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Spatiotemporal analysis of the effects of forest covers on stream water quality in Western Ghats of peninsular India

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SUMMARY

The hydrological research has largely concentrated on two extremes – undisturbed forest cover 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 this reason, research on spatiotemporal variations in the effects of a mix of primary forest, mature secondary forests and disturbed forests on stream water quality was conducted in four watersheds in the Western Ghats of peninsular India. The study indicated that every one percent decrease in the forest cover (all lands with tree cover of canopy density of 10% and above when projected vertically on the horizontal ground with minimum areal extent of one ha) increases turbidity, total suspended solids (TSS) and *Escherichia coli* by 8.41%, 4.17% and 3.91%, respectively as also decreases calcium hardness by 0.49%. However, when the forest cover was segregated into old forests (primary forest, mature secondary forest and undisturbed mature plantations) and, open and disturbed forests the old forests were observed to significantly improve ($p < 0.05$) most water quality parameters. In contrast the open and disturbed forests were observed to deteriorate the observed water quality parameters except for turbidity and TSS. The magnitudes of regression coefficients indicated that the old forests were 2.2 and 2.74 times more effective than the disturbed forests in reducing turbidity and TSS, respectively. Tradeoffs between the provisioning services and water quality improvement services of the forest were apparent.

1. Introduction

It is well accepted that in comparison to watersheds with other land uses, watersheds with natural forests almost always provide higher quality water with less sediment and fewer pollutants (Calder et al., 2004, 2007; Dudley and Stolton, 2003; Welsch, 1991). However, forests today are no longer a undisturbed patch of woodland but a mix of disturbed forests, secondary vegetation and old forest interspersed with patches cleared for agriculture or other non-forest use, particularly in the tropics (Bruijnzeel, 2004; Giambelluca, 2002). But the impact of changes in density and age or other such parameters of the forest cover on the stream water quality has not really been evaluated. Neither do we have studies that quantify the changes in water quality as a result of increase or decrease in the forests (Elias, 2010) making it difficult to incorporate the role of forests in decision making processes like cost-benefit analysis. There is still an ongoing debate regarding whether the land use of the entire catchment or that of the riparian zone is more important in influencing the water quality, all other factors remaining constant (Delong and Brusven, 1991; Johnson et al., 1997; Osborne and Wiley, 1988). Each catchment has a unique combination of characteristics that influence water quality therefore it is difficult to translate such research findings between countries and regions, between different catchment scales, between different forest types and species, and between different forest management regimes (IUFRO, 2007). Therefore the study aimed at finding answers to the questions – what is the influence of deforestation on the stream water quality in the Western Ghats of peninsular India? Is there any variation in the impact of the old and mature forests vis-a-vis the open and disturbed forests on the stream water quality?

The water quality parameters – turbidity, total dissolved solids (TDS), total suspended solids (TSS), pH, total hardness, calcium hardness, total chloride, Ca, Fe and Mg, total coliforms and *Escherichia coli* – were selected for the study. Time series secondary data

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over 13 years (1998–2010) of four watersheds of the Western Ghats, GIS and multivariate analysis tools were used to determine the correlation between water quality and forest cover. The study area is described in Section 2. Section 3 specifies the model, data collection and its processing. Section 4 gives the results followed by discussions and conclusions in Sections 5 and 6, respectively.

2. Description of the study area

This study focused on a cluster of four watersheds of the Western Ghat mountain ranges – Pise, Tansa, Lower Vaitarna and Manda – located between longitudes 73.127°E and 73.65°E and latitude 19.28°N and 19.70°N. Within the Pise watershed water samples were also collected at the sites Bhatsa and Sapgaon thereby adding sub-watersheds Bhatsa and Sapgaon (that are nested within Pise watershed) to the studied watersheds (Fig. 1). The watersheds lie on the Western Ghats mountain range. The main geological formation is the basaltic Deccan trap. This rugged tract is a network of deep cut ravines, numerous cross spurs and isolated hills. Most hills have plateaus with grassy lands and less tree cover as compared to the dense cover on slopes. The salient features of the watersheds are given in Table 1. The distinct seasons in a year are winter (December–February), summer (March–June), southwest monsoon season (June–September), and post-monsoon season (October–November), which is hot. The southwest monsoon season, June to September, provides about 94% of the annual rainfall. July is the wettest month with a rainfall of about 40% of the annual total. The average weighted rainfall is 2635 ± 346 mm per year.

All watersheds were well served with all weather and fair weather roads. They had limited industries or urban settlements. Agriculture was the main economic activity and engaged most of the inhabitants either as cultivators, share croppers or as agricultural labourers. Owing to the inadequate irrigation facilities, most of the crops depend on the monsoon. Paddy (wet rice) was the principal crop while some millets and lentils were also grown in this season. Slash-and-burn agriculture and shifting cultivation was still practiced on a large scale causing rampant fires in the forests and the grasslands during the summer season. Economic compulsions has lead to extensive tracts of steep hill slopes being put under cultivation accelerating soil erosion and deforestation. The time gap for leaving land fallow under shifting cultivation had also reduced considerably (from 10–15 years to 2–3 years). At places plots of shifting cultivation were under permanent cultivation. But because of this practice of burning biomass on agricultural fields there was not much use of fertilizer and pesticides till the last decade (Singh, 2013).

The natural forests in catchments are Southern Tropical Moist Deciduous type (Champion and Seth, 1968). Local people have

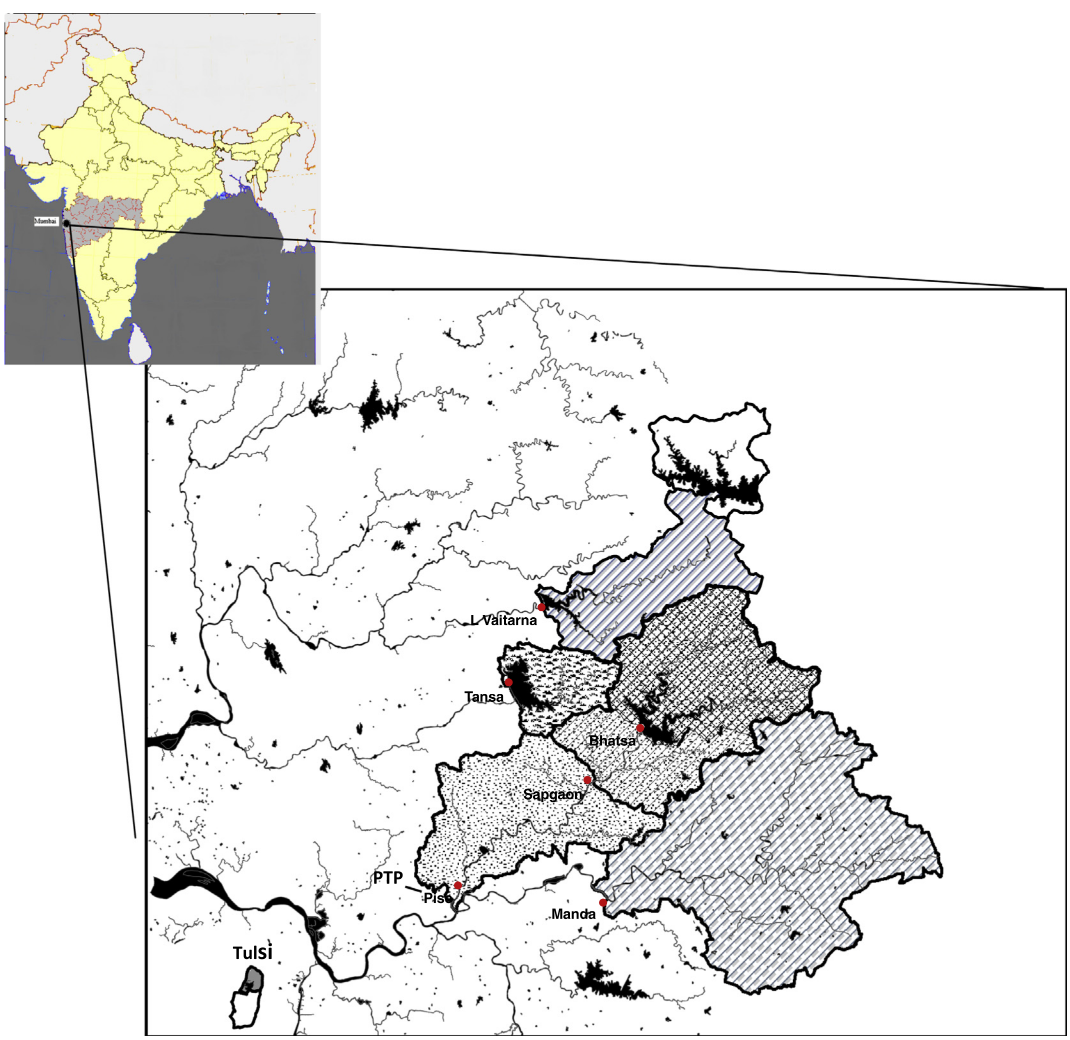


Fig. 1. Location of the study area, selected watersheds and sampling sites for water quality analysis.

Table 1
Area, Landuse and other features of the studied watersheds.

Features		Tansa	Pise	Sapgaon	Lower Vaitarna	Manda	Bhatsa
District		Thane	Thane	Thane	Thane	Thane	Thane
Catchment area (Sq km)		135.975	991.94	595.58	290	954.57	388.5
Av. weighted annual rainfall (mm)		2687	2862	2871	2532	1985.5	2872
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**
	Agriculture	12.66	49.25	47.39	34.55	49.26	45.16
	Grassland	2.6	3.55	3.39	0.14	3.32	1.85
	Wastelands	3.7	10.16	10.05	13.07	23.16	8.83
	Built up	0.07	1.11	0.65	0.87	1.06	0.12
	Water bodies	15.85	4.66	5.99	6.04	2.79	7.94
Forest subtype		Southern moist teak bearing forest					
Geomorphology		Mix of hills and plateau					
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.

depended on these forests for their subsistence from time immemorial resulting in a mix of open and disturbed forests in proximity of the villages, and moderately dense patches of primary forests on the inaccessible slopes. Efforts for recouping the disturbed and degraded forest lands have concentrated on raising more and more plantations with limited investments on its conservation. Consequently there are several patches of forests that have been planted two times or more in past three decades without very satisfactory results. Such plantations have often favoured fast growing species including exotics like *Eucalyptus*, *Acacia* and *Glyercidia*. Soil and moisture conservation works usually consisted of continuous or staggered contour trenches and loose boulder structure in nalas. The forest cover in the watersheds ranged from 25% to 45% of their respective watershed area (Fig. 2).

3. Methodology

Removal of forests tends to increase sediment yield as well as nutrient and chemical levels (Calder et al., 2004, 2007; Dudley and Stolton, 2003; Norton and Fischer, 2000). They, thus, influence the water quality. Some studies (Prepas et al., 2001; Nimiroski et al., 2008; Norton and Fischer, 2000; Sliva and Williams, 2001) have correlated streamflow and subbasin characteristics, such as land use and road density, forest management practices to median values or concentrations of water quality parameters like pH, color, turbidity, total coliform and *E. Coli* bacteria, chloride, nitrate, orthophosphate, iron, and manganese through multiple regressions. The predictors (landscape data) and the response variables of water quality (except pH) have usually been transformed with either a power or logarithmic function, to make the data normally distributed and to reduce the influence of outliers. Prepas et al. (2001), Norton and Fischer (2000) and Sliva and Williams (2001) further perform identical statistical analyses on data both from the buffer zone and the entire catchment to determine relationships between the landscape variables and water quality.

Some studies have attempted at understanding these relationship through spatiotemporal analysis. Like Villamizar and Waichman (xxxx) related changes in stream water quality to deforestation through correlation analysis of median water quality parameters with annual deforestation rates and accumulated deforestation rates over horizon of nine years Reiter et al. (2009) similarly evaluated the correlation between annual levels of forest management (timber harvest and road building) and seasonal median turbidity for four monitoring sites over horizon of 30 years. Figueiredo et al. (2010) used pooled data of land use and monthly water quality from five low order streams over horizon of three years in a mixed-model analysis.

3.1. Model specification

Following these studies the general form of the model was taken as $Q = f(\mathrm{FC}, X)$, where Q is the parameter for surface water quality, FC is Forest Cover as percentage of the watershed area and X is a vector of other environmental variables like soil type, topography, stream density within a watershed, the amount and timing of rainfall, land use patterns, the volume and velocity of waterways available to transport sediment, housing and construction activity, growth of manufacturing, growth of infrastructure, etc. However this study primarily focused on spatiotemporal variations in forest cover and its influence on the water quality. Hence, the complex relationship was simplified by taking forest cover and turbidity as the main variables. Further, as the monthly data spread over 13 years at six sites in four watersheds, multilevel mixed-effects linear model (broadly following Figueiredo et al., 2010) with the following form was used to evaluate impact of the forest cover:

$$\mathrm{Ln}(Q)_{itjk} = \gamma + \gamma_1 \mathrm{Ln}(\mathrm{FC})_{itjk} + \gamma_2 \mathrm{Ln}(R)_{itjk} + \gamma_3 \mathrm{Dre}_j + \gamma_4 \mathrm{Drp}_j + u_{t(i)} + u_{j(i),t(i)} + u_{k(i),j(i),t(i)} + e_{itjk} \quad (1)$$

where Q_{itjk} is water quality parameter in month i for year t at station j in watershed k, FC_{itjk} is forest cover as percentage of watershed area in month i for year t at station j in watershed k, R_{itjk} is monthly average weighted rainfall (in mm), Dre_j is the dummy for site which measures water quality at outflow of the reservoir (Dre = 1 if water sampled at outflow of a reservoir, otherwise Dre = 0.), Drp_j is the dummy for site which have presence of riparian forests (Drp = 1 if a riparian zone was present in over 70% water stream length, otherwise Drp = 0.), $u_{t(i)}$, $u_{j(i),t(i)}$, $u_{k(i),j(i),t(i)}$ is the random effects of year t, site j and watershed k. e_{itjk} is the error term with distribution $N(0, \sigma^2)$, γ is the constant, and γ_1, γ_2, γ_3, γ_4 is the regression coefficients of respective variables.

This specification implicitly assumes that the marginal effect of forest cover (and that of the other environmental variables) on water quality is nonlinear. It also allows to examine the extent of variance is at each level viz., year, site and watershed. Average weighted rainfall in mm (R) was included as variable because water quality parameters are likely to be affected by runoff and sediment levels resulting from rains. To avoid seasonal variations only the months during which rainfall was recorded (generally the months of rainy season i.e. June–October) were included. The dummy variable for reservoir and presence of riparian forests was included to account for influence of the reservoirs and riparian forests on the sediment load and other water quality parameters. Log transformations of water quality parameters (except pH[1])

[1] Since pH is already on log scale and therefore likely to be normally distributed without transformation.

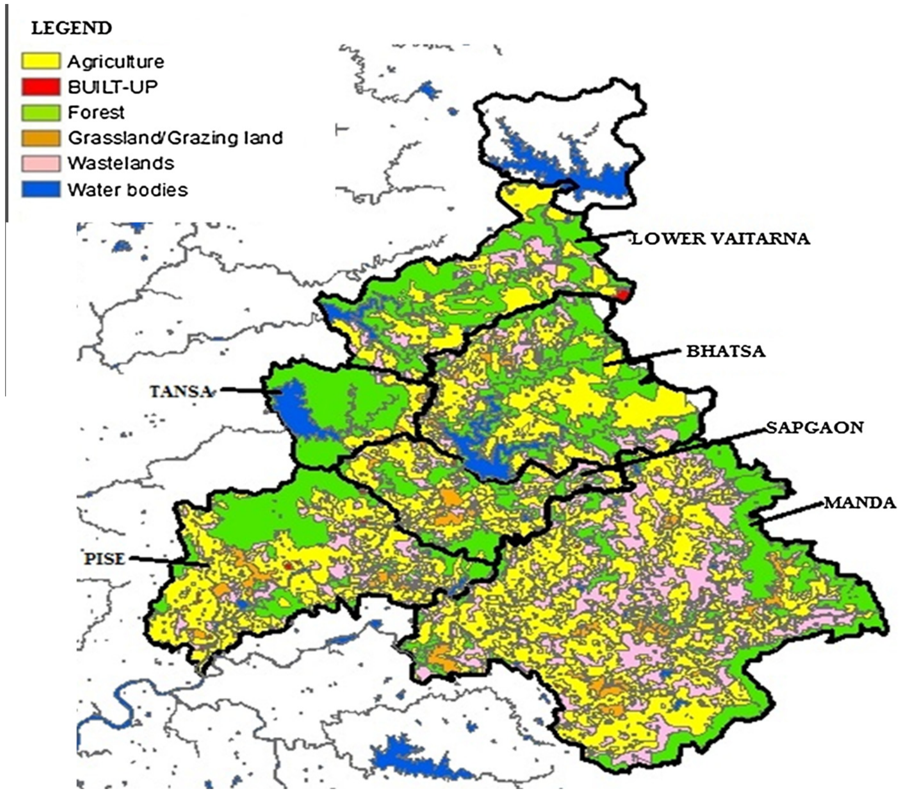


Fig. 2. Land use land Cover of the studied watersheds. *Source:* digitized maps from MRSAC, Nagpur and NRSC, Hyderabad.

and other variables were performed to better approximate a normal distribution. The aforesaid random intercept model was selected over random coefficient model for the forest cover as the Likelihood ratio test indicated that the mean response of the forest cover on water quality parameters did not vary significantly from one watershed to other.

To evaluate the effect of old forests vis-a-vis disturbed forests the forest cover in the aforesaid model was segregated as follows:

$$\mathrm{Ln}(Q)_{itjk} = \gamma + \gamma_{11}\mathrm{Ln}(\mathrm{OF})_{itjk} + \gamma_{12}\mathrm{Ln}(\mathrm{MF})_{itjk} + \gamma_2\mathrm{Ln}(R)_{itjk} + \gamma_3\mathrm{Dre}_j + \gamma_4\mathrm{Drp}_j + u_{t(i)} + u_{j(i),t(i)} + u_{k(i),j(i),t(i)} + e_{itjk} \quad (2)$$

where OF is the old and mature forest cover as percentage of watershed area, MF is the open and disturbed forest cover as percentage of watershed area, and

$$\mathrm{FC} = \mathrm{OF} + \mathrm{MF}$$

The maximum likelihood regressions were conducted with STATA SE. A significant correlation was defined as one with a probability of results from chance associations of the data equal to less than 5 percent (p value < 0.05).

3.2. Data acquisition and processing

3.2.1. Water quality parameters

Monthly average of turbidity and other water quality parameters in standard units for the years 1998–2010 were collected from the records of the Municipal Corporation of Greater Mumbai and the State Hydrological Project. The box plots for water quality databases are given in Fig. 3. Water quality data for the years 1998–2000 for the Manda watershed and for a few months for the Tansa and Lower Vaitarna watersheds were missing. In addition there were no records for calcium hardness, total coliforms and *E. Coli* for the Manda watershed. Hence, the dataset was unbalanced.

Water sampling at three sites i.e. Bhatsa, Tansa and Lower Vaitarna were at the outflow of reservoirs. Hence, Dre for them was taken as 1. Similarly, riparian forests over 70% stream lengths were observed in the watersheds – Tansa, Bhatsa, Lower Vaitarna and Sapgaon. So Drp was taken as 1 for them.

3.2.2. Change in forest cover

Forest cover in the watersheds over the years were interpreted from the orthorectified satellite images for the years 1973 and 1989 acquired from Landsat.org, digitized land use/land cover maps for the years 1994 and 2004 acquired from the National Remote Sensing Centre (NRSC), Hyderabad; and digitized Forest Cover Maps for the years 2000, 2004 and 2007 acquired from the Forest Survey of India (FSI), Dehradun. Methodology followed by Singh and Mishra (2012) and Villamizar and Waichman (xxxx) was adopted for classification and accuracy assessment of the satellite images, calculation of forest cover in the watersheds on year to year basis, and segregation of old and mature forest cover (OF) from open and disturbed forest cover (MF). Monthly change in forest cover in a year was estimated assuming a linear change in forest cover over the months.

3.2.3. Rainfall

Daily/monthly rainfall data from 1997 to 2010 for 20 rainfall stations in and around the study area were collected from various agencies viz. the Indian Meteorological Department (IMD), the State Hydrological Project, the Municipal Corporation of Greater Mumbai and the State Agriculture Department. Monthly rainfall data for missing months and weighted monthly rain as depth for the watersheds (in mm) were calculated by Normal ratio method and Thiessen mean method (Subramanya, 2008), respectively.

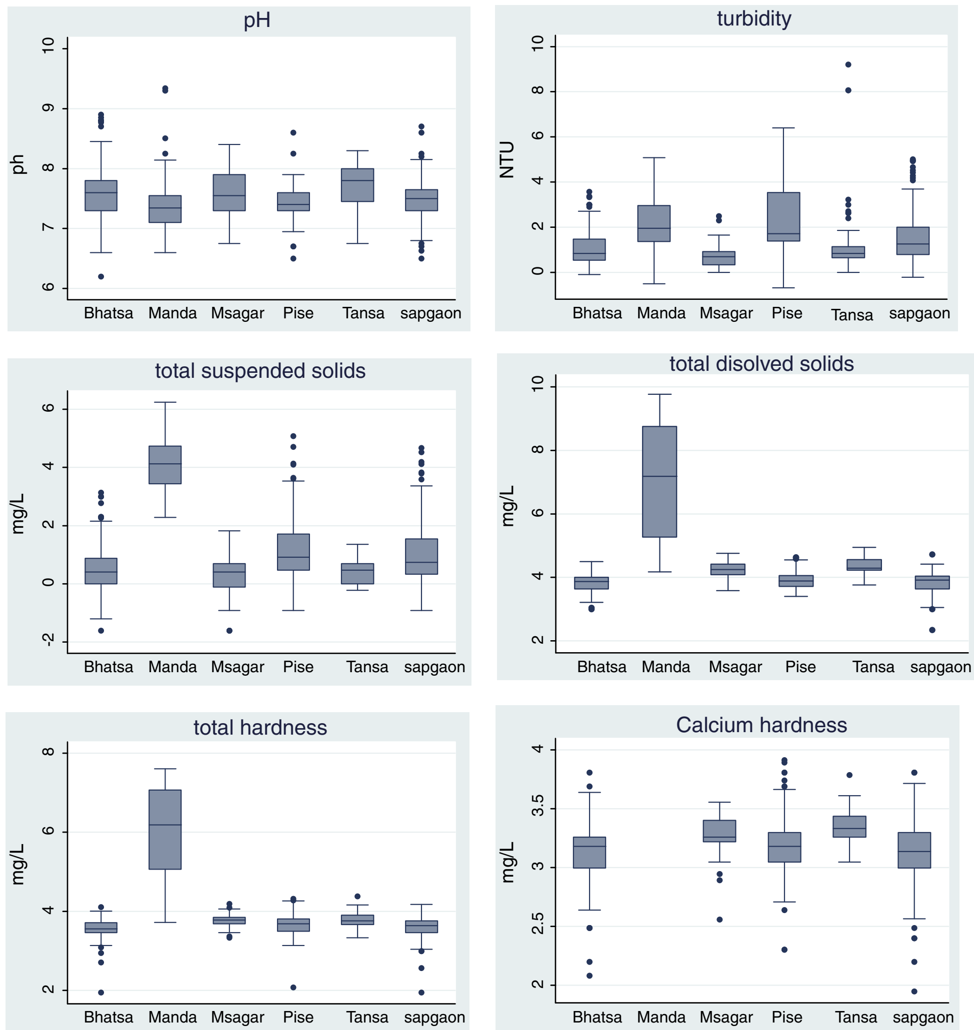


Fig. 3. Box plots of log transformed water quality parameters for different watershed.

4. Results

Amongst the 12 water quality parameters studied, the maximum likelihood regressions of Eqs. (1) and (2) were significant for nine water quality parameters – turbidity, pH, TSS, TDS, total hardness, calcium hardness, Ca, total coliforms and *E. Coli* – suggesting their correlation with the dependent variables. The regression coefficients of the forest cover for turbidity, TSS and *E. Coli* (Eq. (1), Table 2) were negative and significant ($p < 0.05$) while it was positive and significant for calcium hardness. The regression coefficients for other parameters – pH, TDS, total hardness, Ca and total coliforms – were insignificant. The elasticity of turbidity, TSS, *E. Coli* and Ca hardness with respect to the forest cover were −8.41, −4.17, −3.91 and 0.49, respectively which implies that every one percent decrease in the forest cover will increase turbidity, TSS and *E. Coli* by 8.41%, 4.17% and 3.91%, respectively while it would decrease calcium hardness by 0.49% (keeping all other parameters constant).

As expected the estimated coefficients of rainfall for all water quality parameters except for pH (where it was negative but insignificant) and calcium (where it was positive but insignificant) were positive and significant. The riparian forest cover was observed to significantly decrease turbidity and TSS which finds support of Basnyat et al. (2000), Dillaha et al. (1989), Richards et al. (1996), Schlosser and Karr (1981a,b). In addition the riparian forests significantly increased calcium and calcium hardness but no studies could be found for these parameters in the literature. The negative and significant correlation between the presence of reservoir and, turbidity and TSS could be explained by reduction in water flow on entry in reservoirs that favoured settlement of sediments and other such particles. Its negative correlation between other water quality parameters (Table 2) was probably indicative of healthy inflow–outflow ratio of water from the reservoir as the extent of deterioration in water quality is in general related to the retention time of the reservoir.

On segregation of the forest cover into old and mature forest cover (OF) and open and disturbed forests (MF) (Eq. (2)) contrasting responses of the two covers were observed for the most water quality parameters (Table 3 and Fig. 4). Both type of forest covers significantly reduced turbidity but reduction of TSS was observed to be significant for the old forests, only. The magnitudes of regression coefficient indicated that the old forests were 2.2 and 2.74 times more effective than the open and disturbed forests in reducing turbidity and TSS, respectively. The old forests were also observed to significantly reduce total hardness, Ca, total coliforms and *E. Coli*. Its relationship with TDS and Ca hardness was also negative but insignificant. In contrast the open and disturbed forests significantly increased calcium hardness. Its relationship with other water quality parameter was positive but insignificant thereby indicating the tendency of open and disturbed forests to deteriorate most water quality. The response to pH for both type of forest cover was similar, i.e., positive but insignificant.

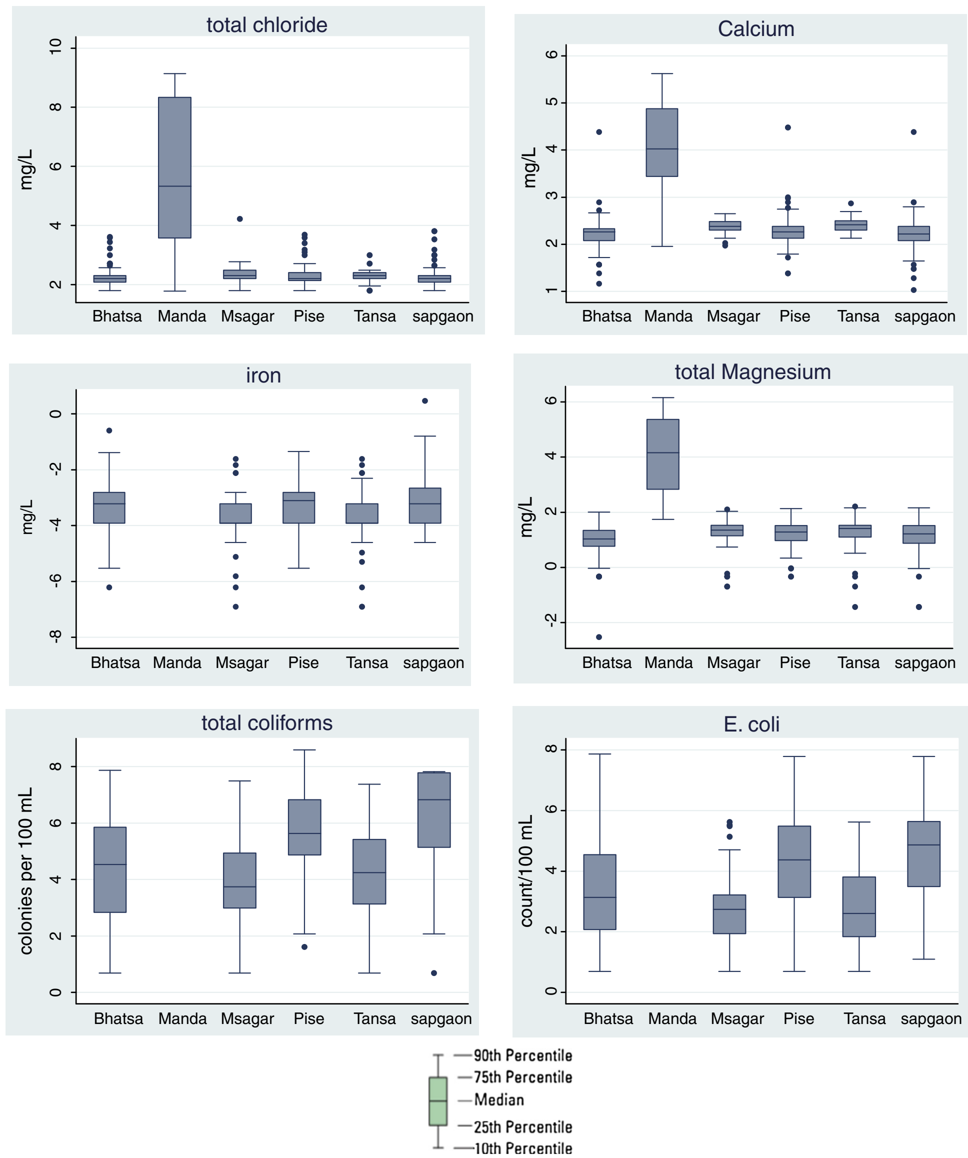


Fig. 3 (*continued*)

Table 2
Elasticity and estimates of variance for random parameter for total forest cover (Eq. (1)).

	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	0.41*	−0.009	0.15*	−0.05	6.11***	1.64×10^{-21}	4.11×10^{-23}	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								

Var_t, var_j, var_k = variation of random effect parameters.
*** $p \leqslant 0.001$,
** $0.01 < p \leqslant 0.05$.
* $0.05 < p < 0.10$.

Table 3
Elasticity of segregated forest cover (Eq. (2)).

	Old forest	Open and disturbed forest
Turbidity	-6.63^{***}	-2.96^{**}
pH	+0.44	+0.11
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

Specifically, every one percent increase in the old forest cover will decrease turbidity, TDS, TSS, total hardness, calcium hardness, calcium, total coliforms and *E. Coli* by 6.63%, 2.21%, 3.42%, 1.57%, 0.49%, 1.5%, 5.39% and 6.60%, respectively (keeping all other parameters constant). But every one percent increase in the open and disturbed forest cover will decrease turbidity by 2.96% and increase calcium hardness by 0.44%.

5. Discussions

Unlike cross sectional analysis by most studies determining land use/land cover–stream water quality relationship this study undertakes spatiotemporal analysis of historical data over horizon of 13 years to estimate the impact of deforestation on the stream water quality. In addition the study evaluates the differences in the impact of the old and the disturbed forest cover by segregating the forest cover within the catchments in two groups, i.e., (a) old forests – the forests that were undisturbed or less used and less disturbed by the people, and (b) open and disturbed forests – the patches of forests that were largely disturbed with occasional sprinkling of young/disturbed plantations and naturally occurring

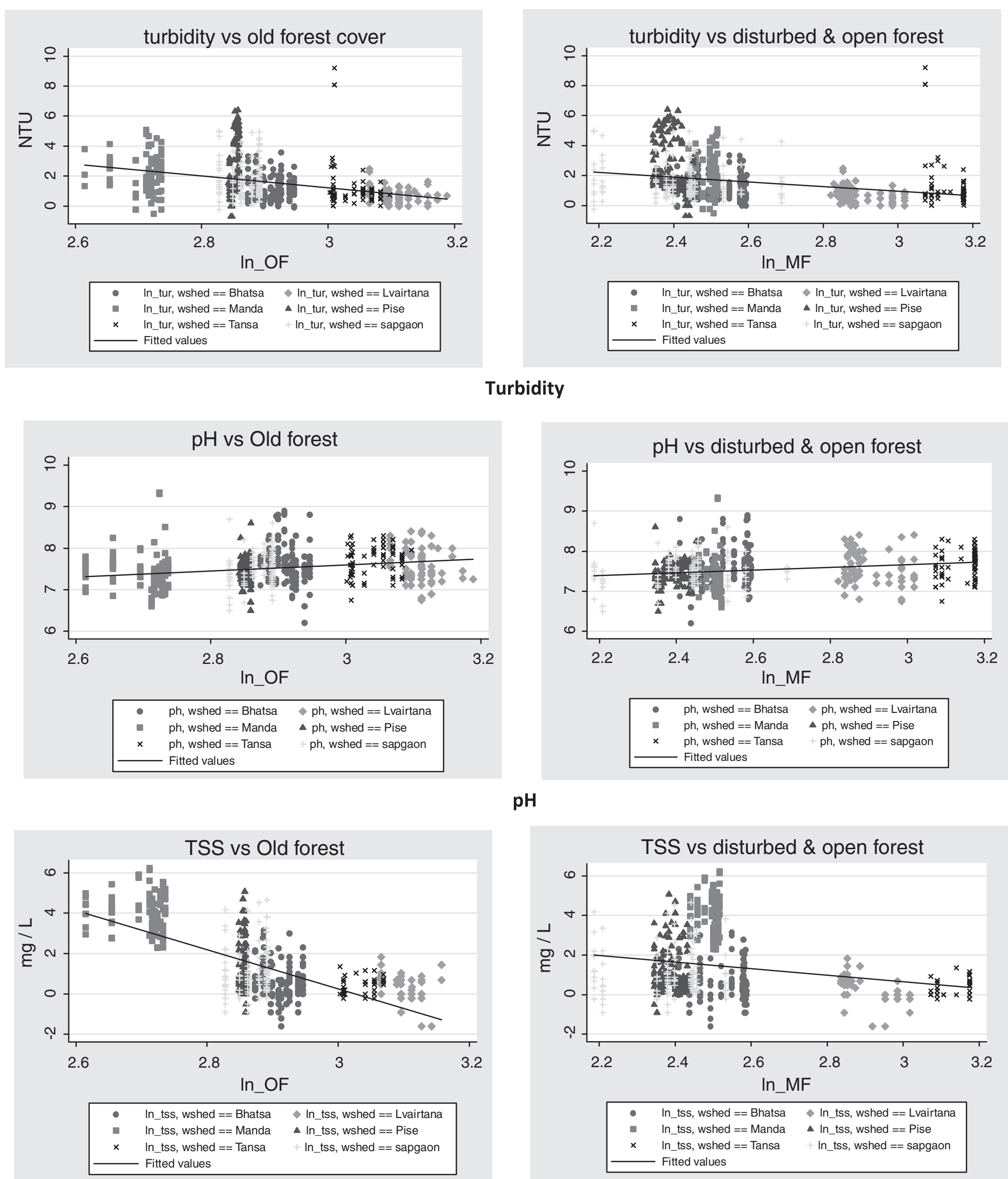
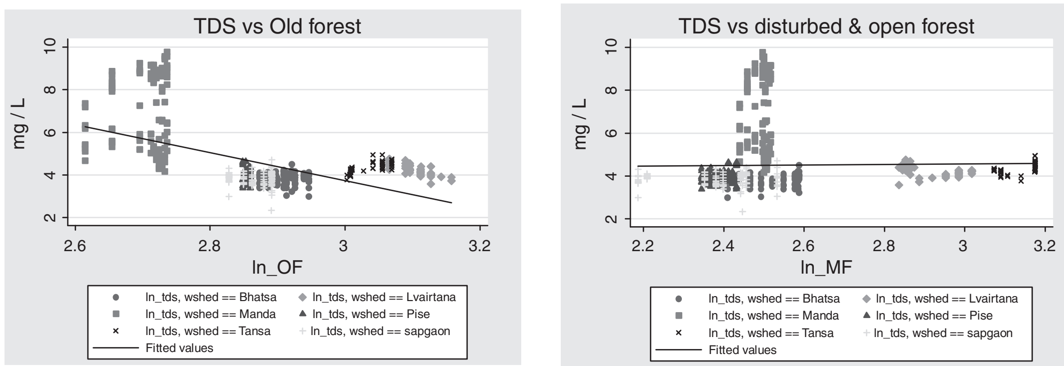
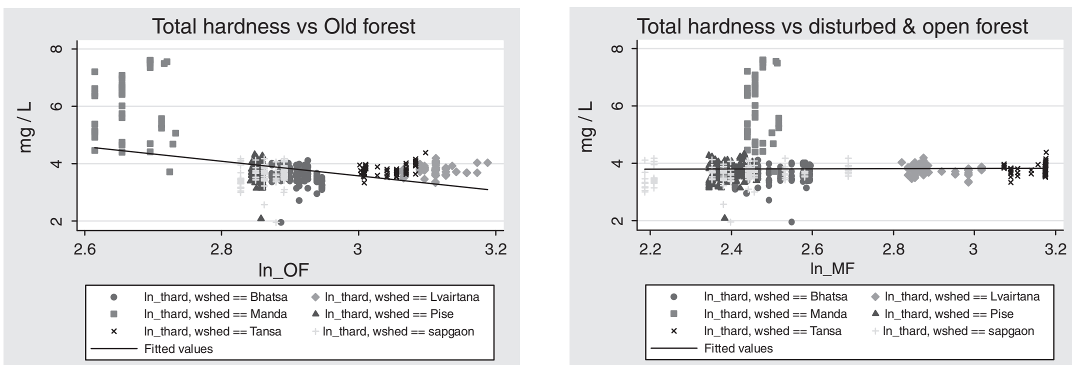


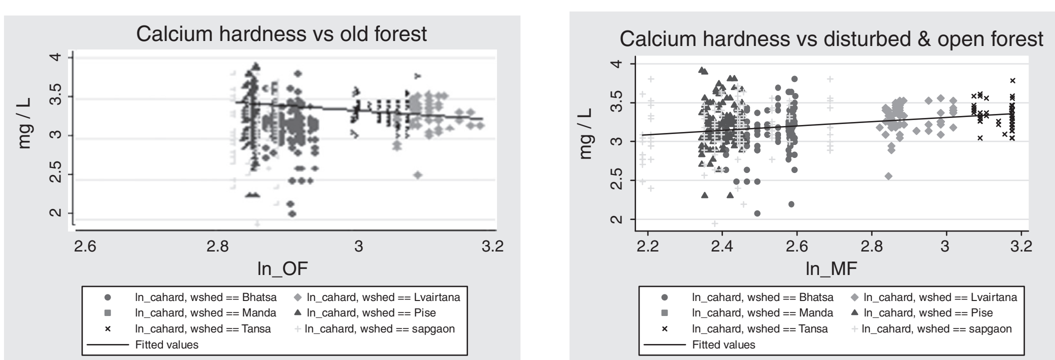
Fig. 4. Scatter plots of various water quality parameters against old forest and, disturbed and open forests and their regression slopes.



Total Dissolved Solids



Total Hardness



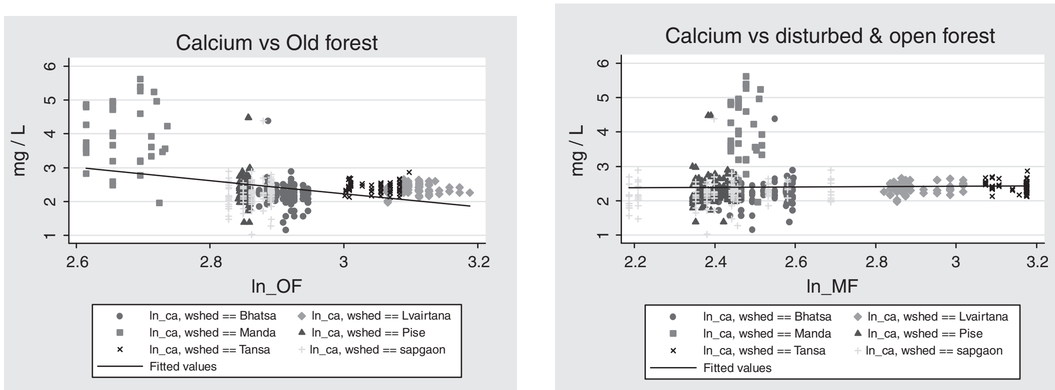
Calcium hardness

Fig. 4 (*continued*)

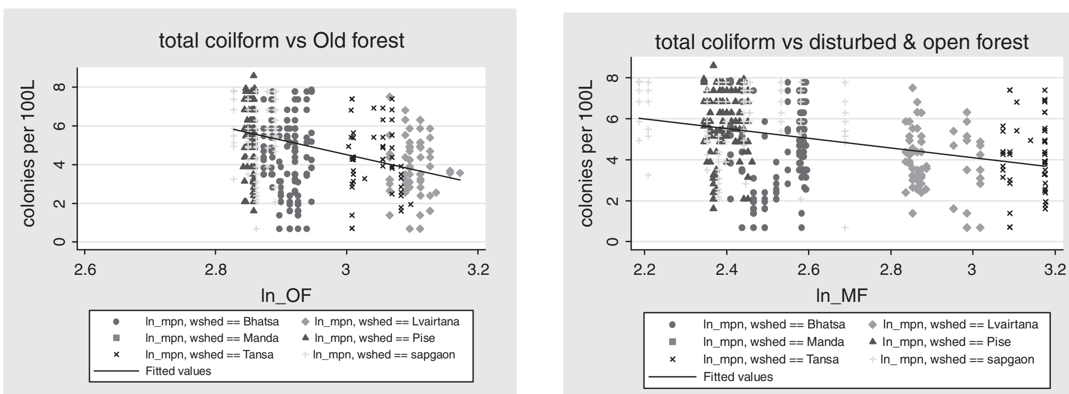
open forests. Such methodology (estimating deforestation over time + segregation of the forest cover within the same watershed) overcomes an important drawback of paired/cross-sectional experimentation, i.e., the possibilities of geological and climatic differences between the catchments that necessitate additional studies to draw concrete inferences. Further, the study has quantified the changes in the water quality in relation to the changes in the forest cover which has not been spelt out in many such studies.

The negative correlation between the forest cover, particularly the old forest, with most water quality parameters are in line with the findings of many studies (Adamski and Knowles, 2001; Bolstad and Swank, 1997; Crosbie and Chow-Fraser, 1999; Johnson et al., 1997; Nimiroski et al., 2008; Prepas et al., 2001; Sliva and Williams, 2001). Further in line with this study influence of forest cover on pH has not been found significant by Villamizar and Waichman (xxxx). The responses observed for the variable rainfall finds support of Figueiredo et al. (2010) who report elevated wet-season measures of conductivity (conductivity estimates the total ion concentration of the water, and is often used as an alternative measure of dissolved solids), alkalinity, and turbidity, with seasonal changes largest in the watersheds that had experienced the most deforestation. Figueiredo et al. (2010) also report insignificant correlations between increasing percent forest and cations but as against it this study found significant negative correlation between Ca and the old forests and significant positive between Ca and the disturbed forests. Lee et al. (2009) observe better water quality when forest patches are unfragmented, have a high value for the largest patch proportion, have complex patch shape, and are aggregated.

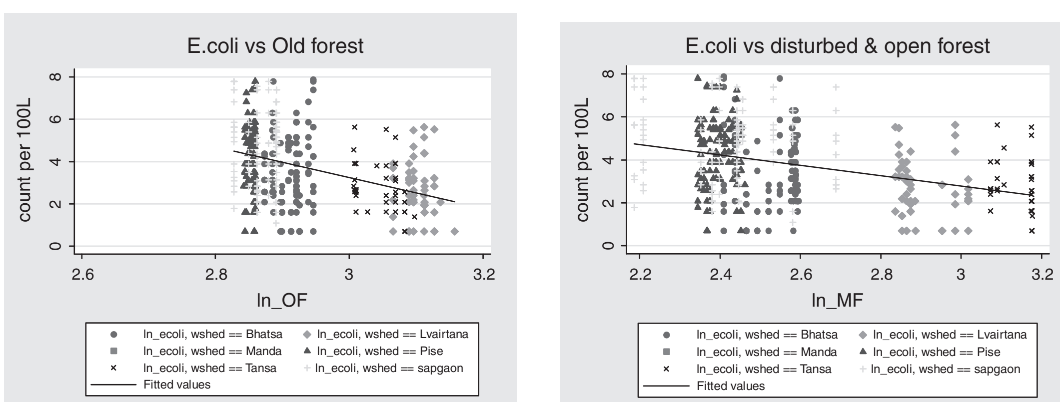
The aforesaid results could be explained by the fact that infiltration of precipitation and its movement through the soil are greatly influenced by vegetative cover (Bonell, 2005). A closed tropical forests promotes high infiltrability (because the dense root mat and the incorporation of soil organic matter in the topmost soil layers) and ground water recharge (by encouraging vertical percolation to comparatively deep groundwater bodies in many geological formations). This creates a positive feedback that avoids regular surface runoff on forested slopes under normal rainfall regimes



Calcium



Total Coliforms



E. Coli

Fig. 4 (*continued*)

(Bonell, 1998). Thus, negligible surface runoff under undisturbed forested conditions is reported by Malmer (1996), Nortcliff et al. (1990), Peh (1981), Roose (1977 in Malmer et al., 2005) and Serrano-Muela et al. (2008) as also the magnitude of peak flows is not found to be influenced by the intensity of precipitation but the depth to the water table in dense forest (Serrano-Muela et al., 2008). 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, 1983; Brinkmann and dos Santos, 1973). In open and disturbed forests this cycle is likely to be disturbed resulting in leaching of nutrients to the streams.

The activities associated with either forest conversion, fire or shifting cultivation disturb the equilibrium between soil hydraulic properties and the prevailing rainfall characteristics (notably short-term rain intensities) as the surface soil hydraulic properties (notably infiltration rates) are particularly sensitive to the preceding perturbations (Bonell and Williams, 1989). Such changed soil properties may cause a dramatic shift in the amount of rainfall partitioned between lateral and vertical pathways of storm water transfer (Bonell, 2005). Overland flow occurrence is enhanced

(increase in the average surface runoff volume and total water yield for a given area of land, increase the intensity of peak flows for a given precipitation event, and increase the frequency and intensity of extreme flow events, especially channel-forming flows) with corresponding dramatic increases in erosion rates, depletion of nutrient stores and degradation of within stream water quality (Bonell, 2005). Forest management activities that expose mineral soil also have the potential to increase surface erosion and deliver sediment to stream channels (Reiter et al., 2009). Thus, contrasting responses of the disturbed forests and old forests on water quality were observed.

Further, Eq. (1) revealed that a reduction in the total forests (TF) results in decreased water quality. Through Eq. (2) it can further be inferred that this reduction is on account of the reduction in the old forests. It is also apparent from the forest cover maps that the reduction in the old forests has occurred by its conversions to the disturbed 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 forests to local communities and sustaining livelihoods. Thus, tradeoffs between the provisioning services and water quality services of forests were apparent.

The forest cover in the watersheds studied was in the range of 25–45% of their respective watershed area. It emerges from findings of Ernst (2004) that changes in water quality with changes in forest cover are observed up to about 60% of the forest cover. Villamizar and Waichman (xxxx) too observe that the effects of deforestation on water quality are related more to the total area deforested than the annual rates, and those effects begin to be visible when a certain level of deforestation is reached. Hence, the relationship derived in this study may not be applicable for watersheds having forest cover higher than 60% or so.

6. Conclusions

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 (Malmer et al., 2009). However, the study pointed out at the need to maintain such distinctions as the responses of different forest covers on the surface water quality were different. In particular, the impact of disturbed and open forest cover on water quality was found to be opposite of the general perceptions about the forests. The study also brings out the tradeoffs between the hydrological and provisioning services of the forests. Hence, there is a need to protect the old and dense forest cover in the source area. Disturbed forests as well as plantations in the upstream should similarly be conserved so that with age they are able to extend better water quality services.

The study also observed that every one percent decrease in the forest cover will increase turbidity, TSS and *E. Coli* by 8.41%, 4.17% and 3.91%, respectively while it would decrease calcium hardness by 0.49% when other variables are kept constant. The old forests were 2.2 and 2.74 times more effective than the open and disturbed forests in reducing turbidity and TSS, respectively. Conversion of these results in economic values and their use in cost-benefit assessment could be a more meaningful indicator of such intangible services provided by the forests. Hence, research studies in this direction needs to be undertaken.

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