output	Arc GIS 10	79.47
4	Relative perimeter (P_r)	$P_r = A/P$	Schumn(1956)	8.73
5	Mean width (W_b)	$W_b = A/L_b$	Horton (1932)	30.39
6	Length area relation km (L_{ar})	$L_{ar} = 1.4*A^{0.6}$	Hack (1957)	149.93
7	Lemniscate (k)	$k = L_b^2/A$	Chorley (1957)	2.62
8	Form factor ratio (R_f)	$R_f = A / L_b^2$	Horton (1932)	0.38
9	Elongation ratio (R_e)	$R_e = 2/ L_b*(A/\pi)^{0.5}$	Schumn (1956)	3.11
10	Drainage texture (D_t)	$D_t = N_u/P$	Horton (1945)	4.15
11	Texture ratio (R_t)	$R_t = N_u/P$	Schumn (1956)	3.19
12	Circularity ratio (R_c)	$R_c = 4*\pi (A/P^2)$	Miller (1953)	0.396

Table 29.4: Morphometric analysis – Relief aspects

No	Relief - Parameters	Formula	Method	Result
1	Basin Relief (H)	$H = Z-z$	Strahler (1957)	2333
2	Relief Ratio (R_h)	$R_h = H / L_b$	Schumm (1956)	31.62
3	Relative Relief (R_{hp})	$R_{hp} = H*100/P$	Melton (1957)	842.97
4	Ruggedness Number (R_n)	$R_n = D*(H/1000)$	Strahler (1957)	2.20

Table 30.5: Morphometric analysis – Aerial aspects

No	Morphometric Parameters	Formula	Method	Result
1	Stream frequency (F_s)	$F_s = N_u / A$	Horton (1932)	0.47
2	Drainage density (D_d)	$D_d = L_u / A$	Horton (1932)	0.94
3	Drainage Pattern (D_p)	GIS output	Arc GIS 10	Dendritic
4	Drainage Intensity (D_i)	$D_i = F_s / D_d$	Faniran (1968)	0.50
5	Constant of Channel Maintenance (C)	$C = 1/ D_d$	Schumn (1956)	1.06
6	Infiltration No (I_f)	$I_f = F_s * D_d$	Faniran (1968)	1.97
7	Length of overland flow (L_g)	$L_g = A/2* L_u$	Horton (1945)	2.12

29.3 clearly explains that the maximum amount of rainfall for the year 2000 and 2010 was received in the Western Ghats, Anaimalai and Nilgiri hills, which are located in the south of the study area. From the south towards the north, rainfall gradually decreases. Annual rainfall data for the year 2000 reveals that the maximum and minimum amount of rainfall was received by Sholaiyar (4,611 mm) and Nattakalpalayam (494 mm), respectively. More than 3,000 mm of annual rainfall were received by the areas of Chinnakallar, Lower and Upper Nirar, Valpara and Anaimalai and Less than 600 mm of rainfall was received by the areas of Gomangalam and Poolankinar. Annual rainfall data for the year 2010 reveals that the maximum and minimum amount of rainfall was received by Upper Nirar (5,893 mm) and Gomangalam (491 mm), respectively. More than 3,000 mm of annual rainfall were received by the areas of Chinnakalaar, Iyerpadi, Lower Nirar, Sholaiyar, Valparai, and Anaimalai and less than 600mm of rainfall received by the areas of Nattakalpalayam and Sulthanpet.

29.4.3 Morphometric Analysis (2000)

Dury (1952), systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the drainage network, aerial aspects of the drainage basin, and relief (gradient) aspects of the channel network and contributing ground slopes Strahler (1964). The critical morphometric characteristics of a drainage basin which influence the drainage functions are discussed (Table 29.2 to 29.5, and Figures 29.4, 30.5).

Linear aspects of the morphometric parameters (Table 29.2) of the study area watershed is characterized up to V order stream network. Total and mean stream number of the study area is 1,148 and 191.33. The total length, mean length, total log value and mean stream length of the stream is about 2,278.4, 379.7 km, 12.41 and 8.3. Total and mean bifurcation ratio is 18.57 and 3.71. It has been found that the bifurcation ratio characteristically

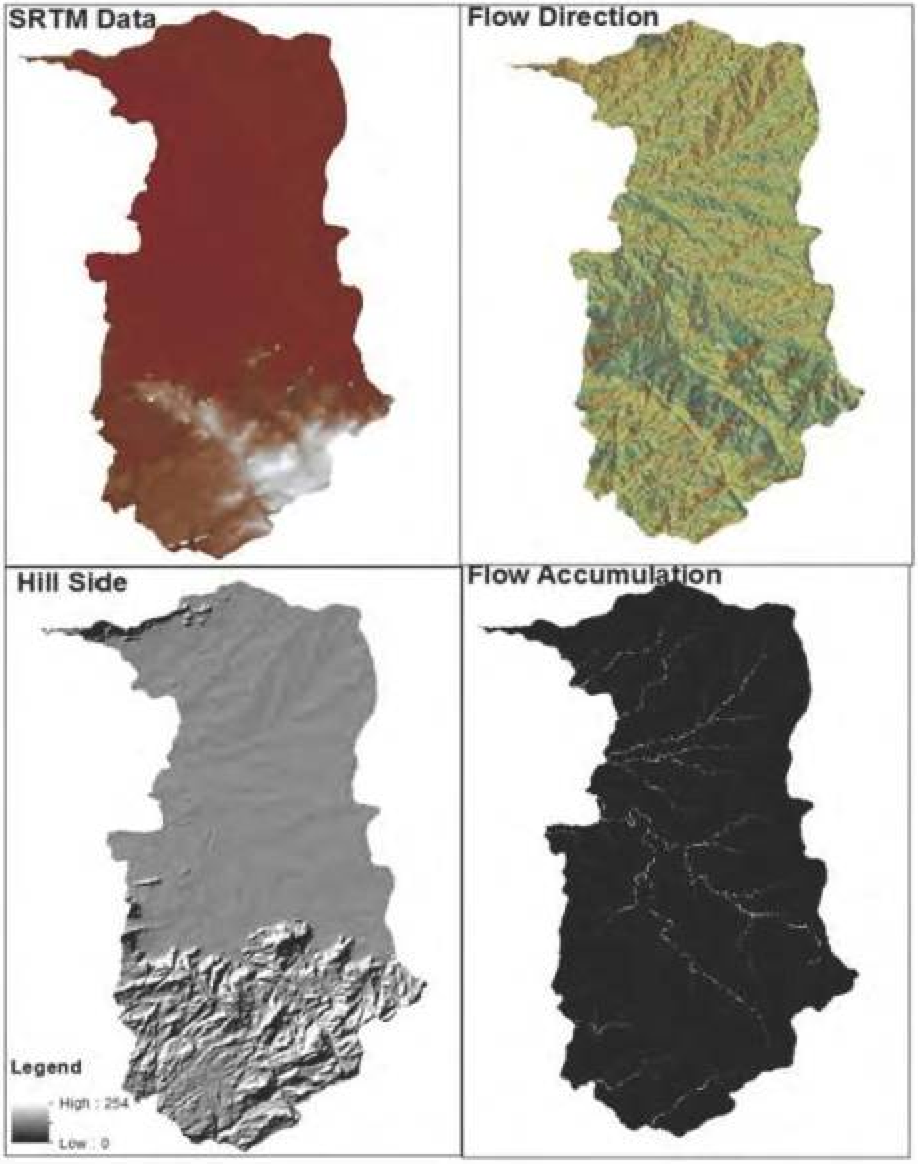

Figure 29.4: Watershed Delineation - Raster Processing

ranges between 3 and 5 for a watershed in which the geology is reasonably homogeneous without structural disturbances to the drainage basin. Higher value of the bifurcation ratio indicates some sort of geological control and lower indicates that the basin produces a sharp peak in discharge and if it is high, the basin yields low, but extended peak flow (Agarwal, 1998). In a well-developed drainage network the bifurcation ratio is generally between 2 to 5 (Horton, 1945; Strahler, 1964). Watershed geometry (Table 29.3) is characterized by various factors among them the important factors of the watershed area (A), perimeter (P), length (Lb), relative perimeter (Pr), mean width (Wb), length area relation (Lar), lemniscate (k), form factor ratio (Rf), elongation ratio (Re), drainage texture (Dt), texture ratio (Rt) and circularity ratio (Rc) with an values of 2,415.01 sq.km, 276.76 km, 79.47 km, 30.39 km, 149.93, 2.62, 0.38, 3.11, 4.15, 3.19 and 0.396. Circularity ratio value indicates that the watershed is circular in shape. A circular basin is more efficient in discharge of run-off than that of an elongated basin (Singh and Singh, 1997). The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor will have a flatter peak of flow for longer duration. The drainage texture value clearly indicates that it has moderate texture category. Watershed relief aspects (Table 29.4) determined basin relief (H), relief ratio (Rh), relative relief (Rhp) and ruggedness number (Rn) with values of 2333, 31.62, 842.97 and 2.20. Watershed has a low value of relief ratios mainly due to the high degree of slope The higher the infiltration number, the lower will be the infiltration and higher will be the runoff and length of overland flow indicates low surface runoff flow. Overland flow is significantly affected by infiltration and percolation through the

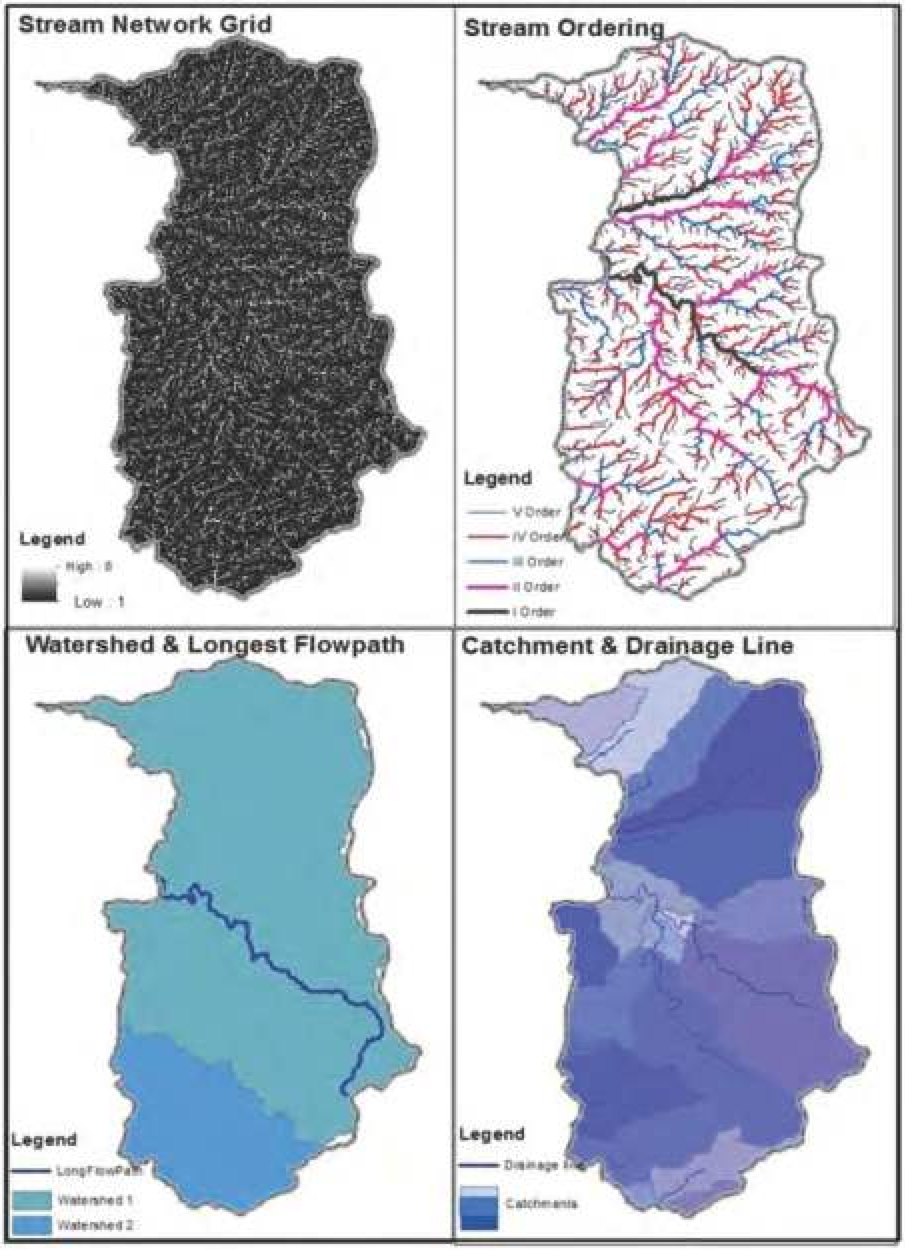

Figure 29.5: Watershed Delineation - Vector Processing

soil, both varying in time and space (Schmid, 1997). Watershed aerial aspects include stream frequency (Fs), drainage density (Dd), drainage pattern (Dp), drainage intensity (Di), constant of channel maintainace (C), infiltration no (If) and Length of overland flow (Lg) with values of 0.47, 0.94, Dentritic pattern, 0.50, 1.06, 1.97 and 2.12. Basin area is hydrologically important because it directly affects the size of the storm hydrograph, magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to the size (Chorley *et.al.*, 1957). Drainage density value indicates that it has highly permeable subsoil, dense vegetative cover and high relief. It has been observed through this measurement made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant of highly permeable subsoil material under dense vegetative cover, and where relief is low. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964). High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density is also indicative of relatively long overland flow of surface water; it is also related to the climate, surface roughness and runoff of the area. The type of rock also affects the drainage density. In a dendritic system, there are many contributing streams, which join together into the tributaries of the main river. They develop where the river channel follows the slope of the terrain (Lambert, 1998). The longer the time of formation of a drainage basin is, more easily the formation of dendritic pattern. Low value of drainage intensity implies that the drainage density and stream frequency have little effect on the extent to which the surface has been lowered by agents of denudation.

29.5 CONCLUSION

Forests which occupy over one-third of the earth's land surface have been increasingly recognized as a key player in global climate moderation, stream flow regulation and purification, erosion control, carbon sequestration and many other ecosystem services that humans need indeed; human civilizations originate from forests and water. However, forest and fresh water resources are increasingly threatened by ongoing global climate and land cover changes. Fresh water scarcity is becoming more problematic across the planet due to increasing population growth, land-use change such as deforestation, and climate change variability. Global change has resulted in a series of chain reactions in both natural ecosystems and human dominated systems. Remote sensing and GIS plays a vital role to accesses the climate dynamics in forest hydrology of the Western Ghats by various aspects like NDVI classification, rainfall and morphometric analysis. These results clearly indicate how changes in the forest ecosystem occur, variability in the rainfall analysis, and how morphometric characteristics were affected due to climate change. Growing concerns over watershed degradation, water scarcity, poverty, and social sustainability due to global change require new approaches to manage forests and water resources. Currently, there is little science-based guidance for resource managers and policy makers to adapt to the novel and ever changing environment in the 21st century. Understanding the interactions among forests, climate, water resources, and human activities is essential in advancing actionable sciences and developing robust climate change mitigation and adaptation strategies and methodologies.

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30

Managing Water, Forests and People - Case Studies of Jharkhand, India

A.K. Mishra and Satya Prakash Negi

30.1 INTRODUCTION

Jharkhand, the newest state of India with geographical area of 79,714 sq.km constitutes 2.42 per cent of the country's land area and lies between latitude 22°00' and 24°37'N and longitude 83°15' and 87°01'E (FSI, 2011). The state is marked by the plateau of Chhotanagpur, and has four distinct plateaus, viz. Pat plateau, Ranchi plateau, Lower Chhotanagpur plateau and Rajmahal highlands. The undulating nature of land resulting in increased surface runoff not only reduces percolation but also continuously erodes top soil thereby diminishing fertility of soil leading to impoverishment of soil, hills and people. Water, forests and people are natural allies. Forested catchments supply a major proportion of all water use for domestic, agricultural and industrial needs. Availability and especially the quality of water are strongly influenced by forests and thus depend on proper forest water management. Unfortunately, there is ever-growing pressure on forests, as the state is one of the important mineral producing states of India. Further, about 76 per cent of its population is tribal dominated rural population with dependence on forests for multitude of benefits. Therefore, *in-situ* and *ex-situ* conservation of water to check the surface runoff and productive utilization of conserved water through appropriate technology is imperative. In this paper, case studies in Bokaro, Palamu and Simdega districts of Jharkhand where community driven traditional, people and eco-friendly, cost effective, and sustainable *in-situ* water conservation methodsare described. With the harvesting of water that would have otherwise gone waste as surface run-off, communities are able to cultivate their land and grow variety of agricultural, horticultural and silvicultural products through improved technological practices. This provides the communities with productive and meaningful employment with additional source of income in a sustained manner reducing dependency on government and external mechanism.

30.2 RURAL ECONOMY IN JHARKHAND

Agriculture, collection of forest produce and allied activities are the main source of employment and income for the tribal dominated rural population, though the area under cultivation is only about 14 per cent of the total land area. The low productivity is mainly due to difficult terrain and consequently inadequate irrigation facilities. Therefore, majority of the rural population are resigned to the mercy of nature for the minimal agricultural harvest. It is clearly evident from Table 30.1 which shows that only 11.54 per cent of the net sown area is irrigated. Although the state receives adequate rainfall over small period; but due to the undulating terrain, the surface runoff reduces the percolation, and hence the rainwater is not available to the agricultural crops sufficiently for productive utilization. Active involvement of local communities and harnessing their age-old, cost effective local technical knowledge in constructing and de-silting tanks, ponds, and wells, etc., for judicious soil and water management is an ideal strategy. Further, the local people need to be supplemented with the technology that ensures conversion of water into useful multi-layer vegetation.

Fortunately, a beginning has been made by the few conscious villagers in Palamu, Ranchi and other districts of Jharkhand wherein they interacted and replicated *'Chakriya Vikas Pranali'* conceptualized and pioneered by Padam Shree Late Dr. P.R. Mishra in his famous Sukhomajri (near Chandigarh) experiment in the Shivalik hills. The concept of *'Chakriya Vikas Pranali'* means the Cyclic Mode of Development. In other words, the benefit from one investment becomes the capital investment for the next, and thus the cycle moves on to provide economic and social benefits to the villagers in a sustainable manner by generating common social and environmental capital on the principle of *'all protect, all pay, and all receive'*. Basically, this involves one-time investment of cash, kind, technology and to convert it into a self-sustaining process of production and reinvestment from a common village fund. It involves *'multi-tiered, multi-rooted and multi-layered'* planting cycles – guarantees year-around employment for all members of village society and in return – in the short, medium and longer term from grass, vegetables, fruits and timber, respectively.

30.3 METHODOLOGY

In Jharkhand, the *'Chakriya Vikas Pranali'* was initiated in Palamu district in the year 1986 when the state of Jharkhand was part of erstwhile undivided Bihar. The concept was more or less replicated in other districts by dedicated individuals and groups. In recent years, the concept gained momentum due to few spirited persons and youths in respective districts. They have taken the initiative to change their lot by forming groups, societies and co-operatives. In the present study, the qualitative study technique has been used wherein the authors made field visits to those districts where *in-situ* soil and water management interventions

Table 30.1: Land UtilizationScenario in the Districts under Case Studies(Period: Year ending 2010 -11) (Area in hectare)

Sr. No.	Name of District	Reporting Area for Land Utilization Statistics	Forests	Not Available for Cultivation	Other Uncultivated Land excluding Fallow Land	Fallow Land	Area under Cultivation		Area under Irrigation	
							Net Area Sown	Percent of Total Land Utilization	Net Sown Area under Irrigation	Percent of Total Net Area Sown
1	2	3	4	5	6	7	8	9	10	11
1.	Bokaro	288,992	74,182	73,843	18,648	102,833	19,486	6.74%	2,723	13.97%
2.	Palamu	460,431	169,819	54,749	10,299	171,013	54,551	11.85%	13,888	25.46%
3.	Simdega	379,434	103,674	45,203	32,246	118,870	79,441	20.94%	3,323	4.18%
Jharkhand		**7,970,075**	**2,239,481**	**1,332,421**	**538,912**	**2,773,895**	**1,085,366**	**13.62%**	**125,241**	**11.54%**

Source: Directorate of Economics & Statistics, Ministry of Agriculture, Govt. of India.DACNET Project, Agricultural Informatics Division, National Informatics Centre.

by the communities have been done. The authors visited the intervention sites and interacted with the communities/villagers/ groups/societies/co-operatives involved in persevering to change their conditions for the better. On the basis of field visits and interaction with communities in some of the districts, the three districts, viz. Bokaro, Palamu and Simdega, were selected for the present case studies because of their successful interventions that made positive awakening amongst the communities and inspired them to believe they could improve their conditions through community based management of land, water and forests.

30.4 CASE STUDIES

30.4.1 Palamu District

Situated along the bank of the rain-fed Koel River, Palamu district has a population 19,36,319 persons with literacy rate of 65.5 per cent. The net sown area of the district is 11.85 per cent and area under irrigation is only 25.46 per cent of the net sown area. Most of the land outside forest is fallow locally known as '*tanr*'. The concept of '*Chakriya Vikas Pranali*' was initiated in Palamu district through the 'Society of Hill Resource Management School' in the year 1986. The communities were trained in nursery and motivated to adopt agro-forestry farming techniques of papaya, tubers, leucaena, etc. One of the novel agro-forestry techniques is '*Tie-Ridgetillage*' wherein the horticultural and forestry compatible tree species are grown on the bunds of the agricultural field. The tree species were selected according to the requirements of the individual farmer but mainly involve papaya, banana, lemon, guava, jackfruit, mango, *gamhar* and leucaena, etc., as these species are normally short rotation crops.The tie-ridges are also constructed for individual tree species. Further, various kinds of multi-tier vegetables are grown in each tie-ridge. The below-ground vegetables mainly involve *ole*, tapioca, turmeric and ginger. The above-ground vegetables are mainly lady finger, chilli, brinjal and tomato, etc. Pulses especially *moong* and *arhar* are also grown in the tie-ridges. Here, compatibility of the species is crucial.

The tie-ridge tillage improved soil and water availability to the plants as compared with traditional practice of planting without ridges, as the '*rain water is harvested on the spot*' in the tie-ridges. The agriculture, olericulture, horticulture and silviculture activities carried out on the same piece of land increased the productivity from the farm leading to improved and productive dairy farming as well. Ultimately, framers' income per acre land increased leading to self-sufficiency to a great extent. More and more farmers are adopting the improved farming technology. The experiment is being carried out in Bhusaria village mainly inhabited by the primitive Pahariya tribe with good results of common property resource management.

30.4.2 Bokaro District

One of the coal-rich industrialized zones of India, Bokaro district has a population of 20,61,918 persons with a literacy rate of 73.48. The district has a maze of valleys and sub-valleys formed by the river Damodar and its tributaries. The net sown area of the district is 6.74 per cent and the area under irrigation is only 13.97 per cent of the net sown area. People's involvement through Joint Forest Management in Hisim village (Kasmar block) and Utasara village (Peterbar block) of the district are success stories in the area. Local leadership of Shri Jagdish Mahto in Hisim village and Shri Radha Nath Soren in Utasara village supported by young foresters was crucial. The people were involved to protect natural forests and planted area. The efforts bore fruits. The people get firewood, bamboo and small timber on sustained basis. Forest Management Registers have been opened and made part of a working plan. All removals from forest are recorded. Protection has yielded results. Saplings have become poles and the poles have become trees.

A notable feature of Hisim and Utasara villages is initiation of planting of *asan* and *arjun* tree species in private fallow land for sericulture. Bringing of *tanr* land under bamboo plantation and tree cover by planting useful tree and shrub species is to be seen to believe. This has brought unproductive land into production and acts as buffer to natural forests in reducing biotic pressure. Involvement of villages of Chandrapura and Bundu villages of Peterbar block in the district in medicinal plant aspect of forest management is worth mentioning. Medicinal plants forming the understorey of forests had been earlier neglected in forest management. Villagers joined with great interest. The programme comprised of three vital components, viz. identification,

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propagation and utilization of medicinal plants. This created mass involvement of forest fringe villages in protection of forest floor which is vital for water conservation. Training of villagers by qualified *Ayurvedic* (herbalist) practitioners boosted their confidence in propagating plant based medicines on a sustainable basis.

30.4.3 Simdega District

With a landscape formed of hills and undulating plateau, Simdega district has a population of 599,813 persons with a literacy rate of 67.59. The net sown area of the district is 20.94 per cent and area under irrigation is only 4.18 per cent of the net sown area. Dr. M.S. Swaminathan during one of his visits to Simdega was surprised to see vast stretches of fallow, barren land. In 2012, a few spirited and educated youth guided by experienced thinkers and foresters formed a co-operative society named as 'Simdega Agro Labour and Multipurpose Self-supporting Co-operative Society Ltd'. *Mahua* grows abundantly in the forests of Simdega district.*Mahua* flower is edible and is an important food item for the people of the district. The byproducts of *mahua* are syrup for medicinal purpose, fermented alcoholic drink, etc. The seed of the *mahua* is also edible and its drink is part of the cultural heritage in Jharkhand, and enjoyed by both men and women during celebrations.

Before the formation of the co-operative society, the poor villagers used to collect *mahua* flowers and sell them in the market individually. But the co-operative society provided them better bargaining capacity and a good return from the market from the sale of *mahua* flowers. Interestingly, each member of co-operative purchases one share of Rs. 100 which may be cash or equal value of *mahua* flowers, tamarind or other produce. The money earned from selling *mahua* flowers was used as seed money for cultivation of maize and vegetables in land lying fallow since years due to lack of investment with the poor land-holders. The main activities involve soil and water management activities in Sonajhari Riverand its tributaries in the forest areas using low cost traditional technology. This involves using gunny bags filled with sand and erecting/piling across the main river and its tributaries. With the *in-situ* storage of water in the forests, the society is able to till their additional acres of otherwise *tanr* land.

The society is able to harvest good return through multi-layered multiple cropping. Initially, the villagers were engaged in mono-cropping only. But with the source of irrigation through conserved water, they are able to cultivate their land more than once. Farming is also done collectively as individual families contribute *tanr* land to the society for collective farming. Now, the society is able to raise agricultural crops like maize and rice; vegetables like *ole*, beans, cauliflowers, cabbage, chilli, ginger, lady finger, tomato, potato, ginger, and turmeric, etc. The horticultural crops are mainly mango, papaya, and lemon. Tree species along the bunds are short rotation species like *gamhar*, jackfruit and leucaena, etc. A notable feature is that a part of the income goes to a common fund which acts as 'future capital' for investment in land and water management. With the increased income, the society is able to purchase good quality seeds for better and productive agronomic practices. During the field visits, the society was planning to construct ponds, wells and water channels for irrigation. The society plans to install drip-irrigation system so as to minimize wastage of water thereby increasing utility per unit land and water.

30.5 RESULT AND DISCUSSION

With the increase in per acre productivity as well as increase in total land under cultivation due to *in-situ* and *ex-situ* water conservation, the villagers involved in the new and improved agronomic practices either in small groups (Palamu, Bokaro) or collectively through co-operative (Simdega) are able to come out from the dependency syndrome on the government and the weather. This new awakening amongst the villagers around the intervention areas is attracting more and more villagers/households to adopt improved practices and/or join the co-operative movement. Communities are realizing that with guidance, innovation, hard work, technology, unity and determination, they can change their conditions of life on their own. This is the biggest feat of the concept of *'Chakriya Vikas Pranali'* by harmonizing human and natural capital on a sustained basis.

30.6 CONCLUSION

The case studies described in the paper clearly demonstrate how by reversing the trend of dwindling resources of land, water and forests to productive use, the attitude of self-reliance and collectivism have developed among the villagers. The interventions have surely improved the economic base of the individuals and the community as a whole on sustained basis which is a good sign for better environment and happy humanity.

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31

Ecological and Socio-Economic Prosperity Through Rain Water Harvesting Involving Local Communities: Haryana and Chandigarh Experience

Jagdish Chander

31.1 INTRODUCTION

Rainwater harvesting during rainy season when water is in excess and using it during water scarcity period for crop production and even for drinking purpose is an age-old tradition in India. Natural resource conservation through rainwater harvesting, regenerating degraded forests, reducing soil erosion, and using harvested water (which otherwise goes waste) for crop and fodder production, is the first step to reverse the vicious circle of poverty and land degradation. The process of eco-restoration of forests and prosperity in the region started with participatory forest management approach involving forest department and local communities. It all started in the late 1970s in a village called Sukhomajri in district Ambala (now Panchkula). In fact, Dr. Parashu Ram Mishra of Central Soil & Water Conservation Research & Training Institute (SWCRTI), Chandigarh surveyed the catchment area of Sukhna Lake and ultimately reached at place where there were landslides, pot holes, and deep gullies. This was a place where Sukhna's malady was waiting for the arrival of Dr. P.R. Mishra. In the vicinity of this area was a village which was identified as Sukhomajri. This village is located in the lap of the Shivalik hills near Chandigarh and forms about 20 per cent catchment area for the famous manmade Sukhna Lake of Chandigarh. Tonnes and tonnes of soil was being eroded from here and was being deposited in Sukhna Lake. The life of the lake was being shortened and its water quality was deteriorating. The people of Sukhomajri and forest department had different directions. They had no legal access to forest resources. While forest department officials used the *danda* (stick), the people cut the trees and set the forests on fire.

After a series of dialogues between soil conservation expert Dr. P.R. Mishra of SWCRTI, Haryana Forest Department and local communities, it was concluded that the problem of forest degradation does not lie in the forest but in the village. And that the problem was poverty. Water was identified as catalytic agent for bringing ecological and socio-economic change. People agreed to protect the forest in lieu of providing water to them for crop and fodder production. They also agreed to sell goats, sheep, resort to stall feeding rather than open grazing in forest, and rear buffaloes in place of cows. Accordingly, four earthen rain water harvesting dams were constructed in the village. This water was utilized for growing food and fodder crops and even for drinking purpose. The participation of each and every member of the village was ensured by having a share in water. The water brought prosperity to the village. Temporary human and animal migrations stopped and people started caring for the forests and watershed. The soil erosion was reduced considerably and quality of forests was improved as a result of improved soil moisture regime.

By the early 1980s, the Sukhomajri concept of water harvesting and forest management became recognised worldwide and this approach was replicated throughout Haryana and Chandigarh Shivaliks. Over 200 and 190 such earthen dams have been constructed in Haryana and Chandigarh, respectively, thereafter and the process is still on. Most of them have brought ecological and economic prosperity. People have sold goats and sheep, have started rearing buffaloes and have resorted to stall feeding. The thatched houses have been replaced by pucca ones. People have shifted to cash crops due to availability of water year around. However, in some cases, desired results have not been achieved due to some untrained staff and lack of follow-up dialogue between forest department and villagers.

31.2 MATERIAL AND METHODS

The study was conducted in 2013 in the Shivalik belt of Haryana state of northern India and Union Territory, Chandigarh of India as excess rainwater was tapped and harvested in these areas. This excess water was used for crop/fodder production and eco-restoration of biodiversity. Three villages, viz. Sukhomajri, Rampur Gainda and Paniwala, were selected in Haryana for this purpose where rainwater harvesting dams were constructed and the excess rainwater stored was used for crop production. While Sukhomajri falls in Panchkula district, Rampur Gainda and Paniwala are in Yamunanagar district. There are about 250, 65 and 45 households in these villages, respectively. All households in these villages belong to the Gujjar community who traditionally rear sheep, goats, cows and buffaloes.

On-the-spot study in these villages related to ecological and socio-economic changes was conducted by visiting the site and holding face-to-face dialogue with people. The data so collected after long discussions with people and on-the-spot verification was compared with old data available with the forest department. While ecological prosperity was studied in terms of rehabilitation of forest in the catchment areas and restoration of biodiversity, increase in tree density, increase in water table, adoption of agroforestry by villagers, socio-economic prosperity was studied by comparing the pre-dam construction scenario with the present scenario in terms of rise in living standards, change in cropping pattern, shift from rainfed farming to irrigated farming due to assured availability of water, growing of high value cash crops, increase in area under high value crops, absence of thatched houses, construction of modern RCC houses, presence of luxury cars, and literacy among the children.

Chandigarh was also selected for the study as the rainwater harvesting dams have turned the dry Shivaliks into lush green forests with assured perennial flow of water. In the case of Chandigarh, as many as 190 water harvesting dams have been constructed. As there are no dependent villages on forests in Chandigarh, socio-economic studies could not be conducted. However, ecological studies were conducted on the spot and the ecological prosperity in terms of richness in biodiversity of flora and fauna, perennial flow of water in the streams, was compared with the adjoining hills where water harvesting was not done.

31.3 RESULTS AND DISCUSSIONS

The results of the socio-economic study, discussion with people, on-the-spot study for three villages viz. Sukhomajri, Rampur Gainda and Paniwala of Haryana, and ecological studies conducted in Chandigarh are described below:

31.3.1 Sukhomajri Village

Located in Haryana Shivalik foothills in Panchkula district about 30 km away from Chandigarh, it was a little known village some 35 years ago. The people and forest department were having opposite directions. The Forest Department would plant saplings and people uprooted them. Villagers cut the trees and set forests on fire. They grazed herds of sheep and goats in the forests. Soil erosion was at a peak. The Forest Department's policy of managing forests by *danda* (stick) led to conflicts with people. However, after a series of dialogues between Dr. P.R. Mishra, then Divisional Forest Officer S.K. Dhar and the people, an agreement was arrived at. While the forest department constructed four rainwater harvesting dams, the people sold all goats and sheep and started rearing buffaloes. With the construction of water harvesting dams, there was year around availability of water and as a result of this, people shifted to irrigated farming. They grew fodder and resorted to stall feeding. There was return of greenery in the hills. Economic prosperity reached in the village and this lead to the birth of Joint Forest Management (JFM)/Participatory Forest Management, a concept of managing forests involving local communities which never happened before anywhere in the world. Later, the Sukhomajri concept of water harvesting was adopted elsewhere in the entire Shivaliks of Haryana and Chandigarh. The results of this approach are given below:

31.3.1.1 Change in cropping pattern

As a result of the construction of four water harvesting dams whose command area is around 50 hectares, the change is cropping pattern before and after construction of water harvesting dams is given in Table 31.1.

Table 31.1: Pre and post earthen rain water harvesting dam - crop and yield scenario

Crop	Pre (1976) water harvesting dam scenario	2013 scenario
	Area (Acres)	Area (Acres)
Maize *(Zea mays)*	9.00	2.00
Sorghum (Fodder) *Sorghum bicolour*	5.00	2.00
Black Gram *(Vigna mungo)*	1.00	---
Paddy *(Oryza sativa)*	---	40.00
Wheat *(Triticum aestivum)*	8.00	50.00
Bengal Gram *(Cicer arietinum)*	2.25	---
Sugarcane *(Sachharum officinarum)*	1.50	45.00
Egyptian Clover/Barseem *(Trifolium alexandrinum)*	---	20

It can be seen from Table 31.1, that the area under maize has come down from 9 acres in 1976 to 2 acres in 2013. This has happened because maize is basically a subsistence crop. Before the dam, the people were dependent upon rainfed farming and grew maize to meet their own food requirement. However, after the year around availability of water, people shifted to high value cash crops. The same explanation holds true for sorghum also.

It can also be seen from Table 31.1 that Black Gram is not grown in the village any more. This has nothing to do with water. In fact, it is a kharif (summer) crop and does not need much water. During the last few years, it is being severely attacked by blight disease. As a result of this, growing black gram is no longer a profitable business. Therefore, absence of black gram from the village has nothing to do with Sukhomajri. This is true with the entire area and it is not being grown in other villages as well. As regards Bengal Gram, it is a rabi (winter crop) and because of modern agricultural practices, it no longer grows in the area and again, there is nothing specific to Sukhomajri. The important thing to note from the above table is that the villagers have either started growing high value irrigated crops due to the assured availability of water or the area under such crops has increased. So, at present there is 40 acres area under paddy cultivation against none before 1976. The same explanation holds true for Egyptian Clover (Barseem) except that this crop is grown in the village to stall feed the buffaloes and is not for sale. It can also be seen from the above table that there has been significant increase in the area under wheat and sugarcane as a result of availability of water. While sugarcane is sold to sugar factory, wheat which is staple food of the villagers, not only meets the requirement of the village but the surplus quantity is sold which earns them sufficient money.

31.3.1.2 Animal husbandry scenario

As a result of availability of fodder and sale of goats and sheep as per the advice of soil conservation experts and forest department, the pre and post water harvesting scenario has been given in Table 31.2.

It can be seen from Table 31.2 that people have disposed

Table 31.2: Pre and post earthen rain water harvesting dam- domestic animals scenario

Animal	Pre (1980s) water harvesting dam scenario (No.)	Milk production (Kg)	2013 scenario (No.)	Milk production (Kg)
Goat *(Capra hircus)*	250	15.00	---	---
Sheep *(Ovis aries)*	250	---	---	
Cow *(Bos indicus)*	100	300	10	100
Buffalo *(Bubalus bubalus)*	5	75	300	3000

of goats and sheep and are mainly rearing buffaloes. House to house survey revealed that all buffaloes in the village belong to improved breeds. The important thing to note is that before the water harvesting dam, some goat milk was being produced but it was not meant for sale. The house-to-house survey further revealed that at present more than 3,000 kg of milk is being sold from the village daily and the net return from the sale of milk is more than Rs 1 lakh per day. The net profit is more than Rs 50,000 per day.

31.3.1.3 Socio-economic change

The study revealed that all thatched mud houses have been replaced by brick and cement ones as a result of rise in incomes. The literacy rate has increased from 20 per cent in 1975 to 100 per cent in 2013 as a result of the rise in economic status and awareness generated in the village. The younger generation goes to public school. Literacy among women has also improved and now all girls go to school. Presence of luxury cars is a common sight in the village.

31.3.1.4 Concept of social fencing

Fencing means erection of some physical barrier to prevent entry. In the case of social fencing, there does not exist any barrier or the fence post but the villagers themselves decide the physical boundary beyond which the people will neither let loose their animals for grazing nor will use the resource. At the time of the mutual agreement between forest department and people of the village, the forest department had erected barbed wire fencing in the forest. The result of participatory forest management was that the people themselves decided the boundary and the forest was left for regeneration. The barbed wire fencing was removed after four months only. This led to the concept of social fencing.

31.3.1.5 Ecological changes

A comparison of the grass production, presence of trees, shrubs, climbers, herbs and grasses before and after water harvesting dams has proved that there is return of greenery in the area and the forest has been rehabilitated. There are now wildlife species like Goral and variety of birds in the forest. The presence of wildlife, birds, herbs, shrubs, climbers and trees indicates that the forest has become rich in biodiversity. In terms of quantification of productivity, grass production has increased from 25 kg per hectare before the people adopted the concept of social fencing to about 2,000 kg per hectare at present. This has happened as a result of stall feeding and better forest protection.

As a result of stall feeding and social fencing approach adopted by the people, the tree density per hectare has increased from an average of about 13 in the early 1980s to more than 1,000 trees per hectare. There are all classes of trees from seedlings to saplings and mature trees and their presence shows presence of required type of healthy forest. However, species like *Acacia catechu*, Gum Arabica *(Acacia nilotica)*, Tree of Sorrow *(Nyctanthes arbortristis)*, Christ's Thorn *(Carissa carandus)* and Sabai Grass *(Eulaliopsis binata)*, etc., have been suppressed by invasive alien species called Spanish Flag *(Lantana camara)*. At places *Murraya koenigii* has shown its presence. The spread of *Lantana camera* is, however, a cause of concern as it is decreasing the grass production. But this phenomenon is common to the entire Shivalik belt and not restricted to Sukhomajri alone. The severely eroded hill tops have been clad with introduced species like Sickle bush Mimosa *(Dichrostachys cinerea)* and local species like Cogon Grass *(Impereta cylindrica)* and Munj Grass *(Saccharum munja)* have appeared in the channels. Though these are not palatable grasses but they are the best soil binders and their presence is an indication that the process of ecological succession has started.

31.3.1.6 Water Table

In the pre-rainwater harvesting era, the water table in the village was at about 200 feet but now the water table is at about 70 feet.

31.3.1.7 Tube wells

Ten tubewells are today functioning as a result of the rise in water table. There was none before 1976.

31.3.2 Village Rampur Gainda

Located in the lower Shivalik hills of Yamunanagar district, this village was unknown before 2006. A European Union aided Haryana Community Forestry Project (HCFP) was being implemented in this area during that period. The village had about 50 households at that time and the entire population comprised of Gujjar community. The literacy rate was only 25 per cent. The people were very poor. They lived from hand to mouth. The forest in the vicinity of the village was totally degraded. The village had 1,000 sheep and equal number of goats. These animals would graze in the forest. The soil erosion was at an extreme. Conflicts between the people and forest department were very common.

The village fitted into the selection criteria of HCFP and was selected for community forestry intervention in 2005. The project aimed at community capacity building for the management of common property resources and construction of a water harvesting dam was one of the components of the project. It was felt that water would bridge the gap between the people and the forest department. Accordingly, one water harvesting dam was constructed in 2006. The dam can irrigate area up to 60 hectares.

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31.3.2.1 Change in cropping pattern

After about seven years of construction of water harvesting dam, the comparison of the present cropping pattern with the pre dam scenario is given in Table 31.3

Table 31.3: Pre and post earthen rain water harvesting dam – crop and yield scenario

Crop	Area before 2006 (ha)	Area in 2013 (ha)
Maize *(Zea mays)*	20	2
Pearl Millet *(Pennisetum glaucum)*	10	0.75
Peanut *(Arachis hypogaea)*	6	1
Paddy *(Oryza sativa)*	2	60
Cheri *(Sorghum bicolor)*	12	4
Wheat *(Triticum aestivum)*	6	80
Egyptian Clover *(Trifolium alexandrinum)*	---	3.5
Sugarcane *(Sachharum officinarum)*	2	40

It can be seen from Table 31.3 that the area under maize has come down from 20 hectares in 2006 to 2 hectares in 2013. This has happened because maize is basically a subsistence crop. Before the dam era when people resorted to rainfed farming, they grew maize to meet their own food requirement. However, after the year around availability of water, people shifted to high value cash crops. The same explanation holds true for pearl millet and cheri also. As regards peanut, the area has come down from 6 hectares to 1 hectare. This has nothing to do with water. In fact, it is becoming increasingly difficult to grow peanut because of severe attack of White Grub *(Holotrichia consanguinea)* in the area. Very positive development to note from the above table is that the area under paddy, sugarcane and wheat has increased considerably. Availability of assured water for irrigating crops explains the shift. The people have also started cultivating Egyptian Clover for stall feeding their animals.

31.3.2.2 Animal Husbandry scenario

Before 2006, the village had about 1,000 goats and equal number of sheep. At present, there is not even a single goat/sheep in the village. People are rearing improved breeds of buffalo. They are selling milk and are earning handsome money which they never did before the dam construction.

31.3.2.3 Return of greenery in the catchment area

As a result of sale of goats and sheep, stall feeding and protection provided by the villagers to the forests in the catchment area of the water harvesting dam, the forest is on way to rehabilitation. The regeneration of herbs, shrubs, climbers and trees is clearly seen. The area now looks lush green instead of the dry, ugly scene before the water harvesting dam. The records of silt load are not available but as per the villagers and the forest department officials, there is considerable reduction in the silt load. Species like *Acacia catechu, Lannea coromandelica, Terminalia tomentosa, Disopyros melanoxylon, Butea monosperma, Cassia fistula, Premna barbata, Litsea, Casearia, Nyctanthes arbortristis, Bauhinia vahlii, Carissa carandus, Pueraria tuberosa, Helicteres isora, Holarrhaena antidysentrica, Murraya koenigii, Adhatoda vasica, Chrysopogon fulvus, and heteropogon contortus*, etc., are flourishing. However, as a result of improved conditions, *Lantana* is invading which was not there before as the soil and the forest were degraded.

31.3.2.4 Improved water table

Records are available that the water table in the village before the construction of the dam was at 70 feet. But within a period of seven years, the water table has risen to about 35 feet.

31.3.2.5 Agroforestry is visible in the village

The village land remained mainly dry during winter and summers as there was no source of irrigation. However, at present not only have the people of the village shifted to irrigated and high value crops but have also started practising agroforestry. They have started growing poplar and eucalyptus on their land. This is also an indication of improved water table. There are about 2,000 each of poplar and eucalyptus in the village against none before the water harvesting dam.

31.3.2.6 Socio-economic changes

All *kachcha* houses have been replaced by *pucca* ones as a result of good income from crops like sugarcane and wheat. Villagers have almost disposed of their cows and are rearing buffaloes. Besides meeting their own requirement, they are now selling milk which they never did before.

31.3.2.7 Literacy

The literacy rate in the village before the prosperity brought about by water harvesting was about 25 per cent. At present, though the older generation continues to be illiterate, all children of the village go to school with nearly half attending public schools for better education.

31.3.2.8 Ecological changes

The whole catchment area has been rehabilitated and silt load has been reduced considerably. Water table has increased from 70 feet to 35 feet.

31.3.3 Village Paniwala

This village is also located in the Lower Shivalik hills of Yamunanagar district. Like Rampur Gainda village, in 2005 this village was selected under European Union aided HCFP for management of common property resources. The village had about 45 households at that time and the entire population comprised of Gujjar community. Rearing of sheep and goats was their main occupation. They grew subsistence crops like maize and lived from hand to mouth. The forest in the vicinity of the village was totally degraded. The village had more than 1,000 sheep and equal number of goats. These animals would graze in the forest. Soil erosion was at a peak. Conflicts between the people and the forest department were very common.

As people of the village wanted water harvesting dam, under HCFP one dam was constructed in 2006 with some people's share in the form of labour or monetary contribution. It was felt that water would bridge the gap between the people and the forest department. The dam can irrigate area up to 60 hectares.

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31.3.3.1 Change in cropping pattern

After about seven years of construction of water harvesting dam, the comparison of the present cropping pattern with the pre dam scenario is given in Table 31.4, It is evident from the table that as regards cropping pattern, we have got almost the same results as in the case of Rampur Gainda. Hence, a detailed description of these changes need not to be given.

As regards the socio-economic and ecological changes, we have got almost similar developments in this village as well. The water table here has improved still better from 50 feet to 30 feet. Agroforestry is more common here. People have become wiser and they decide on a cropping pattern after proper cost benefit calculations. So, they do not raise *barseem* fodder in their village but buy it from nearby villages. They raise cash crops which brings them more money than *barseem*. They use some of this money for buying fodder from the nearby village and save the rest. People of the village now lead a better life. Except four *kachcha* houses, all houses have been replaced by *pucca* ones. They have resorted to stall feeding. The children go to nearby public schools. The catchment area has been rehabilitated.

Table 31.4: Pre and post earthen rainwater harvesting dam – crop and yield scenario

Crop	Area before 2006 (ha)	Area in 2013 (ha)
Maize *(Zea mays)*	24	---
Pearl Millet *(Pennisetum glaucum)*	8	---
Peanut *(Arachis hypogaea)*	8	---
Paddy *(Oryza sativa)*	---	42
Cheri *(Sorghum bicolor)*	8	7
Wheat *(Triticum aestivum)*	15	32
Egyptian Clover *(Trifolium alexandrinum)*	---	4
Lentil *(Lens culinaris)*	2	2
Sugarcane *(Saccharum officinarum)*	2	40

31.3.3.2 Ecological prosperity through rain water harvesting in Chandigarh

The Union Territory of Chandigarh is a well-planned modern city of India and is the capital of Punjab and Haryana States. It is situated in the lap of the panoramic Shivaliks and the city is just an extension of the hills. Sukhomajri type of JFM approach can't be applied here as there are no villages dependent upon forests in Chandigarh. However, rainwater harvesting approach was adopted here as well. As of August 2013, Chandigarh Forest Department had constructed 190 water bodies in Sukhna Wildlife Sanctuary.

As a result of rainwater harvesting, there have been nearly textbook pattern changes in eco-restoration of biodiversity. The underground water regime has been improved considerably. The rate of soil erosion has been reduced from 160 MT/ha/year (in 1988) to 5.6 MT/ha/year in 2004 from the forest area. The water that comes from the forest has improved the quality of Sukhna Lake water. However, some problems still persist as some portion of the lake's catchment area falls in privately owned fields. The owners of these fields till the land and therefore, continue to send silt down into Sukhna Lake.

Within the sanctuary area in the control of Chandigarh Forest Department, there is perennial flow of seepage water in seasonal streams/choes not expected in dry Shiwaliks. As a result of this, the sanctuary has rich flora and fauna. The wildlife lives in complete harmony with nature as there is availability of water and palatable fodder year around. You enter the forest and you are sure to see wildlife including Sambar Deer *(Cervus unicolor)* and Spotted Deer *(Axis axis)*; leave a variety of chirping birds, honey bees and butterflies. Occasional sightings of leopard *(Panthera pardus)* and Barking Deer/*Muntjac (Muntiacus muntjac)* prove beyond doubt that a healthy forest exists in Sukhna Wildlife Sanctuary.

31.4 CONCLUSION

It can be concluded from this study that water acts as a catalyst in bringing about ecological and socio-economic prosperity. Constant dialogue with the people bridges the gap between the forest department and the people, and the people in return protect forests, biodiversity and watersheds. Working in isolation however, widens this gap leading to ecological and economic disasters. The study also leaves no doubt that the dry Shivaliks can be turned into lush green hills by harvesting and storing the excess water during rainy season which otherwise goes waste besides causing soil erosion and floods down in the plains. The availability of fodder as a result of improved moisture regime keeps a proper balance between flora and fauna and prevents man-animal conflicts as well. Even honey bees and butterflies, which are integral part of the ecosystem, are taken care of as the sources of pollens and nectar increase in the forest.

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32

Hydrological and Ecological Studies towards Integrated Water Resource Management: A Case Study of Shimla Water Catchment Sanctuary, Himachal Pradesh

Dipika Rana, K. S. Kapoor and V. R. R. Singh

32.1 INTRODUCTION

Under the given hydrological and ecological circumstance, forests always occupy the front seat being the best land cover thereby, leading towards maximizing water yield and regulating seasonal flows. Besides, forested watersheds generally offer high-quality water as undisturbed forest with understorey, leaf litter and organically enriched soil. Forested catchments also supply a high proportion of the water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas. In addition, the availability and quality of water in many regions of the world are getting more and more threatened by its overuse, misuse and pollution. Moreover, climate change is also altering forest's role in regulating water flows thereby influencing the availability of water resources (Bergkamp *et.al.*, 2003). Therefore, relationship between the forests and water is a critical issue that must be accorded high priority especially in view of the overgrowing menace of climate change. Accordingly, a key challenge being faced by the land, forest and water managers is to maximize the wide range of multi-sectoral forest benefits without any deterrent to water resources and ecosystem functions.

Similarly, there is a need to develop institutional mechanisms to enhance synergies in dealing with issues related to forests and water as well so as to implement and enforce action programmes at the national and regional levels. The International Year of Freshwater, 2003 and the Third World Water Forum (Kyoto, Japan, 2003) helped drive the incorporation of this understanding of bio-physical interactions between forests and water into policies. The International Expert Meeting on Forests and Water, held in Shiga, Japan in November 2002 in preparation for these events, highlighted the need for more holistic consideration of interactions between water, forest, land uses and socio-economic factors in complex watershed ecosystems (Megahan, 1977; Cassells *et.al.*, 1984; FAO, 1996, 1999; Hamilton, 2004; Thang and Chappell, 2004). They include measures to protect soil water and nutrient status, the recharge of major aquifers, micro-climate and evaporation, and river resources.

Many municipalities (certainly not all) cite maintenance of a pure water supply as a reason for introducing forest protection or reforestation. In the United States, all states are required under federal law to have a Source Water Assessment, which promotes the idea that protecting drinking water at the source is the most effective way of preventing drinking-water contamination (NRDC, 2003). The city of New York is famous for its use of protected forests to maintain its high-quality water supply.

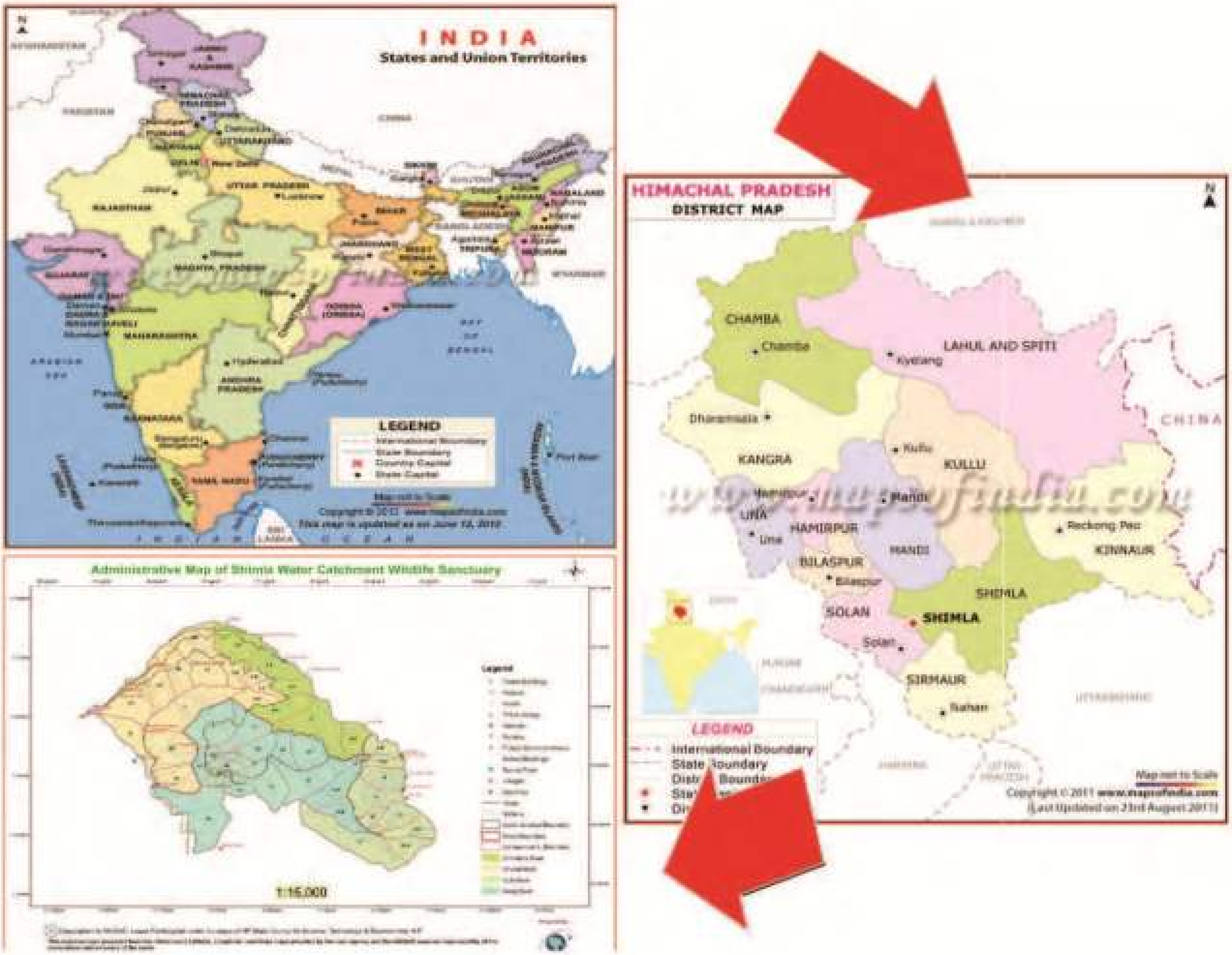
Similar examples are found in many tropical and sub-tropical regions. The Mount Makiling Forest Reserve south of Manila, the Philippines, is a 4,244 ha area of forest administered and managed by the University of the Philippines. More than 50 per cent of the reserve is forested, and its watershed ecosystem supplies five water districts and several water cooperatives serving domestic, institutional and commercial water users. Other examples of major cities drawing some or all of their drinking water from protected areas include Mumbai, Jakarta, Karachi, Singapore, Colombia; Brazil, Zimbabwe, etc. To address this challenge, there is an urgent need for a better understanding of the interactions between forests/trees and water for awareness and capacity building in forest hydrology.

32.2 METHODOLOGY

In view of the above, the present study was undertaken in Shimla Water Catchment Sanctuary, located 8 km east of Shimla, Himachal Pradesh and having an area of 1,020.32 ha in between 31°05' to 31°75'N latitude and 77°12' to 77°15' longitudes. Located in the Lesser Himalayas, the climate of the sanctuary is temperate with cold winters. The temperature touches a maximum of 32°C in summers whereas the minimum temperature drops down to 4°C in winters. The average annual rainfall is 2,000 mm with typical monsoon type pattern and having its maximum downpour during July to September. During winters, precipitation is in the form of snowfall which, of course, has reduced considerably over the years. The altitude of the sanctuary varies between 1,850 m and 2,750 m above msl and the terrain is moderate to very steep and precipitous at places. The sanctuary area is divided into 4 beats and 2 blocks. Out of its four identified beats, water sources in the sanctuary are present in Seog and Churat beats. In total 11 perennial sources and about 14 seasonal sources are present. The sources both perennial and seasonal at Seog lie at an altitude between 2,134-2,622 m above msl whereas sources of Churat lie at an elevation varying between 2,100-2,530 m above msl (Figure 32.1).

The sanctuary has its historical significance and derives its name from the hydrological functions it is performing for more

Figure 32.1: Location of Shimla Water Catchment Sanctuary



than last 120 years for Shimla city. Water supply originally started in the year 1875 for a population of 16,000 residents and was a major source of water till 1992. However, part of the water supply to the city is still contributed by the Shimla Water Catchment Sanctuary. It is drained by a number of seasonal and perennial streams and all the streams form the catchment of the Ashwini Khad which ultimately drains into the Giri river, a tributary of the Yamuna river. The data on water hydrology was analyzed by taking data from the records of IPH (Irrigation & Public Health) Department for the period of last seven years. The data on total water output for the two blocks were studied, analyzed and compared for the different seasons, i.e Summer, Winter, Monsoon and Autumn. Floristic studies were undertaken to identify the vegetation present in the given blocks at different elevations. For this, simple random sampling method was used. In each aspect a plot of 50m×50m was marked. Within this plot, sufficient number of quadrats of the size 10m×10m for trees, 5m×5m for shrubs and 1m×1m size for herbs were laid randomly. The data was analyzed for density, frequency, abundance, total basal area, IVI, etc., following standard ecological methods (Curtis and McIntosh, 1950; Samant *et.al.*, 2002).

32.3 RESULTS

The results showed that the total water discharge of Seog block declined from 268.2 MLD in 2004-05 to only 3.6 MLD in the year 2012-13. Maximum collective water discharge in the Seog beat was recorded during the monsoon season which was 180.7 MLD during 2004-05 but showed tremendous decline to 3.6 MLD by 2012-13. Though the water contribution in case of Churat was found fluctuating yet it contributed its maximum to the water discharge in the sanctuary (Table 32.1). For Churat, the maximum water discharge was seen both in the spring and winter seasons with decline in the summer season over a period of time. Total water discharge was 2,089.8 MLD in 2004-05 and decreasing trend reached 812 MLD by 2010-11 but the water discharge again

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showed a slight increase to 968.5 MLD in 2012-13. Maximum water discharge (865 MLD) was seen in the spring followed by summer (480 MLD) in 2004-05 but declined by 2012-13 with spring season showing discharge to 176.7 MLD and summers contributing only to 188 MLD (Table 32.2). The winter season has maintained little consistency in its water discharge over the period of time followed by monsoon. From these observations it can be concluded that Churat has more efficient water yielding capacity as compared to Seog but its improper maintenance and usage of old water harvesting techniques over the past 100 years has led to its declined water discharge. This can also be attributed to the effect of climate change over the period of time.

The vegetation around these sources has also been analyzed and it was found that the main perennial sources were present in the forested region mainly comprised of trees like *Cedrus deodara*, *Quercus spp*, *Picea smithiana*. Shrubs mainly included *Daphne papyracea*, *Berberis spp* whereas *Gallium aparine*, *Viola spp*, *Fragaria spp*, *Oxalis spp* and ferns were the associated herbs in the sanctuary area. *Hedra helix*, *Clematis spp*. *Vitis semicordata*, *Rubia cordifolia*, *Ficus pumila* comprised of some climbers present in the area. Other details pertaining to the distribution of vegetation in the sanctuary can be had from Tables 32.3 and 32.4.

Table 32.1: Total yearly water discharge (MLD) of the Churat & Seog blocks over a period of time in Shimla Water Catchment Sanctuary

Year	Seog	Churat
2004-05	268	2089.8
2006-07	35	1017.7
2008-2009	130	738.7
2010-2011	42	812
2012-13	3.6	968.5

Table 32.2: Seasonal water output (MLD) of the Churat & Seog blocks in different seasons

Year	Spring		Summer		Monsoon		Winter	
	Seog	Churat	Seog	Churat	Seog	Churat	Seog	Churat
2004-05	0.001	865	31.792319	480	181	324.9	58.1	419
2006-07	0.338	200.6	3.553219	229.5	16.2	196	15.2	391
2008-09	0.551	200	7.7202	242	58	124	40.2	172
2010-11	0.55	145	4.1448	225	24.2	209	17.1	232
2012-13	0.024094	176.7	0.001218	187.9	3.2	314.9	0.35	288.9

Table 32.3: Vegetation pattern of the Churat block for different sources at different altitudes

S. No.	Perennial sources (elevation 2100-2530m)	trees	shrubs	herbs
1	1a	*Cedrus deodara, Picea smithiana*	*Prinsepia spp, Rubus spp, Berberis spp*	*Mostly ferns, Viola, Gallium aparine, Hedra helix*
2	20	*Cedrus deodara, Picea smithiana*	*Daphne spp,Sarcococa saligna*	*Ophiopogon intermedius, ferns, stellaria media,Hedra helix*
	Seasonal sources (elevation 2000 m-2530m)	**trees**	**shrubs**	**herbs**
1	9b	*Q.diltata, Cedrus deodara*	*Viburnum spp, Deutizia spp*	*Viola spp,Ophiopogon intermedius*
2	9a	*Picea smithiana Q.diltata, C.deodara*	*Indigofera spp,Deutizia spp, Berberis spp*	*Gallium aparine, Fragaria spp, Oxalis spp*
3	8(2)	*Cedrus deodara, Cupressus torulosa*	*Daphne spp, Viburnum spp*	*Poa spp, viola spp*
4	4a	*Cedrus deodara, Picea smithiana*	*Daphne spp, Rosa moschta*	*Rumex nepalensis, Viola spp., poa spp*
5	3a	*Cedrus deodara*	*Rubus spp, Daphne spp*	*Rumex nepalensis, ferns*
6	1a	*Cedrus deodara,Quercus spp.*	*Bonninghausenia albiflora, Daphne spp.*	*Ferns in plenty, impatiens spp,Gallium spp*
7	26(2)	*Cedrus deodara, Quercus spp*	*Indigofer spp, Viburnum spp, Rosa moschta, Desmodium*	*Viola spp, Fragaria spp, ferns*

Table 32.4: Vegetation pattern of the Seog block for different sources at different altitudes

S. No.	Perennial sources (elevation 2134-2622m)	trees	shrubs	herbs
1	14	*Cedrus deodara, Q.leucotricophora*	*Viburnum spp, Berberis lycium*	*Thalactrum spp, Gallium aparine, Hedra helix*
2	12	*Deodar,Pinus wallichiana*	*Berberis spp, Prinsepia spp*	*Viola spp., Fragaria spp., grasses, Clematis spp.*
3	9c	*Cedrus deodara, Picea smithiana*	*Rubus ellipticus, Daphne spp, Boenninghausenia albiflora*	*Gallium aparine, Thalactrum spp, Fragaria spp, Hedra helix*
4	5	*Deodar, Quercus diltata*	*Berberis spp, Rubus spp*	*Ferns, Gallium aparine, Viola spp., Hedra spp.*
5	16a (2)	*Moru, Pinus wallichiana*	*Rumex spp, Rubus spp, Rosa moschta*	*Bergenia spp, Gerbera gossypina, viola spp., Clematis spp.*
6	19 (3)	*Deodar, Pinus roxburgii,*	*Berberis spp, Rubus spp, Daphne spp.*	*Viola spp, Gallium aparine, grasses*
	Seasonal (elevation 2165m-2560m)	**trees**	**shrubs**	**herbs**
1	30	*Deodar, Q.diltata, Q.leucotricophora*	*Indigofera heterantha,Berberis spp, Prinsepia*	*Ainselia aptera, Viola spp*
2	31	*Deodar*	*Berberis spp, Daphne ssp, Prinsepia*	*Gallium aparine, Viola spp*
3	33	*Deodar, Quercus diltata*		*Viola spp., Fragaria spp., grasses, Clematis spp.*
4	6	*Deodar, Pinus wallichiana, Rhododendron*	*Berberis spp,Rubus spp, Prinsepia*	
5	5	*Deodar, Quercus diltata*	*Berberis spp, Rubus spp*	*Ferns, Gallium aparine, Viola spp*

32.4 DISCUSSION

The present study revealed that the forests play a major role in towards water conservation. A study conducted by Dudley and Stolton (2003), indicated that about one-third (33 of 105) of the world's largest cities obtained a significant proportion of their drinking water directly from protected forest areas. Impacts of forests are influenced by many factors including the age and species of the trees, the amount of watershed under forest, soil, and forest management practices. A meta-study conducted for the World Wide Fund for Nature (WWF) on the role of forest protection in drinking-water provision (Dudley and Stolton, 2003), including a survey of more than 100 of the world's most populous cities, described a clear link between forests and the quality of water coming out of a catchment, a much more sporadic link between forests and the quantity of water available and a variable link between forests and the constancy of flow. Accordingly, the fluctuating trends in the water output of the catchment area studied over the period of 7-8 years can be the effect of various components of climate change as regulated by rainfall, snowfall, temperature, humidity, etc. Leakage and breakage of the underground pipes in the century old system installed in the 1880s might have added to the fluctuation and accordingly need early replacement.

Despite years of catchment experiments, the precise interactions between different tree species and ages, different soil types and management regimes are still often poorly understood, making accurate predictions difficult. In contrast with popular assumptions, many studies suggest that in both very humid and very dry forests, evaporation is likely to be greater from forests than from land covered with other types of vegetation; thus less water flows from forested catchments than, for example, from grassland or crops (Calder, 2000). A specific study made by Tremolieres, *et al.*, 2002 showed that *Hedera helix* benefits forest communities by protecting the floor from frost and erosion, increasing soil nutrient levels through the rapid decomposition of its litter in early summer, and by providing winter shelter and food to many species of birds, insects and mammals. As such, *Hedera helix* plays a significant role in the forest ecosystem and should not be manually removed in polders, especially as it is naturally regulated by floods.

RECOMMENDATIONS

People have settled historically in areas rich with natural resources, and today most of the world's population lives downstream of forested watersheds (Reid, 2001). Societies have created strong cultural links with forests, and it is widely assumed that forests help to maintain a constant supply of good-quality water. Conversely, loss of forests has been blamed for problems ranging from flooding to aridity. The contributions of forests in providing clean water depend to a large extent on individual conditions, tree species and age, soil types, climate, management regimes and needs from the catchment. It is, therefore, perhaps not surprising that information on best practices for policy-makers remains scarce and models for predicting responses in individual catchments are at best approximate. Perhaps some steps can be recommended for better functioning and combating water scarcity. Maintenance and replacement of pipes, reservoirs, tanks, etc., that are leading to improper functioning and leakage in water supply. Identification of various important water harvesting points and their altitude which contributes to the maximum water flow needs to be studied. There is a need for installation of various experimental instruments to check the water flow trends viz-a-viz undergoing scientific studies related to climate change, vegetation and soil. These measures would further help scientifically in combating problems of water scarcity in the future.

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