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A Cost-Benefit Analysis of Watershed Rehabilitation: A Case Study in Farta Woreda, South Gondar, Ethiopia

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ABSTRACT

In addressing land degradation, a number of watershed rehabilitation programs have been carried out in Ethiopia. This study aims to financially quantify watershed rehabilitation in a way that incorporates major costs and returns. We also construct scenarios to portray cost-benefit information about the future. The data were obtained from a physical survey and supplemented with secondary sources. Total cost and return values for the watersheds were compared monetarily through cost-benefit analysis and these values were extrapolated to the future. The results indicate that the benefit was Ethiopian Birr 918,049 and 4,651,167 (US\$73,821 and US\$374,008) for the smallest and largest of the rehabilitated watersheds, respectively, while the expenditure was Birr 154,178 and 205,712 (US\$17,701 and US\$23,620). Under optimal management in the future, these benefits can reach up to Birr 19,334,643 and 76,699,254 (US\$2,219,821 and US\$8,805,884), while the costs remain the same. The results clearly indicate that investment in watershed rehabilitation may be an economically viable short-term and long-term proposition. Hence there is a strong case for sustainable management of rehabilitated watersheds in view of the very high economic benefits from the rehabilitation.

Keywords: ecosystem services, Ethiopia, sustainable watershed management, watershed rehabilitation

In the highland and upland areas of Ethiopia, natural vegetation is an essential part of the stability and sustainability of watershed ecosystems. Removal of vegetative cover due to expansion of agriculture on these steep lands exacerbates soil erosion, with concomitant watershed ecosystem instability, including siltation of lakes and reservoirs (Poesen et al. 1996) and massive loss of topsoil and furrowing that cuts away all the soil to the stony ground below. Wide, deep gullies are common in the highland watersheds of Ethiopia.

It can be extremely difficult and costly to restore such degraded watersheds, but much attention has been paid recently to revegetation, as stakeholders realize that long-term sustainability depends on establishing good

vegetative cover. By watershed rehabilitation, we mean the revegetation of degraded areas to provide protection against scouring and minimize soil erosion. The on-site benefits of revegetation include carbon sequestration, biofuels, water conservation, and soil conservation. Off-site benefits include downstream water availability, reduced siltation of downstream rivers and lakes, biodiversity conservation, aesthetics, and ecotourism. Some of these benefits are currently impossible to evaluate monetarily because existing markets either do not place value on these goods and services or discount them severely.

One may ask what economic valuation has to do with watershed rehabilitation. The answer is that rehabilitating degraded watersheds is very expensive, and managing them is a very large economic problem. Economic information can indicate to stakeholders the value of watersheds and, in some cases, management benefits from

rehabilitated watersheds. Moreover, rehabilitation costs and benefits need to be clearly distinguished to provide an estimate of the relative rates of return. The economic implications of rehabilitation projects have rarely been addressed by researchers. Despite the qualitative arguments that rehabilitation improves the microclimate and conserves water and soil, the economic feasibility of such rehabilitation programs is hardly ever assessed.

In Ethiopia, rehabilitation is a rarely practiced conservation measure, and certainly not addressed in quantitative monetary terms. Considering the limited data, we formulated major valuation techniques in this study to quantify the chief rehabilitation benefits and costs. Specifically, the “benefits” include a quantification of tree volume and grass and tree biomass, in addition to carbon sequestration, while the “costs” account for the rehabilitation investment. Current costs and benefits were estimated in order to extrapolate

Figure 1. Location of the rehabilitated watersheds used in the cost-benefit analysis (Farta Woreda, Ethiopia).

future costs and benefits so that we could compare both the current and future rehabilitated watersheds.

Study Area

The study was conducted in 2007, in Farta Woreda of South Gondar, Ethiopia. Woreda is an administrative district in Ethiopia, with an average population of 100,000 (Figure 1). Farta is a highland area where food insecurity is a chronic problem. The study watersheds are located in four Peasant Associations of the Farta Woreda; a Peasant Association (PA) is the smallest administrative unit of Ethiopia, similar to a ward or neighborhood. The rehabilitation activities were conducted in degraded areas of the watersheds: 2.6 ha in Werken Gashajagre, 1.87 ha in Worken Adura,

1.51 ha in Eshim Wofena, and 0.95 ha in Tsegur Eyesus. The study Woreda lies between 11°32' to 12°03' N latitude and 37°31' to 38°43' E longitude and covers an estimated area of 1,118 km². Altitudes vary between 1,900 and 4,035 m above sea level. In terms of topography, 45% of the total area is gentle slope, while flat and steeply sloped lands account for 29% and 26%, respectively. The average annual mean temperature is 15.5°C. The area's rainfall is unimodal, stretching from May to September. Annual rainfall ranges between 1,097 and 1,954 mm per year with a long term annual average of 1,448 mm (GTZ 1997). Cambisols, Regosols, Lithosols, and Andosols are the predominant soil types.

The soil characteristics, coupled with sloping terrain and intense rain events,

make the Woreda very susceptible to watershed degradation. Moreover, increasing human population together with unemployment and poverty have imposed considerable stress on the land and vegetation resources. Natural resources have deteriorated markedly in the last few decades. According to information from the local agricultural office, problems of the watershed include depletion of soil fertility, animal diseases, field infestation with rodents and pests, irregular rainfall pattern, hail damage, and shortages of potable water, food, fuel and construction wood, and animal forage.

To address most of these problems, a holistic watershed development strategy was designed, aimed at improving the watershed area. The project was started in 2000 as a joint operation between the government's Ministry of

Agriculture and Rural Development Office and the German Technical Cooperation (an international NGO). The holistic strategy was adopted based on an understanding of the socioecology of each watershed and the local communities. The strategy embraced improved agricultural techniques, revegetating hills and hillocks that constitute the village common lands, and creating a management plan that would institute these changes. The bulk of the revegetation was done in the first year (2000 for Tsegur Eyesus, 2001 for Eshim Wofena, and 2003 for Worken Adura and Gashajagrie), while refinements and maintenance were carried out in the years after revegetation. Initial steps were based on the natural resource data available and on field work. Each village development committee chose the species to be planted and the types of soil and water conservation measures to be adopted in the agricultural fields. Further discussions were held regarding protecting and distributing rehabilitated common lands and the likely benefits that would accrue to the community.

Soil and water conservation measures were applied to the entire watershed area, from the crests of the hills down to the deep gullies. Hillside terraces were constructed on slopes for moisture conservation and the reduction of runoff. A variety of fast-growing indigenous and non-native trees were planted to enrich the flora in the area and to provide much needed animal fodder (Table 1). Plantings were designed with the multiple aims of providing soil and water conservation, fodder, construction and fuel material, and nutrient enrichment. Thus the tree species within these rehabilitated watersheds are multipurpose, with fuelwood and construction being the most important uses. They include silk-oak (*Grevillea robusta*), orange wattle (*Acacia saligna*), tree lupine (*Lupinus arboreus*), stink bean (*Parkia speciosa*), Egyptian rattlepod (*Sesbania sesban*), pigeon pea (*Cajanus cajan*), and blackwood (*Acacia*

Table 1. Establishment year of trees and frequency of occurrence within four rehabilitated watersheds (Farta Woreda, Ethiopia).

	Site:	Tsegur Eyesus	Worken Gashajagrie	Eshim Wofena	Worken Adura
Size (ha):		0.95	2.6	1.87	1.51
Year:		2000	2003	2001	2003
Species	Abundance				
<i>Populus ciliata</i>	279	659	550	390	
<i>Acacia angustissima</i>	97	351	—	138	
<i>Acacia saligna</i>	325	80	501	17	
<i>Sesbania sesban</i>	44	199	1647	85	
<i>Eucalyptus globulus</i>	67	382	—	14	
<i>Salix × sepulcralis</i>	48	628	—	261	
<i>Grevillea robusta</i>	117	12	—	—	
<i>Acacia abyssinica</i>	202	248	—	19	
<i>Acacia baileyana</i>	2	—	—	—	
<i>Acacia melanoxylon</i>	149	67	—	78	

melanoxylon). Consideration was also given to timber production separate from multipurpose trees. Bare spaces were seeded with grass and legumes, such as weeping lovegrass (*Eragrostis curvula*), alfalfa (*Medicago sativa*), and crown vetch (*Coronilla varia*).

Across the deep gullies, check dams were constructed with loose stones, gabions, and arc weirs to stabilize and reduce silt loads. The side walls of the gullies were stabilized with layers of stone and a newly tested system involving bundles of elephant grass (*Pennisetum purpureum*), poplars (*Populus ciliata*), and branches of Egyptian rattlepod and orange wattle tied with wire and pegged down across the gully walls. After some time, most of the vegetative matter will sprout and develop roots, thus both anchoring the soil and producing fodder which will later be harvested. In addition, the steep gully walls were planted with plugs of crown vetch. Plant species tolerant of waterlogging were planted in the gully bed, including weeping willows (*Salix × sepulcralis*), Harding grass (*Phalaris aquatica*), and kikuyu grass (*Pennisetum clandestinum*). The gully walls, embankments, and the offset or adjacent land have been planted to species such as poplars, red mulberry (*Morus rubra*), orange wattle, Nyanga flat-top (*Acacia abyssinica*), Egyptian rattlepod, tagasaste (*Chamaecystis palmensis*), and French

broom (*Genista monspessulana*). In addition, suitable grasses and legumes such as serradella (*Ornithopus sativus*), tall fescue (*Lolium arundinaceum*), and alfalfa were sown to ensure ground cover.

Estimating Tree Parameters, Benefits, and Costs

The study included a complete inventory of extant trees, providing us with a measurement of tree density for the watershed. Our estimates of tree volume and biomass were based on measurements of diameter at breast height (dbh), total height, merchantable height, canopy depth, and crown diameter. We estimated tree volume as a function of merchantable wood volume and crown volume (Box 1).

The merchantable wood volumes and crown volumes were financially valued based on the nearest local market price for wood and leaves (Kengen 1997). The local market price for trees is less dependent on species type than on the condition of the wood or leaves, because these tree species are used mostly for fuel, wooden ploughs, and housing construction. The local market prices for wood and leaves were averaged to estimate values for all species of woods and crowns.

Biomass—There are seven carbon pools in any forest ecosystem:

Box 1. Estimating Merchantable Wood Volume

The merchantable wood volume of standing trees was estimated as a function of three basic parameters: diameter at breast height, height, and form factor. The form factor converts the cylindrical volume to a realistic tree volume value that considers the diameter changes of individual trees along the height. Form factors usually lie within the range of 0.25–0.5 (Teshome 2000). In a study by Magnussen and Reed (2004), a minimum range of form factor was estimated by referring to volumes of a cylinder and a cone. Trees are neither cones nor cylinders, but empirical analyses often indicate that the volume of a single-stemmed tree is between that of a cone and a cylinder, with tree volume often lying between 0.40 and 0.45 times that of an equivalent cylinder. In this study, we used the average of this form factor range (0.425) to estimate cubic volume of wood.

$$V = fBh \quad \text{eqn 1}$$

where V is the merchantable wood volume

$f = 0.425$

B is the basal area at breast height ($= \pi/4 \times D^2$, where D is diameter at breast height)

h is tree merchantable height

There has been, and continues to be, a need to determine the volume of crowns because crown volume data may be used to describe fuel hazards and to estimate volumes of pulpwood and fuel wood in crowns (Teshome 2000). The most common dimensions used in crown volume estimation are crown width and crown area, crown depth, or length.

$$V_c = \pi d_b^2 h_c / 12 \quad \text{eqn 2}$$

where V_c is crown volume in m^3

d_b is diameter at base of crown, m

h_c is crown depth, m

aboveground trees, aboveground nontrees, belowground roots, forest floor (or litter), dead wood, soil, and long-term wood products. However, not all seven pools are significant in a given ecosystem (Pearson et al. 2005). In this study we measured only those three pools that we expected to change significantly as a result of the revegetation efforts: aboveground biomass, root biomass, and grass biomass. We used the model by Chave and others (2005) to estimate this biomass (Box 2). This model considerably expands upon previous studies by including new data from different tropical environments and countries. The approach also relies on penalized likelihood, a method for selecting the correct model by testing each model against all other models (Preminger and Wettstein 2005). In addition, the equation has been developed for wet, moist, and dry forests. This is important in mountainous

areas, since potential evapotranspiration changes as elevation increases and temperature decreases, and the climate will become wetter for any given rainfall (Brown 1997).

The estimation of grass biomass (non-tree vegetation) was done by harvesting 50 cm $\times$ 50 cm sample plots (Tadesse 1997), measuring the dry weight, and then extrapolating to the whole area of grass cover in each watershed.

Carbon—A range of simple to complex techniques are available for measuring the quantity of carbon from biomass. In general, the techniques are more reliable for plantation species like the trees and grasses in our study. The carbon content of dry biomass of a tree has been assumed to be 50% (Malhi et al. 2004); however, it should be emphasized that the wood carbon fraction may vary slightly across species (Elias and Potvin 2003).

Monetizing carbon sequestration is hypothetical here, since currently there is no national market for carbon in Ethiopia. Any actual monetary transfers will have to take place in international markets (Andrew et al. 1999). The voluntary carbon market reached a value of US\$91 million in 2006. Forestry projects accounted for 36% of the carbon transactions, with about 10% originating in Africa. We relied on the voluntary emissions reductions prices of Capoor and Ambrosi (2007) for monoculture afforestation and reforestation of US\$10 to US\$13 per ton of reduced carbon dioxide emissions. Prices for mixed native afforestation and reforestation were US\$0.50 to US\$45 per ton (Walker et al. 2008). Carbon dioxide equivalent (CO_2e) was estimated as equal to the amount of carbon times 3.6667. The conversion between CO_2e and carbon equivalent (CE) is directly

Box 2. Estimating Biomass

Aboveground biomass was estimated using the following equation:

$$(AGB)_{est} = \exp(-2.977 + \ln[\rho D^2 H]) \quad \text{eqn 3}$$

where $(AGB)_{est}$ is Above Ground Biomass estimated, T/ha

ρ is density of wood

D is diameter at breast height

H is height

The measurement of aboveground biomass is relatively established and simple. Belowground biomass (BGB), however, can only be measured with time, labor, and cost-consuming methods. The efficient and effective method is to apply a regression model to determine belowground biomass from knowledge of aboveground biomass. Accordingly, the regression model by Pearson and colleagues (2005) is used in this study, as it has been used widely for tropical areas:

$$BGB = \exp(-1.0587 + 0.8836 \times \ln[AGB]) \quad \text{eqn 4}$$

where BGB is belowground biomass, T/ha

AGB is aboveground biomass, T/ha

Box 3. Calculating Acquired Cost and Future Maximum Benefit

$$P = a(1 + i)^n \quad \text{eqn 5}$$

where P is present value of money or compounded value

a is the previous amount, or principal lost

i is interest rate index (= 3%)

n is number of years the principal is obtained

$$P = \frac{a}{(1 + i)^n} \quad \text{eqn 6}$$

related to the ratio of the atomic mass of a carbon dioxide-equivalent molecule to the atomic mass of a carbon-equivalent atom (44:12) (Eggleston et al. 2006).

Investment Cost—The rehabilitation expenditure or investment cost was figured by estimating the entire financial expenditure for three years from the beginning of the rehabilitation to the end of the last maintenance cost, which is the phase out of the project. The German Technical

Cooperation provided estimates for all the study sites. The acquired cost was compounded so as to validate the time value and make comparison with the 2007 benefits (Box 3). The compounding is done using the National Bank of Ethiopia's money deposit interest rate index (3%), which is the smallest index available.

Future Maximum Benefit

In the future, the rehabilitated watershed yield and its financial benefit are expected to increase; this increase is estimated using maximum yield potential, considering the time when the planted trees mature, which fundamentally determines the maximum yield amount. As almost all the planted trees are fast growing, they can mature within 20–25 years of planting, which is around the year 2025. This will be the year when tree volume in the area will increase to the maximum, and the carbon sequestered also rises to the utmost. However, this parameter of maximum increase is only approximate; hence it was mandatory to refer to forestry studies conducted in the tropics that utilized different techniques like growth models and volume tables to estimate the mature tree parameters (Duke and Wain 1981, Huxley 1992, Johnston 1996, Evans 2001, Preece and Brook 2001, Morgan and Sedgley 2002, Odenyo et al. 2003). Though the parameter values of these mature trees vary even within a forest stand, this study considered the average values from the studies, in order to obtain a reasonable result. After attaining the maximum tree parameter estimates, biomass and volume yield values were determined via equations 1–4 (Boxes 1 and 2).

In our maximum yield estimation, we expected grass biomass to be comparable from year to year since we do not anticipate significant changes in harvest biomasses between years. Thus the future carbon sequestration of grass is equal to the present estimated value.

Given the current volatility of the carbon market, it was hard to envisage future carbon prices or tree volume sell prices. We therefore used current market prices to estimate financial benefit from the maximum carbon sequestration and tree volume. The future maximum benefit of the byproducts was discounted to the year 2007 using equation 6 in order to

compare all the results using the 2007 money value (Box 3).

The choice of discount rate is a contentious topic in the literature. Many environmentalists argue against discounting in general, and high discount rates in particular, because they believe high discount rates to be a cause of degradation because individuals prefer short-term measures to satisfy immediate needs at the expense of environmental conservation (Goodin 1982, Pearce 1987). Several solutions have been posed for this problem. An extreme case would be to use negative rates, thus guarding resources for the future. However, as future benefits would then always be valued higher than the present, no investment project would ever be sanctioned. Some suggest abandoning discounting (Price 1993). However, this ignores the validity of positive time preference and capital productivity. One solution that was reasonably commonplace until this decade or so was the preferential reduction of discount rates in the appraisal of projects deemed to yield positive external benefits to society (Bazelon and Smetters 2001). An extreme example of this is reflected in a decision of Great Britain's forestry commission that a return of only 3% is required on past investments. In this study, the market price of the yield has been discounted using the index of National Bank of Ethiopia's money deposit interest rate index, which is the smallest index available (3%), as compared to the interest rate index utilized nationally for loan.

Results

Total tree volume was calculated based on merchantable wood volume and crown volume. The monetary values for the crown and merchantable wood volume were estimated independently and then summed together (Table 2). The table reveals that the volume observed depends on the size of the planting area, number of planted species or trees per area, and the year of planting, which mostly determines

Table 2. Total monetary benefit obtained from the tree volume, calculated based on merchantable wood volume and crown volume, of all the trees in four rehabilitated watersheds (Farta Woreda, Ethiopia). The currency exchange rate used for calculation is 1 USD = 8.71 Birr.

Watershed	Volume (m ³)		Financial benefit	
	Merchantable wood	Crown	Birr	USD
Tsegur Eyesus	32.29	18,168.73	2,159,895	247,979
Worken Gashajagrie	60.46	32,648.47	3,881,897	445,683
Eshim Wofena	52.71	39,163.34	4,651,167	534,003
Worken Adura	13.44	7,723.16	918,050	105,402

Table 3. Carbon content of the trees and equivalent financial benefit that could be obtained from carbon credits in four rehabilitated watersheds (Farta Woreda, Ethiopia). The currency exchange rate used for calculation is 1 USD = 8.71 Birr.

Watershed	Tree carbon (tons)	Monetary benefit	
		Birr	USD
Tsegur Eyesus	32.29	2,813	323
Worken Gashajagrie	63.77	5,554	638
Eshim Wofena	51.84	4,515	518
Worken Adura	11.43	995	114

Table 4. Carbon content of the grasses and equivalent financial benefit that could be obtained from carbon credits in four rehabilitated watersheds (Farta Woreda, Ethiopia). The currency exchange rate used for calculation is 1 USD = 8.71 Birr.

Watershed	Grass carbon (tons)	Monetary benefit	
		Birr	USD
Tsegur Eyesus	1.98	173	20
Worken Gashajagrie	5.60	488	56
Eshim Wofena	6.14	534	61
Worken Adura	7.17	625	72

Table 5. The total biomass carbon content (tree and grass) and equivalent financial benefit that could be obtained from carbon credits in four rehabilitated watersheds (Farta Woreda, Ethiopia). The currency exchange rate used for calculation is 1 USD = 8.71 Birr.

Watershed	Total biomass carbon (tons)	Monetary benefit	
		Birr	USD
Tsegur Eyesus	34.27	2,986	343
Worken Gashajagrie	69.37	6,042	694
Eshim Wofena	57.98	5,049	579
Worken Adura	18.60	1,620	186

Table 6. Cumulative rehabilitation benefit calculated from the benefits that could be obtained through carbon credits and the tree volume in four rehabilitated watersheds (Farta Woreda, Ethiopia).

Watershed	Benefit (Birr)		
	Sequestered carbon	Tree volume	Total rehabilitation
Tsegur Eyesus	2,986	2,159,895	2,162,881
Worken Gashajagrie	6,042	3,881,897	3,887,939
Worken Adura	5,049	918,050	923,099
Eshim Wofena	1,620	4,651,167	4,652,787

Figure 2. Comparison (in USD) of 2007 tree-volume benefit and the 2025 discounted benefit in four rehabilitated watersheds (Farta Woreda, Ethiopia).

Figure 3. Comparison (in USD) of total (tree + grass) benefit obtained through carbon credits in 2007 and discounted benefit in 2025 in four rehabilitated watersheds (Farta Woreda, Ethiopia).

the volume size. Accordingly, this was shown in Table 2 with the highest volume or benefit observed in Eshim Wofena, followed by Worken Gashajagrie, and finally Worken Adura.

Similar to the tree volume, the amount of tree or grass biomass, carbon sequestration, and its financial benefit depends on the size of the rehabilitation area, number of planted species or trees, and planting year. In this regard, biomass and carbon benefits in Table 3 show that the most tree carbon is sequestered in Worken Gashajagrie, while grass carbon sequestration (Table 4) is highest in Worken Adura and lowest in Tsegur Eyesus. The total carbon sequestered (grass and tree carbon) (Table 5) and its monetary gain have the highest value in Eshim Wofena and the lowest in Worken Adura. Table 6 compares

the benefit from carbon sequestration with tree volume, which shows that under our market assumptions, the monetary gain from tree volume is significantly higher than the carbon sequestration benefit at each study site.

Of rehabilitation expenditures, the highest costs are for staff training, salaries of project workers, and auxiliary and consultancy services (Table 7). Accordingly, because of the extent of degradation, size of the rehabilitation area, and year of rehabilitation, the highest establishment cost is invested in Eshim Wofena watershed area, while the smallest is for Worken Adura.

In our computation of the extrapolated future cost-benefit in the year 2025, the major estimable monetary benefit increase was expected from

tree volume and carbon, which have shown a remarkable rise between the 2007 and 2025 maximum benefits (Figures 2 and 3). The tree volume in Worken Gashajagrie watershed area provides the highest benefit increase in the year 2025, whereas it was the second largest in the year 2007, next to Eshim Wofena (Figure 2). The total carbon sequestration benefit has also grown dramatically (Figure 3), since the maturation of the trees also increases the carbon sequestration potential. The benefit increase expected from carbon sequestration between 2007 and 2025 is greater than the relative increase recorded in the benefit from tree volume.

Discussion

Table 2 shows the total monetary value from merchantable woods and crowns of trees, which varies for each study watershed based on the number of planted trees, area of rehabilitation, and year of planting. The monetary benefit obtained from tree volume means that if hypothetically the trees are sold for construction and fuelwood purposes in 2007, they would provide significant monetary profit even in such short rotation period of four to seven years.

The main determinants for tree carbon sequestration amounts are tree height and dbh. The tree species are young; as a result, the values observed in Table 3 are small relative to their potential contribution for carbon sequestration. The variation in the amount of carbon sequestration observed between study watersheds is associated with the size of the watersheds and to some extent the planting age difference and the species diversity within the study watersheds. The Worken Gashajagrie site has higher values of carbon, which are associated with its large area and higher species diversity. Even though Worken Adura is the same establishment age as Worken Gashajagrie, it has the smallest carbon value, due to the small number of trees planted (Table 1).

Comparison of the biomass carbon benefit with that of tree volume benefit shows an extreme difference of about 500%. These large differences are a reflection of the high prices for construction wood and especially fuel in the locality. The international market value of carbon, however, is insignificant compared to the local fuel and construction wood prices, and this exacerbates deforestation owing to a lack of viable opportunity cost to sustainably protect and manage the trees to benefit from carbon credit (carbon payments are for standing trees, but construction and fuel benefits are after harvest). The other reason for such large differences between the carbon credit and tree volume benefits is that, for carbon sequestration to be significant, the scale of the planting area must be large—a minimum eligible area for carbon payment is 500 ha (Locatelli and Pedroni 2003)). In this case study, the rehabilitated areas are too small to have enough of a carbon value to raise the benefit. This means the opportunity cost for local beneficiaries from carbon sequestration is much less than the benefit gained from felling the trees (volume benefit).

Cost-Benefit Analysis

Rehabilitation investment was taken as the cost of the watershed (Table 7), while the biomass carbon sequestration and tree volume were taken from the benefit side (Table 6). The comparison of cost and benefits shows that the full return can be obtained within a few years of rehabilitation (Figure 4). Benefits accumulated seven years after rehabilitation of Tsegur Eyesus and six years after rehabilitation of Eshim Wofena. Benefits for Worken Adura and Gashajagrie accumulated after four years. The benefits from both carbon sequestration and tree volume are higher than the cost, which means rehabilitation work is beneficial. In actuality, however, these byproducts (tree volume and carbon sequestration) are currently too small for direct financial revenue; this calculation is just to show the beneficial value added

Figure 4. Comparison (in USD) between the total rehabilitation costs and the current total benefits in 2007 obtained from the rehabilitated watersheds (Farta Woreda, Ethiopia).

to the watershed. Moreover, the real objective of the rehabilitation project is sustainable development over a longer period of time. The tree volume and carbon sequestration amounts will continue to grow as the trees mature, as long as there is no major disturbance to the watershed. Thus if the rehabilitated watershed is sustainably managed, the byproducts will also keep growing with time, creating viable financial revenue in the future.

In terms of the future benefit, the sequestered carbon benefit in 2025 is higher than the 2007 benefit, over 10,000% for all the study sites (Figure 3). This implies that the maturing trees increase the amount of carbon sequestered, which consequently means a higher monetary benefit can be obtained only from carbon credits. In comparing the watershed sites, Worken Gashajagrie shows the highest carbon benefit increase in terms of tree volume in 2025, while it had been the second largest in 2007, next to Eshim Wofena. This is due perhaps to the species diversity found in this watershed (Table 1), where the number of species is smaller than Eshim Wofena. Moreover the particular species that can produce better dbh and height determined the carbon sequestration potential.

Kyoto Protocol negotiations in 2001 provided for carbon credits to be gained from afforestation,

reforestation and rehabilitation, agroforestry, and rangelands (Walker et al. 2008). In accordance with this, the rehabilitation sites described here are eligible for the voluntary carbon market, since they are planted on degraded land, are mixed tree-grass plantations, and are also on rangelands the community had been using for grazing. A recent analysis of carbon credit projects indicates that the minimum area necessary for a project to be eligible is 500 ha (Locatelli and Pedroni 2003), while the minimum requirement of sequestration capability is one unit or 10,000 metric tons of carbon dioxide each year. Compared to this, our study sites are small, but the total available degraded watershed in each Peasant Association is more than 8,000 ha. An area this size, if similarly rehabilitated, could provide the locality with a carbon credit production capacity of over 50,000 tons. Furthermore, while the study watersheds are too small to take advantage of the carbon market, these sites could join another watershed as an “offset aggregators group” in order to reach the requirement of one sequestration unit each year.

Another future benefit is obtained from estimating fuel and construction benefits. While mature trees offer services and benefits besides fuel and construction, when considering only fuel and construction services, the

Figure 5. Comparison (in USD) between the total rehabilitation costs and the future total benefits (2025), including carbon credits and tree volume benefits, obtained from the rehabilitated watersheds (Farta Woreda, Ethiopia).

benefit grew radically over time—over 1,500% from the present.

Volume benefit (Figure 2) far outweighs the estimated benefits of carbon sequestration (Figure 3), because the market price for wood construction and fuel in the study area is immensely high. In other words, the future of watershed rehabilitations is jeopardized by a low demand for carbon.

Figure 5 reflects the discounted benefits (carbon and tree volume) of trees grown until 2025 and the compounded rehabilitation cost. Future extremely high values make the costs of rehabilitation insignificant compared to the present cost-benefit comparison (Table 4). The increase in benefit over time implies that sustaining rehabilitated areas is well worth investment expenditures.

Conclusions and Recommendations

In this study, an economic valuation technique was developed to analyze the dynamics of watershed rehabilitation, measured by comparing costs and benefits. Notwithstanding its deficiencies, the economic valuation approach in this study, if carefully applied, is judged to be the most appropriate. The usefulness of this methodology is further enhanced through its capability

in handling ecological and economic scenario setting. As the methodology of this study indicates, a universally acceptable methodology does not exist in economically accounting ecological entities; hence straightforward procedures were applied. However, estimating the values of rehabilitation is complex, and more research is needed on the biological as well as the economic aspects of valuation. Moreover, it was hard to estimate precise values for prices and benefits when little information was. Hence, further studies could investigate thoroughly scaling up the results from small watershed sites. This also requires local participation to improve the research input and consequently its output. In addition, it distributes the ownership of the research results to the various players and ensures that results are used as input in decision making in the planning process.

The results revealed that the rehabilitation investment has brought ecological and economic benefits. The experience to date with the four rehabilitation project sites indicates that such investment is profitable. Given an appropriate mechanism for sustainable management of the rehabilitated watershed sites, the amount of carbon sequestration benefit would rise sharply within a few years. This, however, is considering the anticipated

development of a viable carbon market. The results clearly indicate that investment in rehabilitation may be a viable short-term proposition; the long-term benefits are more pertinent from the point of view of monetary return. Hence there is a strong case for sustainable management of rehabilitated watersheds in view of the high economic benefits.

The sustainable management of rehabilitated watersheds will likely be an important element of livelihood development investment in Ethiopia. The most critical question is not the current cost of rehabilitation per se, but whether the long-term benefits of rehabilitation make these costs of abatement worth bearing. Finally, enabling policies and laws to support sustainable utilization of rehabilitated watersheds and to hasten the development of markets for these rehabilitation goods and services would be important. Another critical point of investigation is establishing who benefits, and to what extent; that is, who can demand payment for services rendered by rehabilitation. Research is also necessary to establish practices and benchmarks for fair negotiations between producers and consumers.

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