CHAPTER – 5

DEFORESTATION INDUCED COSTS ON THE DRINKING WATER SUPPLIES OF MUMBAI METROPOLITAN

5.1 INTRODUCTION

The earlier chapters characterized the relationships between forest cover, water quality and water quantity in the Western Ghats. But unless such biophysical relationships between forests and water are converted into monetary values, the economic contributions of forests to societal goals may not be communicated effectively. Such valuation can also generate market signals to encourage agents to take into account the costs and benefits of the provision of ecosystem services in their decisions about resource use and thus, solve potential environmental externality problems (Ranganathan et al., 2008). For this reason, this chapter attempts at addressing the questions: What is the economic relationship between FC and (a) ‘treatment costs \((C_t)\)', (b) ‘water losses due to backwash and desludging \((V_{BW})\)', and (c) decrease in ‘water yield \((V_{WY})\)' in the Western Ghats of peninsular India? What are the cost implications of deforestation on the drinking water supplies to Greater Mumbai?

The study takes turbidity as measure of raw water quality because it is considered a reasonably accurate measure of overall water quality. The Forest Cover-Treatment Cost relationship is estimated in two stages through Forest Cover-Turbidity and Turbidity-Treatment Cost relationships. The Forest Cover-Turbidity relationship is characterised through monthly time series data of four watersheds of the region, while the Turbidity-Treatment Cost relationship is characterised through monthly time series data of the Panjrapur treatment plant. The Forest Cover-Water Losses due to Backwash and Desludging relationship is similarly worked out in two stages (backwash refers to the process of restoring functionality of clogged filter beds
through air and water under pressure while desludging refers to the process of sludge removal from the settling tanks. The frequency of backwash and desludging depends on incoming water quality. The Forest Cover-Water Yield relationship is taken from another study of the authors (Singh and Mishra, 2012) for the study area. Based on these relationships the increase in the annual costs due to unit (ha) reduction in the forest cover is estimated (the change in productivity method).

5.2 DESCRIPTION OF THE STUDY AREA

As pointed out in Section 1.5 domestic water supply to Greater Mumbai is through six man-made reservoirs - Tulsi, Vihar, Tansa, Upper Vaitarna, Lower Vaitarna and Bhatasa. The earlier water sources viz. Vihar, Tulsi, Tansa and Lower Vaitarna (Fig. 3.1) were developed exclusively for drinking water supplies. They had forests in 50 to 88% of their watershed area. Many legal and administrative mechanisms were attempted for protecting the forests viz. acquiring of agriculture lands, resettlement of the inhabitants, prohibition of grazing, felling and construction activities, and declaring the forests of the watersheds along with the adjoining forested areas as Sanctuaries/National Park. Though such measures were successful for Tulsi and Vihar, the forests of the Tansa and Lower Vaitarna continued to face moderate biotic pressure. Till early seventies the water supply from the aforesaid sources was chlorinated water (disinfected water) without any other treatment (Vilankar and Chavan, 2006). But gradual deterioration in water quality of Lower Vaitarna along with decision to draw water from upcoming Upper Vaitarna Hydroelectric-Water Supply Project and Bhatasa Multipurpose Project (where water traversed a river course before being collected by Municipal Corporation of Greater Mumbai and, thus, had higher chances of pollution) led to setting up of conventional treatment plants at Bhandup and Panjrapur. The new infrastructure along with escalating difficulties in conserving the forests (due to increasing population pressure) delegated source protection to a low priority.

5.2.1 The Watershed

This study focuses on the Panjrapur Water Treatment Plant which collects water from Bhatasai River that flows through Pise watershed (Figs. 4.1 and 5.1). The river has
multipurpose dam – Bhatsa – which provides nearly 52% of water supply (approx 2020 MLD) to the Greater Mumbai (the reservoir along with its catchment is called Bhatsa watershed). The Pise watershed and its forest cover have been described in chapter 4. The average FC over the study period of 13 years was $28.3 \pm 0.25\%$ of the watershed area.

5.2.2 Water Treatment at Panjrapur Water Treatment Plant

The water released from the Bhatsa Dam traverses the river course of 48 kms before impounding at Pise weir at the far end of the Pise watershed (Fig. 5.1). The impounded water is chlorinated (pre-chlorination) at Pise to reduce some quantum of organic polluting load and to restrict algal growth. It is then lifted with the help of vertical pumps to 37 m head and brought to Panjrapur (site of water treatment). The designed capacity of the treatment plant is 1365 MLD. Nearly 30-35% of the pre-chlorinated water received at Panjrapur is pumped to the Bhandup Water Treatment Plant while the remaining is processed for further treatment (Fig. 5.2). Since 2003-04, additional dose of chlorine (pre-chlorination) is being given to the water supplied to Bhandup Water Treatment Plant.

At Panjrapur, the prechlorinated water is first passed through settlement tanks. The settling tanks work on the principle of up flow sludge blanket filtration. The stage I settling tanks are a multi hopper bottom tank unit with entry of raw water at the bottom of individual hoppers. The stage III settling tanks are flat bottom type with provision of scraper on flat bottom for removal of accumulated sludge. The PAC20 dose based on jar test is added at each subunit considering the flow at each subunit (till year 2005-06, alum instead of PAC was used). After removal of impurities through process of coagulation, flocculation and sedimentation in settlement tanks, the clearer water is passed through layers of sand for removing the remaining solids. The filter beds are rapid sand gravity flow declining rate filters. The filter beds are allowed to clog over a period of time without adjusting the inflow or outflow. Once clogged their functionality is restored by backwashing with air and water under pressure. Initially air is used for 2 to 3 minutes. Then, wash water along with air is used for 5 to 6 minutes, after which

\[20\text{ Poly Aluminium Chloride}\]
rinsing with only wash water is continued for 5 to 6 minutes. The frequency of backwash and desludging depends on incoming water quality. Usually, in fair season the backwashing is carried out at every 27 Hrs. Postchlorination dose to filtered water is given to achieve disinfection and to maintain the residual chlorine level of 1.8 to 2.0 ppm in the final water reaching pumping station after a contact period of 30 minutes.


5.3 METHODOLOGY

5.3.1 Model Specification

5.3.1.1 FC- C\textsubscript{t} and FC-V\textsubscript{BW} relationship

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; Sliva and William, 2001). They, thus, influence the treatment cost of the water supplies. Some studies have estimated cost of municipal water treatment as function of raw water quality and report significant increase in treatment cost due to increase in turbidity/sediment load (Table 5.2). Holmes (1988) in addition estimates the linkages between sediment loadings to waterways and the resultant economic costs through the two-stage model taking the derivative of ambient water quality with respect to sediment loading times the derivative of cost with respect to ambient water quality as an estimate of the marginal effect. Ernst (2004) through cross sectional analysis defines the relationship between percentage forests in watersheds and treatment cost. Using monthly time series, Nunez et al. (2006) applied the change in productivity method to derive economic value of forest in supplying water.

Following Holmes (1988) the general form of the economic model was taken as \( C = f (Q, Z) \), where \( C \) is the cost, \( Q \) is the raw water quality, and \( Z \) is a vector of economic variables. As water losses due to backwash and desludging too depend on quality of incoming water, its model was taken as \( V_{BW} = f (Q, X) \), where \( V_{BW} \) is volume of water lost due to backwash and desludging, \( Q \) as above is the raw water quality and \( X \) is a
vector of other environmental variables. The two models were linked in a recursive fashion with forest cover taking general form of model as $Q = f(FC, X)$, where FC is percent forest cover in the watershed and X as above is a vector of other environmental variables.

It was assumed that (a) the marginal effect of water quality on cost is influenced by the output level and input prices, and (b) the relationship between cost and source water quality is nonlinear. The first assumption is justified as the economies of scale and factor prices are found to influence the cost of treating water supplies (Holmes, 1988). The second assumption is also reasonable for the water treatment industry as it was observed that chemical costs and other operating costs increase rapidly with turbidity and then level off as a saturation level is reached. So Cobb-Douglas cost models in following expanded forms were used to characterise the relationships between raw water quality (turbidity) and the dependent variables – chemical costs, treatment costs (including chemical cost) and water losses due to backwash and desludging.

\[
\begin{align*}
\ln(C_{Ch}) &= \alpha + \beta_1 \ln(T) + \beta_2 \ln(V_t) + \beta_3 \ln(C_{Ch-1}) \\
\ln(C_t) &= \alpha' + \beta'_1 \ln(T) + \beta'_2 \ln(V_t) + \beta'_3 \ln(C_{t-1}) \\
\ln(V_{BW}) &= \alpha^* + \beta^*_1 \ln(T) + \beta^*_2 \ln(V_t) + \beta^*_3 \ln(V_{BW-1})
\end{align*}
\]

(5.1) (5.2) (5.3)

where,

- $C_{Ch}$ = Monthly cost of chemical used for water treatment (in INR per ML),
- $C_t$ = Monthly operating costs (chemical, electrical, repairs and maintenance, establishment and transport costs) in INR per ML,
- $T$ = 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),
- $C_{Ch-1}, C_{t-1}, V_{BW-1}$ = Lagged dependent variables,
- $\alpha, \alpha', \alpha^*$ = Constants, and
- $\beta_1, \beta_2, \beta_3, \beta'_1, \beta'_2, \beta'_3, \beta^*_1, \beta^*_2, \beta^*_3$ = Regression coefficients of the respective variables.
The variable – volume of water treated – was added to account for the scale effects. Lagged dependent variable was added to account the link between current and past production decisions of the firm. Investments towards the fixed costs during the study period were ignored as such expenditures were for increasing the capacity of the water treated per day at Panjrapur Water Treatment Plant and not because of any major deterioration in the water quality.

**The Forest Cover and Turbidity relationship** obtained through multilevel mixed-effects model (Eq. 4.1, Chapter 4) was as follows:

\[
\ln(T)_{ijk} = 30.36 - 8.41 \ln(FC)_{ijk} + 0.23 \ln(R)_{ijk} - 0.82 D_{rej} - 0.72 D_{pj} \quad (5.4)
\]

where,

\[
T_{ijk} = \text{Turbidity in month } i \text{ for year } t \text{ at station } j \text{ in watershed } k,
\]

\[
FC_{ijk} = \text{Forest cover as percentage of watershed area in month } i \text{ for year } t \text{ at station } j \text{ in watershed } k,
\]

\[
R_{ijk} = \text{Monthly average weighted rainfall (in mm)},
\]

\[
D_{rej} = \text{Dummy for site which measures water quality at outflow of the reservoir},
\]

\[
D_{pj} = \text{Dummy for site which have presence of riparian forests},
\]

From the aforesaid relationships, i.e., (a) FC – T and (b) Cch – T, Ct – T and VBW – T, the marginal effects of FC on Cch, Ct and VBW were obtained by multiplying the regression coefficient of FC in Eq. (5.4) with the regression coefficients of T in Eqs. (5.1), (5.2) and (5.3), respectively (in line with Holmes, 1988). Marginal effects were expressed in per Ha terms through following calculations:

\[
V_{BW,h} = (\gamma_1 x \beta_1^*) \times \bar{V}_{BW}/\bar{FC}
\]

\[
C_{t,h} = (\gamma_1 x \beta_1^{'}) \times C_t^#/\bar{FC}
\]

where,

\[
V_{BW,h}, C_{t,h} = \text{Effects on } V_{BW}, C_t \text{ induced by a Ha change in the forest cover},
\]

\[
\bar{V}_{BW} = \text{Mean values of } V_{BW} \text{ for the study period}
\]

\[
\bar{FC} = \text{Mean forest cover},
\]

\[
C_t^# = C_t \text{ at 2010-11 prices, and}
\]
\[ \beta_1, \beta_1^*, \gamma_1 = \text{Regression coefficients from Eqs. (5.2), (5.3) and (5.4), respectively} \]

Economic value estimate of \( V_{BW.h} (C_{BW.h}) \) was obtained as \( V_{BW.h} \times P \), where \( P \) is the market price of raw water. Municipal Corporation of Greater Mumbai is paying 1188 INR per ML for water drawn from Bhat's dam to Water Resources department (at 2010-11 prices). However, as this is a subsidized price, the price of water derived from unit volume expense of building reservoirs following the replacement cost approach was considered a better estimate. Hence, \( C_{BW.h} \) was estimated taking the price of water to be 1363.07 INR per ML.

5.3.1.2 Water Yield

The following relation between the runoff coefficient and the FC characterised through Eq. 3.4 was used.

\[ RC = 0.43 + 0.0013F^{**} + 0.00004wR^{**} + 0.0006Rd^{**} - 0.0001CA \]  

(5.7)

where,

- \( RC \) = Runoff coefficient,
- \( CA \) = Watershed area in Km²,
- \( wR \) = Average weighted rain (in mm),
- \( Rd \) = Number of rainy days
- \( ** = 0.01 < P < 0.05 \)

Effects induced by a Ha change in the FC were evaluated from Eq. (5.7) at mean values of runoff coefficient (\( \bar{RC} \)), forest cover (\( \bar{FC} \)) and weighted annual rainfall in million litre (\( \bar{R} \)) as:

\[ VWY_{h} = \frac{\left((\bar{RC} - 0.0013) \times (\bar{RC} \times (\bar{R})/\bar{FC})\right)}{\bar{FC}} \]  

(5.8)

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21MUNICIPAL CORPORATION OF GREATER MUMBAI is constructing Middle Vaitarna dam between Upper and Lower Vaitarna dam for supplementing drinking water supplies to Mumbai city. Its gross storage capacity is 202 million cubic metre (MCM) while live storage and dead storage is 193.5 MCM and 8.5 MCM, respectively. This source would supplement the supplies by 455 MLD. The cost of the project (in 2010-11 prices) excluding costs towards rehabilitation of 43 affected persons, compensation and other payments to the Forest Department is 19348.1 million INR. On including rehabilitation and other such expenses cost is 20373.5 million INR. It is assumed that the life of the reservoir is 90 years. This in turn implies that 455 MLD of raw water is available for 90 years. Thus, the unit volume expense of building reservoirs works out to be 1363.07 INR annually.
From Eq. (5.8) it emerged that every one percent 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% of \( V_{WY} \) 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 \( V_{BW} \).

5.3.1.3 **Total cost**

The economic value of the impacts induced by loss of one Ha of the forest cover \( (C_F) \) is taken as the follows

\[
C_F = C_{t,h} + C_{BW,h} + C_{WY,h}
\]  

(5.9)

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

5.3.2 **Data Acquisition And Processing**

The data was collected from Government agencies that followed standard procedures of data collection and meticulously maintained the records. Hence quality of data was good. The shortcoming was the missing data for establishment, transport and repairs and maintainece for two years. But as there was no practical alternative this data was used and the shortcoming was tried to be addressed through extrapolation and statistical methods.

5.3.2.1 **Water treatment cost**

Yearly expenditure towards establishment, transport, repairs and maintenance, and payments made to Water Resource Department for water drawn from Bhatsa reservoir, along with monthly expenditure towards chemicals, electricity, volume of raw water drawn, treated and lost due to backwash for Panjrapur Water Treatment Plant was collected from the records of Municipal Corporation of Greater Mumbai for the period of the study. As indicated earlier Panjrapur Water Treatment Plant does not treat the entire amount of raw water drawn by it at Pise weir but transfers 30-35% of it to Bhandup Water Treatment Plant. Further, water drawn at Pise needs to be pumped up against gravity to a height of about 37m. As a result Panjrapur Water
Treatment Plant incurs heavy expenditure towards electricity as well as many additional costs that are not part of a conventional treatment process. Fortunately, separation of such additional costs was possible due to maintenance of separate records for Pise for each item. At Panjrapur, the amount of water pumped to Bhandup Water Treatment Plant is drawn separately at unit III-A for which separate chemical records are maintained and an independent electrical unit has been installed in the year 2006-07. Hence, costs incurred towards chemicals water pumped to Bhandup Water Treatment Plant were available for the entire period of study while electricity costs were available independently for it since 2007-08.

So the expenditure on chlorine for prechlorination at Pise and postchlorination at Panjrapur, and alum/PAC at Panjrapur were taken as chemical cost and converted to unit cost on the basis of the volume of treated water at the two locations in each month. The breakup of the electrical charges for III-A unit and remaining units at Panjrapur for years 2007-08 to 2010-11 indicated that on average 73% of the electric charges at Panjrapur account for water treatment. Hence, 73% of the monthly electrical charges at Panjrapur were taken as the electrical cost for treatment process and converted to unit cost (cost per ML of treated water). Yearly expenditure towards establishment, repairs and maintenance, and transport at Panjrapur (which on average account for 19% of the treatment cost) were converted to unit cost. Assuming that their unit cost remained constant over each month in a financial year, their monthly estimates were obtained. Yearly expenditure for establishment, repairs and maintenance, and transport for the years 2008-09 to 2010-2011 were missing. As the volume of water treated in each of these years was similar to that of 2007-08, these costs were obtained by appropriately inflating their unit costs for the year 2007-08. The unit costs (chemical, electrical, transport, and repairs/maintenance and establishment) were deflated to 1993-94 prices using Whole Sale Price Index (WPI) for chemicals, commercial electricity, fuel and general WPI, respectively.

5.3.2.2 Turbidity

Monthly averages of turbidity for the period April 1995 – March 2011 were collected from the records of Municipal Corporation of Greater Mumbai. The agency followed
standard procedures of data collection. Hence quality of the data was fair. The size of collected data was also large. In addition no data was missing.

5.3.2.3 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) was adopted for classification and accuracy assessment of the satellite images, and calculation of forest cover in the watersheds on year to year basis. Monthly FC in a year was estimated assuming a linear change in forest cover over the months.

5.3.2.4 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, 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.

5.4 RESULTS AND DISCUSSIONS

Very good data for all the variables in Eq. 5.1, 5.2 and 5.3 was available. So the uncertainty in the regression results is likely to be low.

The relationships through Eqs. (5.1), (5.2) and (5.3) emerged as follows:

\[
\ln (C_{Ch}) = 2.46 + 0.203 \ln (T) + 0.06 \ln (V) + 0.41 \ln (C_{Ch-1}) \quad (5.10)
\]

\[
R^2 = 0.66; \ Prob > F = 0.0000; \ N = 144
\]

\[
\ln (C_t) = 3.8 + 0.188 \ln (T) - 0.043 \ln (V) + 0.41 \ln (C_{t-1}) \quad (5.11)
\]

\[
R^2 = 0.68; \ Prob > F = 0.0000; \ N = 144
\]
\[
\ln (V_{BW}) = 2.13 + 0.072 \ln (T)^{***} - 0.60 \ln (V)^{***} + 0.69 \ln (V_{BW-1})^{***} \\
(5.12)
\]

\[R^2 = 0.66, \text{ Prob > F = 0.0000; N = 108}\]

\((*** = P < 0.01, ** = P > 0.01 & < 0.05, * = P > 0.05 & < 0.10)\)

The estimated coefficients for turbidity (T) were positive and highly significant ($p < 0.01$) in all the regressions. The elasticity of chemical cost ($C_{Ch}$) with respect to turbidity was 0.203 (Eq. 5.10) which implied that every one percent increase in turbidity will increase chemical cost by 0.203 %. Other studies report elasticity between chemical cost and turbidity as 0.119 (Foster et al., 1987), 0.27 (Dearmont et al., 1998), 0.25 (Ernst, 2004), 0.30 (Murray and Foster, 2001) and 0.33 (Moore and McCarl, 1987 cited in Dearmont et al., 1998). Hence, the finding of this study was in the range of these estimates. When other operating and maintenance costs were also considered (Eq. 5.11), one percent increase in turbidity was found to increase treatment cost ($C_t$) by 0.188 percent which was close to the elasticity of 0.07 and 0.3 reported by Holmes (1988) and Murray and Foster (2001), respectively. One percent increase in turbidity was also found to increase water losses due to backwash and desludging ($V_{BW}$) by 0.06 percent (Eq. 5.12). The estimated coefficients for volume of treated water ($V$) were negative in Eqs. (5.11) and (5.12) indicating economies of scale. However, when only chemical cost is considered (Eq. 5.10) the regression coefficient for volume exhibits a positive sign indicating an increase in the chemical cost with increase in volume of treated water. The lagged dependent variable had a significant positive sign reflecting that over time, the current costs of drinkable water relates directly to past decisions.

The elasticity of turbidity with respect to FC (Eq 5.4) is $-8.41$ which implies that every one percent decrease in FC will increase T by 8.41 percent when all other parameters are constant.

The elasticity of FC with respect to $C_{Ch}$, $C_t$ and $V_{BW}$ (obtained by multiplying regression coefficient of FC in Eq. (5.4) with regression coefficients of T in Eqs. (5.10), (5.11) and (5.12)) were $-1.71, -1.58$ and $-0.61$, respectively. This implies that every one percent decrease FC would increase $C_{Ch}$, $C_t$ and $V_{BW}$ by 1.71%, 1.58% and 0.61%, respectively. Ernst (2004) reports 2% increase in treatment and chemical
costs for every one percent decrease in forest cover in the source area up to about 60 percent forest cover. Hence, the findings of this study are close to that of Ernst (2004).

Taking an average FC of 28145.37 Ha in the Pise watershed during the study period, increased annual costs per cubic meter (m$^3$) of treated water per Ha FC lost, estimated through Eqs. (5.5 – 5.9), was 64.96 INR (1.32 USD) (Table 5.3). The annual cost induced by loss of one Ha of the FC for the Panjrapur Water Treatment Plant (at 2010-11 prices) was estimated to be 31059.53 INR (630.51 USD). Nearly 99% of the increase was attributable to increases in treatment costs.

Some studies in India (Table 5.4) have estimated annual value of the Forest Watershed Services. However, there is no study in relation to water treatment plants. In other countries, Kumari (1996), Hernández et al. (2002) cited in Núñez et al. (2006) and Torras (2000) report annual value per Ha of the tropical forests in water regulation as 15 USD, 202 USD and 19 USD, respectively. Bernard et al. (2009) estimate annual avoided costs for drinking water treatment plants using the Tapantí National Park, Costa Rica water supply services to be in range of 13 – 32 USD per Ha while van Wilgen et al. (1996) have valued forest watershed services as 6770 USD per Ha. Elias (2010) estimates annual increase in treatment cost following forest to urban land conversion to be between 1.2 million USD and 2.5 million USD per Ha. The wide variation in estimates thus indicates the need for site specific valuation.

Taking that on average 120 Ha of FC is lost in a year (assuming the annual rate of change in FC to be -0.0046%$^{22}$), the deforestation induced costs for a year (at 2010-11 prices) was estimated as 3.73 million INR (0.075 million USD). Thus, if deforestation is avoided Municipal Corporation of Greater Mumbai can save significant amount towards recurring costs of water treatment and source development. However, Municipal Corporation of Greater Mumbai practically does not make any investment towards source protection and is neither 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

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$^{22}$ The average annual rate of change in FC between the years 1994-2007
fast growing species to meet the energy and sustenance needs of the local communities. 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. Much against the expectations such actions lead to a landscape that may competes for water resources (Calder et al., 2007; Farley et al., 2005; Fritzsche et al., 2006) and provides less than optimal water treatment and water storage services, and thus impact Municipal Corporation of Greater Mumbai adversely.

Inclusion of forests in the decision making process (like cost benefit or cost effective analysis) of water treatment and water source development would help Municipal Corporation of Greater Mumbai to make appropriate choices between source protection, and infrastructure development and treatment costs. For a country like India, where conservation efforts have often not succeeded because of biotic pressures, it may be in interest of the water agencies to conserve the forests through Payments of Ecosystem Services (PES) approach. This definitely means much higher investments, but such investments appear to be justified by the huge returns they stand to reap from it. Infact Govt. of Maharashtra plans for 2% cess on the municipal corporations, other civic bodies and industries that procure water from reservoirs in forest areas (TOI 2008). However, the approach to collection and utilization of these funds appears to be traditional. Instead, if such funds are collected and utilized in manner akin to PES then better results could be expected.

5.5 CONCLUSIONS

The study estimates that every one percent decrease in the forest cover will increase turbidity by 8.41% and treatment cost of drinking water by 1.58%. In addition it will increase water losses by backwash and desludging by 0.61%. Annual value of impacts (increased ‘treatment cost’, increased ‘water losses due to backwash and desludging’, and changes in ‘water yield’) induced by loss of the forest cover is estimated as 64.96 Indian rupee /m³ treated water/Ha/year ($1.32/m³ treated water/Ha/year). At annual rate of change in the forest cover of −0.0088% (average annual rate of change in the forest cover between the years 1994–2007) the
deforestation induced costs translate to 3.73 million Indian rupee/year ($ 0.075 million/year) at 2010-11 prices for the Panjrapur treatment plant of the Municipal Corporation of Greater Mumbai. This indicates that there is the need for the municipalities to include the forests and its management in their decision making and planning for better decisions and actions relating to the use and management of land, water and forest resources. It also may be in the interest of the water agencies to conserve forests through Payments for Ecosystem Services approach.
Fig. 5.1 Land use and Land cover of the Pise watershed

Fig. 5.2 Scenario-domestic water supply of Greater Mumbai
(Source: Hydraulic Engineering Department, BMC)
<table>
<thead>
<tr>
<th>Features</th>
<th>Tansa</th>
<th>Pise</th>
<th>Lower Vaitarna</th>
<th>Manda</th>
</tr>
</thead>
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<tr>
<td>District</td>
<td>Thane</td>
<td>Thane</td>
<td>Thane</td>
<td>Thane</td>
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<tr>
<td>Catchment Area (Km²)</td>
<td>135.97</td>
<td>991.94</td>
<td>290</td>
<td>954.57</td>
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<td>Av. Weighted Annual Rainfall (mm)</td>
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<td>2862</td>
<td>2532</td>
<td>1985.5</td>
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<td>Land use (as percent of the catchment area)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area legally defined as Forest</td>
<td>65.12</td>
<td>31.27</td>
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<tr>
<td>Agriculture</td>
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<td>Grassland</td>
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<td>13.07</td>
<td>23.16</td>
</tr>
<tr>
<td>Built up</td>
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<td>1.11</td>
<td>0.87</td>
<td>1.06</td>
</tr>
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<td>6.04</td>
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<td></td>
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<tr>
<td>Geomorphology</td>
<td>Mix of hills and plateau</td>
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<td></td>
</tr>
<tr>
<td>Soil texture</td>
<td>Gravelly sandy clayey loam and Gravelly sandy loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil depth</td>
<td>Very shallow (&lt; 10 cm) to Shallow (10-25 cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Digital thematic maps – MRSAC, Nagpur; Management plans of Forest Department, District Gazetteer.
<table>
<thead>
<tr>
<th>Study</th>
<th>Cost variable</th>
<th>Independent variable</th>
<th>Equation form/Method</th>
<th>Regression analysis</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forster et al., 1987</td>
<td>Chemical Cost (C)</td>
<td>Turbidity improvement (T), daily volume treated (S), upstream soil erosion (E) and daily volume (S)</td>
<td>Cobb Douglas</td>
<td>( \ln C = -0.562 + 0.657 \ln S + 0.141 \ln R + 0.406 \ln E )</td>
<td>10% reduction in annual gross soil erosion results in a 4% reduction in annual water treatment costs. For Ohio communities, 25% reduction in soil erosion reduces annual water treatment costs by $2.7 million.</td>
</tr>
<tr>
<td>Holmes, 1988</td>
<td>Operation &amp; management cost (OMX)</td>
<td>Influent turbidity (T); water production (Y); pipe fitters and wage level (W); electricity cost index (E)</td>
<td>Cobb Douglas</td>
<td>( \ln \text{OMX} = -2.55 + 0.85 \ln Y + 0.07 \ln T + 0.77 \ln W + 0.23 \ln E )</td>
<td>On average, sediment discharges to surface water supplies induce treatment costs of $17.11 per thousand tons discharged.</td>
</tr>
<tr>
<td>Dearmont et al., 1998</td>
<td>Chemical Cost (C)</td>
<td>Turbidity (T), pH, water production (Y), average annual rainfall (R), dummy variable for high levels of chemical contaminants (D)</td>
<td>Polynomi al</td>
<td>( C = -0.1314 - 1.6950 \times 10^{-8} (Y) + 1.3496 \times 10^{-7} (T<em>Y) - 1.5130 \times 10^{-7} (T</em>pH)^2 + 5.3013 \times 10^{-1} (T*pH)^3 + 0.0947 (D) + 5.6024 \times 10^{-3} (R) )</td>
<td>A one percent increase in turbidity increased chemical costs by 0.25 percent. Chemical cost of water treatment is increased by $95 per million gallons from a base of $75.</td>
</tr>
<tr>
<td>Murray and Foster, 2001</td>
<td>average variable costs (AVC) and average chemical costs (ACC)</td>
<td>Annual turbidity (T); tillage practices; pesticide application rates (PU); Volume treated (V);</td>
<td>Cobb Douglas</td>
<td>( \ln \text{ACC} = 7.97 - 0.17 \ln V + 0.29 \ln PU + 0.30 \ln T )</td>
<td>One percent increase in turbidity increases chemical costs per million gallons treated water by $0.41. One percent decrease in turbidity results in an annual savings of just over $500 for the average treatment plant in the study area.</td>
</tr>
<tr>
<td>Ernst, 2004</td>
<td>Variable treatment cost</td>
<td>Turbidity</td>
<td>Benefit transfer method</td>
<td></td>
<td>For every 4 percent increase in raw water turbidity, treatment costs increase 1 percent.</td>
</tr>
<tr>
<td>Elsin et al., 2010</td>
<td>Turbidity</td>
<td>Benefit transfer method</td>
<td></td>
<td></td>
<td>30% improvement in turbidity saved $90,000 to $553,000 per year.</td>
</tr>
</tbody>
</table>
Fig. 5.3 Impact of the Forest Cover on the Panjrapur Treatment Plant (in 2010-11 prices)

<table>
<thead>
<tr>
<th></th>
<th>Costs induced by loss of one Ha of FC</th>
<th>Price (at 2010-11 prices) in INR (USD)</th>
<th>Increased annual costs per m$^3$ treated water in INR (USD)</th>
<th>Taking treated water as 1310 MLD increased annual cost in INR (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chemical cost ($C_{ch,h}$)</td>
<td>204.12 (41.44) per ML treated water</td>
<td>12.38 (0.25)</td>
<td>5920.18 (120.18)</td>
</tr>
<tr>
<td>2</td>
<td>Treatment cost ($C_{t,h}$)</td>
<td>1142.12 (231.86) per ML treated water</td>
<td>64.16 (1.30)</td>
<td>30679.58 (622.79)</td>
</tr>
<tr>
<td>3</td>
<td>Economic Value-water losses due to backwash &amp; desludging ($C_{BW,h}$)</td>
<td>1363.07 (276.70) per ML raw water</td>
<td>0.51 (0.010)</td>
<td>241.17 (4.89)</td>
</tr>
<tr>
<td>4</td>
<td>Economic Value - losses in water yield ($C_{wy,h}$)</td>
<td>1363.07 (276.70) per ML raw water</td>
<td>0.29 (0.006)</td>
<td>138.77 (2.817)</td>
</tr>
<tr>
<td></td>
<td>Total deforestation induced costs $C_F = C_{t,h} + C_{BW,h} + C_{wy,h}$</td>
<td></td>
<td>64.96 (1.32)</td>
<td>31059.53 (630.51)</td>
</tr>
</tbody>
</table>
Table 5.4  Economic value of forest watershed services derived from Indian case studies

<table>
<thead>
<tr>
<th>Benefit valued</th>
<th>Annual Value</th>
<th>Location</th>
<th>Methodology used</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil conservation</td>
<td>Cost of soil erosion 21583 INR/Ha</td>
<td>Doon Valley</td>
<td>Replacement cost approach</td>
<td>Kumar (2000)</td>
</tr>
<tr>
<td>Soil Conservation</td>
<td>200000 INR/Ha meter soil</td>
<td>Lower Siwalik (Yamuna basin)</td>
<td>Indirect method (reduced cost of alternate technology)</td>
<td>Chopra and Kadekodi (1997)</td>
</tr>
<tr>
<td>Soil Conservation</td>
<td>602.98 INR/Ha dense forest</td>
<td>India</td>
<td>Resource value of soil loss</td>
<td>GIST (2006)</td>
</tr>
<tr>
<td>Ground water</td>
<td>16.44 INR/Ha dense forest</td>
<td></td>
<td>Water balance method with</td>
<td></td>
</tr>
<tr>
<td>Reduction in silt load</td>
<td>823.7 INR/Ha 63.35 INR/tonne</td>
<td>Lake Nanital catchment (Uttarakhand)</td>
<td>Replacement cost approach (dredging cost)</td>
<td>Semwal et al. (2007)</td>
</tr>
<tr>
<td>Watershed services</td>
<td>23387 INR/Ha</td>
<td>Himachal forests</td>
<td>Weighted average for Himachal Pradesh</td>
<td>Kanchan Chopra Committee, 2006 cited in CEC, 2007</td>
</tr>
<tr>
<td>Watershed services</td>
<td>Av. NPV = 5773 INR/Ha</td>
<td></td>
<td></td>
<td>CEC (2007)</td>
</tr>
</tbody>
</table>