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ECONOMIC VALUATION OF GULLY REHABILITATION;

A CASE STUDY AT FARTA WOREDA, IN SOUTH GONDAR, ETHIOPIA


BY
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List of Acronyms

AGB	Above Ground Biomass
DBH	Below Ground Biomass
DBH	Diameter at breast height
H	Height
MW	Mouth Width (Gully)
BW	Bed Width (Gully)
SFM	Sustainable forest management
STM	Sustainable Timber Management
CL	Conventional Logging
C	Carbon
L	Length (distance)
EHRS	Ethiopian Highland Reclamation Study
M	Meters
ANRS	Amhara National Regional State
DAP	DiAmoniumPhosphate
UV	Use Value
NUV	Non Use Value
N	Nitrogen
P	Phosphorous
K	Potassium
Cm	Centimeter
Kg	Killogram
USD	United State Dollar
Ha	Hectare
OC	Organic Carbon
OM	Organic Matter
kg/ha/yr	kilogram per hectare per year
GTZ	German Technical Cooperation
MOA	Ministry of Agriculture
mg/kg	milligram per killogram
FAO	Food and Agricultural Organization of the United Nation
masl	meter above sea level
SLGully	Soil Loss Gully erosion

Abstract

In addressing land degradation problems a number of interventions have been made in Ethiopia, gully rehabilitation is one of such measures. But so far, the economic value of gully rehabilitation from the point of view of estimating the opportunity cost has not been undertaken. Hence this study attempted to develop methods of valuation of gully rehabilitation, by formulating a technique in valuing the gully rehabilitation work in monetary terms, in a way that incorporates all the major costs and returns of the gully and its rehabilitation. The study also tried to construct scenarios to gain opportunity cost information about the future. Four model-rehabilitated gullies (Eshim Wofena, Worken Gashajagrie, Worken Adura, Tsegur Eyesus) in Farta woreda, South Gonder, Ethiopia, were studied to economically quantify rehabilitation projects under a range of techniques. The data used were obtained from a physical data survey and supplemented with secondary sources. Data were obtained on all the major costs like gully soil loss area with yield loss cost, and establishment cost. The major returns were nutrient accumulation with local price of fertilizer, tree volume (crown and wood) with local tree volume benefit after felling, and standing plant biomass with carbon sequestration benefit. The total costs and return values of the data were compared monetarily through opportunity cost computation. The results of the study indicate that at current stage by taking the smallest and largest gullies (Worken Adura and Eshim Wofena), the gully benefits Birr 208,874.6 to 406,489.26 respectively accounting the sustainable carbon sequestration and nutrient components. While the short-range ideal gain which considers tree volume gain besides sustainable components, for the same gullies reaches from Birr 1,126,924.22 to 5,057,656.48. However the cost side attains the same amount in both cases. Under optimal management on the year 2021 the cost side is estimated to be in between Birr 263,869.74 to 470,727.18 while the benefit was between Birr 29,644,486.24 and 116,368,436.40 for Worken Adura and Worken Gashajagrie gullies respectively. The cost or benefit variation between gullies depends on the specific gully cross sectional area, tree number and species diversity type etc. The high monetary return with a very meager cost, in this regard, establishing gully rehabilitation is a proficient investment that is worth spending. Hence the study reminding the complexity of valuation methodology, calls for major multidisciplinary and participatory research efforts in order to make such study results more useful and the results more credible.

Key Words- Gully rehabilitation, Economic value, Scenario, Opportunity cost, Sustainable and Ideal benefit

1. Introduction

1.1. Background

Land degradation is currently estimated to affect about 3,600 million hectares of the world's total land surface. About 16 percent of the world's agricultural land is affected by soil degradation (UNEP, 2002). In Africa alone, an estimated 5- 6 million hectares of productive land are affected by land degradation each year (Stocking and Niamh, 2000). This means that several million hectares of new land, often-marginal land, has to be opened up for agriculture every year just to offset the effects of degradation. In Africa where large section of population are dependent on natural resources for their livelihood, and subsistence agriculture and pastoralism (Klaus, 2002) the only alternative for survival of local communities is often to expand agriculture and grazing areas onto marginal land and wilderness areas. All physical and economic evidence shows that loss of land resource productivity is an important problem in Ethiopia and that with continued population growth the problem is likely to be even more important in the future.

There are several studies that deal with land degradation, (particularly on the effect of soil degradation) at the national level in Ethiopia. These include the Ethiopian Highlands Reclamation Study (EHRS) (FAO, 1986); studies by the National Conservation Strategy Secretariat (Sutcliffe, 1993; Keyzer and Sonneveld, 2001). Conclusions from these studies vary in some aspects. The EHRS concluded that water erosion (sheet and rill) was the most important process and that in the mid 1980's, 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation. Erosion rates were estimated at 130 tons/ha/yr for cropland and 35-tons/ha/yr averages for all land in the highlands, but even at the time these were regarded as high estimates. Sutcliffe (1993) produced new lower estimates for soil erosion, but emphasized the much greater importance of nutrient loss. The Ethiopian Forestry Action Plan outlines the pattern of deforestation which is estimated as 150,000/ha/year (EFAP, 1994), while another estimate puts it 62,000 /ha/yr (World Bank, 2001).

The dwindling of forest resources overtime has led to loss of fertile topsoil at an alarming rate particularly via water and soil erosion (Bedru Babulo *et al.*, 2006a). Agricultural practices are known to be the most important and immediate causes of accelerated soil erosion (Shibru Daba *et al.*, 2003). Gully erosion is one form of accelerated soil erosion and the occurrence of gullies often indicates an extreme form of land degradation warranting special attention. Gully erosion can generally be described as the most catastrophic and usually impressive form of rainfall-induced erosion (El-Swaify, 1983) and gullies are obvious features in a landscape, and may be very large causing the undermining of buildings, roads, and trees. There are several ways of defining a gully; however, what can be agreed upon is that, a gully is a linear incision characterized by intense erosion episodes, already sufficiently large in cross-section to be a potential permanent feature of the landscape (Dino and Lorenzo, 2002). In this work, this definition of gully, albeit not a clear-cut one, is used.

Gullies may be continuous or discontinuous; the latter occurs where the bed of the gully is at a lower angle slope than the overall land slope. Discontinuous gullies erode at the upslope head, but sediment themselves at the end of the discontinuity. Hence, several discontinuous gullies may occupy the same landscape depression, their shapes progressively moving upslope (Herweg, 1996). Gully is caused by the action of water. Runoff is channeled into grooves, which deepen over time to form a distinct head with steep sides. The factors affecting gully formation can be categorized into two groups, man-made factors, and physical factors (Geyik, 1986).

Man made factors: - Improper land use, Forest and grass fires, Overgrazing, Mining, Road construction and Destructive logging

Physical factors*:* - Precipitation, Monthly distribution of rainfall, Rainfall intensity and run-off, Rapid snowmelts Topography, Shape and Size of the catchment, Length and gradient of the slope, Soil properties and Vegetative cover;

Gullies are classified under several systems based on their different characteristics, of these the most important and viable classification parameters are size and shape.

Gully classes based on size: - One gully classification system is based on size, depth and drainage area. Table 1 describes small, medium, and large gullies and is commonly used in manuals of gully erosion.

Table. 1 - Gully classes based on size

Gully classes	Gully depth	Gully drainage area
	M (meter)	Ha (hectare)
(a) Small gully	Less than 1	Less than 2
(b) Medium Gully	1 to 5	2 to 20
(c) Large gully	More than 5	More than 20

Source: Frevert *et al.* (1955).

Gully classes based on shape: -This system classifies gullies according to the shape of their cross-sections as U-Shaped gullies; V-Shaped gullies and Trapezoidal gullies (Weidelt, 1976).

Gullies tend to form where land slopes are long and land use has resulted in loss of vegetation and exposure of the soil surface over a large area so that the land now produces more runoff (FAO, 1977). They are particularly prevalent in deep loamy to clayey materials, in unstable clays (e.g. sodic soils), on pediments immediately down slope of bare rock surfaces and on very steep slopes subject to seepage of water and to landslides.

In steep lands and mountainous landscapes of the tropics, gully erosion is more important than inter-rill and rill erosion. Where, a rill is a shallow linear depression or channel in soil that carries water after recent rainfall. Rills are usually aligned perpendicular to the slope and occur in a series of parallel rill lines. While inter-rill erosion, is due to detachment and transport by raindrop impact and overland flow. Inter-rill erosion has been shown to be approximately proportional to the square of the rainfall intensity. In these highlands or uplands, forests are the natural vegetation and are the essential contributors to the stability and sustainability of watershed ecosystems (El-Swaify, 1983). Removal of the vegetative cover due to expansion of agriculture on those steep lands enhances gullying which in turn promotes ecosystem instability due to both the on-site and off-site effects of soil erosion. An important off-site effect of gully erosion is siltation of valuable lakes and reservoirs as gullies carry a sizeable amount of sediment in a given watershed (Poesen *et al.*, 1996); while one of the on site effect is massive loss of soil or furrowing that cuts away all the soil to the stony part. Occurrence of wide and deep gullies is a common observation in the highlands, of Ethiopia. Krüger *et al.* (1996) have stated that the common occurrence of gullies and shallow soils with rock outcrops are prime indicators of the severity of soil erosion. The soil characteristics, coupled with sloping terrain and intense rain events, make south Gonder very susceptible to gully erosion (Anonymous, 1997). In addition, the silt load carried by these gullies threatens rivers down stream.

It can be extremely difficult and costly to rehabilitate a gully once it has developed. Thus, much more attention needs to be given to developing effective procedures and low-cost measures for gully control and reclamation. In particular, attention needs to be paid on the use of vegetation wherever possible. According to Geyik (1986) gully control structures can be classified as temporary or permanent. Temporary structures are intended to function until vegetation (permanent structures) becomes well established. They include brushwood check-dams, loose stone check-dams, Gabion box, gunny bags, arc wares, and other check-dams. The objective of the check-dams is to slow down the water and cause deposition of silt, which may allow vegetation growth.

The long-term success of gully stabilization work depends on establishing a good vegetative cover on the gully floor, which prevents further gulling and allows the gully floor to gradually silt up reducing the fall over the gully head. Vegetation provides protection against scouring and minimizes the erosion risk by reducing flow velocity. As velocity falls, sediment is deposited forming an ideal environment for new vegetative growth. FAO (2003) reported that indigenous species should be considered, especially in an area where it is not desirable to introduce exotic species. However, a number of exotic grasses and other tree species are well established and have been used with great success for controlling gully erosion in the study woreda, Farta. The role of vegetative cover is to intercept rainfall, to keep the soil covered with litter, to maintain soil structure and pore space, and to create openings and cavities by root penetration. Whenever possible, however, it is desirable to establish a vegetative cover which serves a multi purpose, for example, provision of fodder, fuel wood, fruit, etc. Rehabilitating previously degraded gullies from expansion or development due human and animal interference through gully rehabilitation biophysical measures is one of the most commonly practiced biophysical conservation measures in south Gonder (Tamene H/Giorgis, 1997).

1.3. Problem Statement

Most analysts working on erosion focus their studies only on erosion and its potential impacts per se and often compared the results against a hypothetical and unattainable benchmark. Mostly these researchers studied erosion types as ephemeral erosion and some studied erosion impact by measuring the soil loss amount using very complicated technologies. Very few researchers have dealt with the issue of rehabilitation and its implications. Also, very few authors spend an equal effort on the analysis of the economic system and the constraints that rehabilitations are operating under. This means, despite the qualitative gully rehabilitation arguments, the effect of biophysical gully rehabilitation measures is hardly ever addressed in quantitative monetary terms. The gully rehabilitation technology is rarely practiced conservation measure in Ethiopia, leave alone being addressed in quantitative monetary terms and researched upon. In fact most other conservation works in Ethiopia and specifically in the study woreda, Farta, have never been quantified to prove their worth or worse. There had been some conservation works in the study woreda however this works have never been quantified or studied with the objective of determining their economic value. So the cost incurred to such programs had not been truly or clearly justified, rather the worth of such rehabilitation program is just taken as a panacea approach. Besides these problems, detailed studies were not conducted on issues related to economic valuation of rehabilitation in the study woreda. Hence, this prototype valuation technique will be formulated on the basis of the present limited experience with this methodology.

1.2. Research Hypothesis or Questions

One may ask what does valuing has to do with this entire rehabilitation premises? A whole lot! If we do not know how to value a rehabilitation act, we do not know if it is benefiting or bringing return to the community or if it is just disbursement of money. If the gully rehabilitation costs and benefits are not differentiated to provide an estimate of the relative rates of return, we will have a lesser appreciation for their subsistence. Hence, the hypothesis here is that if monetary value can be given to the biophysical gully rehabilitation, the cost incurred or the benefit gained will prove its success or failure providing a better understanding of the rehabilitated gully. Hence the question posed is, 1) Does the approach of investing in gully rehabilitation and the cost incurred due to it, prove its usefulness? Within these years from the day of establishment of gully or 2) Do the existing biophysical structures, used in gully rehabilitation, bring the benefit they are intended for? 3) Does such, future biophysical gully rehabilitation need rethinking because existing ones have not proven its worth or have provided returns?

1.4. Significance of the study

This investigation of the loss due to gully erosion in monetary cost is vital to recognize the repercussions of the rehabilitation for Farta woreda. This paper highlights the major valuation techniques that could be used to capture the value of goods and services of gully rehabilitation by outlining the chief returns and costs of gully and its rehabilitation. As most of the economic aspects of the study woreda gullies are similar with other gullies in the study region and neighborhood woredas'. Thus this valuation technique can be applied at different stages ranging from a single village to regional case rehabilitations. This study is useful for any institute in charge of rehabilitation or interested in designing rehabilitation strategies for ensuring sustainable use while simultaneously promoting local profitability.

1.5. Objective of the study

1. General objective

This study deals with the cost of gully and its rehabilitation benefit. Using major valuation techniques with particular reference to four gullies found in the study woreda, Farta, particularly from the point of view of opportunity cost analysis. The study tries to formulate a technique, which has some degree of relevance in valuing the gully rehabilitation work in monetary terms. That is quantifying the return from the rehabilitation or loss as a result of the gully formation and the investment in rehabilitation.

2. Specific objectives

1. To measure and determine the area and volume of soil lost as a result of gully formation and to estimate the monetary cost of the crop yield lost from the gully area
2. To assess and compute tree volume produced and estimate the economic benefit of the volume.
3. To measure the soil mass accumulated as a result of the biophysical structure and estimate the nutrient (N, P, K and OC) content in order to estimate their gain.
4. To assess the biomass and thereby the carbon sequestration potential of rehabilitated gully and estimate the monetary gain of the sequestered carbon.
5. To estimate establishment (investment) cost of the gully rehabilitation program using existing data
6. To compute the present opportunity cost of the gully and constructing scenarios to estimate the opportunity cost of the future.

LITRATURE REVIEW

This article examines the role of economic discourse in making progress towards more sustainable rural systems. Because the fundamental argument is in favour of a greater systems approach in economic thinking, this spatial separation may initially appear paradoxical; however, two considerations suggest that we should specifically address rural issues. First, despite the valuable ecological niches contained in urban areas, the countryside contains far greater natural resources systems, supplying food, leisure opportunities and ecosystem services that must be safeguarded for a satisfactory quality of life. Second, economic analysts of rural land use systems, especially agricultural economists, have acquired a reputation for uncritical application of neo-classical approaches to the issue of sustainability, thereby alienating themselves from allied intellectual perspectives, especially those concerned with assessing the impact of human-induced changes on the environment.[1]

The origins of this antipathy are various. Significant contributory elements may be the reductionist character of analytical methods in mainstream economics, especially with regard to ‘resources’, and limited psychological and ethical perspectives (Kerlin and Smith). Whilst the perspective of economists clearly distinguishes between the positive (an attempt to describe things as they exist) and the normative, suspicion arises of guilt by association with the interests of corporate capitalism, due to an (at least implicit) orientation towards market liberalism. Where neo-classical economists have made efforts to incorporate sustainability within their theoretical structure, further distrust has been generated, as they conceive natural capital solely as a productive asset (considering it and ‘human-made’ capital as substitutes) from which to maximise consumption, subject to limiting constraints. The ‘weak’ version (defined by Pearce and Atkinson, 1993) is especially inflammatory to environmentalists, who consider (over)consumption to be the major cause of unsustainable human behaviour.

This article is an attempt to rehabilitate economic analysis by demonstrating that it is not incompatible with recognition of rural environmental concern. We emphasise, with examples of existing techniques, that economics can make valuable contributions to the design and achievement of sustainable ways of living, giving attention to the specific issues raised by rural areas. This theme is developed over four substantive sections. The first examines conflicts over value, in particular criticising conventional theories of market exchange and the resulting policy prescriptions for rural areas. The next section investigates adoption of conscious social choices as an alternative to unrestrained market behaviour, specifically examining the framework in which goals are set. It employs hierarchy theory to demonstrate the superiority of adaptive management strategies over the high levels of aggregation and optimising solutions required for traditional modelling approaches. The third section reviews analyses that can generate information, support social choices, and illuminate the interaction of economic systems with the wider social, cultural, ethical and environmental universe. The conclusion assesses the scope for a reconstructed economics, able to contribute to the formulation of policies for rural sustainability.

2. Values, markets and sustainable rural development

The neo-classical view of economics concerns scarcity and choice, basing value on utility and the availability of resources, of diverse tangibility, to deliver satisfaction. The concept of utility was invented to transcend the division of value into divergent use and exchange components by classical economists, which they had inadequately resolved with the labour theory of value.[2] Though Marshall (1920) (p. 93) noted that utility — satisfaction of wants — was not the only source of value, his conception subtly shifted the emphasis towards the measurable dimension of internal human desires, their external satisfaction through resource utilisation. Consequently, greater potential satisfaction through exchange, mediated by the market and price system, became a governing principle. When the mathematical tractability afforded by optimizing equilibrium[3] was added, the complex edifice of comparative static modeling of exchange and welfare functions resulted in an embedded emphasis on the favourable effects of markets and *laissez-faire* in economic consciousness. In contrast, we argue that rural development policies based on exposure to more vigorously competitive market conditions are likely to result in an unsustainable use of rural resources, even in the weakest sense in which the expression is used. Prominence is given to the tradition of spatial disequilibrium analysis established by Myrdal (1957) except that, rather than being concerned with the effects of consolidated development on a hinterland, the focus is on *underdevelopment* as a primary barrier to the establishment of sustainable rural systems.

Rural areas are presently unsustainable in at least two ways, environmentally and demographically. Through escalating competitive pressures, natural resource-based activities have become increasingly like their counterparts in the manufacturing industries (see, for example, Albrecht, 1997). Agriculture, in particular, has reproduced tendencies apparent in the overall economy of increased segmentation and differentiation, greater use of non-renewable resources and divergence from natural and economic processes. The impact on ecosystems has become increasingly invasive, to the point where the integrity of their major component ecosystems systems are being compromised. Pierce (1993) has argued that, whilst there has been rapid physical production growth, adverse outcomes for income, community stability and resource and environmental conservation have emerged. Coupled with this, the countryside is losing population, at least in gross terms. Clark (1998) argues that this is due to increased interdependency, as corporate capitalism extends its global scope. Both aspects are considered in detail in this section.

Rural economies, at least until recently, have been concerned with primary, or 'near-primary' production: food, fibre, timber, minerals, and labour-intensive manufacturing. Wider, more vigorously competitive markets have emerged as transport costs have declined and trade barriers have withered. Krugman (1996) comments on the importance of agglomeration economies in development of urban centres: consequences for rural areas include a relative decline in the terms of trade, counteracted only if rural labour productivity improves. Evidence of changing agricultural terms of trade (by inference, incorporating all rural near-primary production) tends to be expressed predominantly in international terms. However, inter-sectoral evidence existing for individual countries unequivocally suggests a decline in the terms of trade (see Gopinath and Roe (1996), for the United States; Tangermann (1994), for the transitional eastern European economies; and Lund (1994), for the UK).

The consequence of terms of trade deterioration, given the medium-term inflexibility of local rural labour markets, is a chronic overall decline in rural incomes, although technological change has counterbalanced the effects, at least for privileged groups. Because of this, attempts to counter such declines have involved economic restructuring, applying the logic of cost-saving industrialisation to rural, predominantly natural resource-based activities, whilst concurrently offering (ostensibly interim, though in practice open-ended) protection for the industries concerned. In essence, this has been the approach of post-war agricultural policy in industrialised countries, with variants also applied to forestry, fishing, and energy. As a result, activities have become more systematically organised, exploit economies of scale (particularly to promote mechanisation and the use of agrochemicals) and benefit from greater understanding of the physical, chemical and biological basis for production, yielding much technical change in production methods. Increases in throughput encouraged by this process, both per hour of labour and per hectare, contribute to economic growth even though, as Giampietro (1997) argues, ecosystem health is enhanced when throughput is lessened.

Nevertheless, capital-augmentation and industrialisation of farming is not a necessary consequence of an enhanced climate of competitiveness: the utilisation of existing resources can be improved. In a comparative study of tomato production in California and Northwest Mexico, Zabin (1997) found that institutional factors induced higher labour productivity in California, despite similar production technologies. Interestingly, as a result of NAFTA integration, there is evidence of downward convergence of labour incomes in the two regions. This technical change is likely to be more rapid in future since advances in biochemistry and genetic manipulation are gradually being diffused within production processes. Huttner et al. (1995) emphasise enhanced agronomic performance as a primary contributor to improving competitiveness in the United States farming sector, though their recognition of the attendant biosafety dangers is less critical than that of Westra (1998).

Whereas policy emphasis has been on competitiveness, other responses have had a measure of success. For example, Damianos and Skuras (1996) describe alternative restructuring options, through a mixture of off-farm work and adoption of unconventional enterprises, successfully adopted in Greece. Lighthall and Roberts (1995), in a case-study of Iowa farmers, show how non-commercial, farm-family ethics have been responsible for formulation and dissemination of low input production systems (with notable absence of support from state-sponsored research institutions). They concluded that technological change is a socially constructed phenomenon, and that alternative rationalities could be derived from different combinations of ecological and social conditions.

Past (and anticipated future) transformations of rural systems resulting from these influences are often associated, in economic jargon, with negative externalities. The visual appearance of the countryside has been altered, with changes in surface cover and alterations to other features. Much recent afforestation has been of uniform age and species plantations; mechanised production of arable crops requires large fields, resulting in the loss of boundary and other marginal features. Several studies of landscape change (including Bonfanti et al. (1997), Poudevigne et al. (1997), and Theobald et al. (1997)) indicate overall losses of biological and cultural richness, despite area-based conservation sites that are the major contribution of standard policies to sustainability. Decline in habitat quality and human appropriation of a larger fraction of total biomass leads many (such as Barbier et al. (1994), and Wood and Juniper (1994)) to argue system support services are vulnerable to catastrophic breakdown. Together with soil erosion, irrigation and consequent salinity, acidification and pollution from biocides, these impacts are portrayed as detrimental to long-term physical productivity of agriculture and forestry, although of course industrialisation has also been responsible for a dramatic increase in current financial productivity.

Paradoxically, through protection and substantial increases in the volume (if not the value) of rural output, increased poverty in the countryside has become ambiguous. Cloke (1995) argues that the standard transatlantic perspective on rural poverty needs to be updated to account for cultural changes, redefining responsibilities of the individual, community and state. This cultural shift is blurred by counterurbanisation, the tendency for people to move out from cities and suburbs into rural areas.[4]

The experiences of Europe and America have been different in some respects. In rural USA, the enduring concentrations of rural poverty noted by Lichter and McLaughlin (1995) are most associated with female heads of household (though Brown and Hirschl (1995) found that rural households have the highest probability of poverty even when household and contextual factors were eliminated).[5] Albrecht and Albrecht (1996) observe that classical urban/rural divergences in population characteristics were, in fact, a farm/non-farm divergence, and that major demographic shifts have obscured rather than eliminated them. There are also sub-regional differences, as Barkley et al. (1996) demonstrate in case-study areas in the Eastern United States; urban–rural migration has been more marked in peri-urban areas, but populations were stable or declined in tracts distant from nodal centres. Even if ethnic and regional problems commonly characterising rural social exclusion are absent, there can still be disguised rural distress: see, for example, the analyses of rural communities in upstate New York by Fitchen and Fitchen.

The impact of counter urbanization elsewhere is also generally well documented: for example, in Australia, by Walmsley et al. (1998); Britain, by Champion (1994) and Spencer (1995); Canada, by Dahms (1995); France, by Cavailhes et al. (1994); Germany, by Kontuly (1991); Spain, by Hoggart (1997a); and Switzerland, by Schaeffer (1992). The process normally involves migrants with significantly greater wealth than the indigenous population, contributing a spatial dimension to the generally sharpening division between rich and poor in industrialised countries (Hugo; Saraceno; Boyle; Boyle and Riebsame). However, some less affluent immigrants, seeking a potentially better lifestyle quality in rural areas, may combine to enlarge indigenous deprivation. These have been christened the *nouveaux pauvres* by McLaughlin (1986); see also Cloke et al. (1995).

Whilst numbers of the less well off have diminished, the relative distance between their quality of life and the average has increased more than proportionately. Structures of service provision are considerably affected by mobility. Levels of car ownership in rural areas are high (in Britain, for example, upwards of 70% of rural households have at least one car, with many enjoying multiple car ownership), and rural–urban road networks are improving. Yet for the car-less minority, the increasing assumption of private mobility causes an absolute decline in accessibility to services. Public transport costs in rural areas have risen disproportionately as volumes of private traffic have increased. Mobility has also contributed to the appropriation of rural housing by the wealthier, since greater accessibility makes the countryside more attractive for commuters, or to retire to while still retaining non-rural links (Hoggart, 1997b). In a few cases, entrepreneurial individuals relocate themselves and their businesses as well, seeking the same attractions of space, tranquillity, freedom from pollution, and an integrated sense of community: access to these is taking on the character of an increasingly scarce 'positional good' (Hirsch, 1977). Some evidence (Milbourne, 1997) suggests that in-migrants take over representative institutions like community councils, wildlife, environment and amenity groups, in order to protect the desirable qualities of their acquired rural spaces. This influence prevents developments offering opportunity for less privileged inhabitants, contributing to the cycle of cumulative causation in which divisions between the affluent majority and the rest become deeper.

Thus, increasing competition and technological change, far from promoting sustainability, have increased appropriation of future survival prospects by the present. Deconcentration of population from urban and suburban areas into the countryside has masked disadvantage and lack of opportunities, intensified polarisation, and skewed the demographic structure towards the elderly. Shifts in the production structure of natural resource-based industry suggest that prospects for an environmental dividend from economic liberalisation are optimistically naïve. It seems clear that the economic focus on market equilibrium, optimisation and comparative advantage, based predominantly on comparative static approaches, is too reductionist to comprehend the complexity of cultural, technological and economic changes influencing human interaction with the rural environment. Its entrenchment in a limited psychological and ethical perspective is a further barrier to broader perception. Consequently, and depressingly, primacy is still accorded to the functioning of markets as a 'rational' means of allocating resources. As an example, the UK government's most recent statement of rural policy asserts the need to encourage 'the operation of market forces in the agriculture sector', explicitly linking it to an overall aim to 'encourage and support the creation of productive, sustainable and inclusive rural economies' (Cabinet Office, 1999, p. 8).

The following section describes a potentially broader framework of interpretation, within which market influences are recognised, accommodated, but not accorded supremacy.

3. Social choice encompassing multiple values

A starting point for considering what is requisite for rural systems to develop in a sustainable fashion is *systems thinking* (Checkland and Checkland). Systems thinking provides a means of approaching complex problems such as this, to achieve greater congruence between dynamic human systems and ecosystems.

One of the core features of systems thinking is the conceptualisation of reality as existing in layers within a *hierarchy*. Such layers are referred to as *scales* or *holons* and result from *emergent properties* within the system. These emergent elements have relevance at particular scale levels in the system, but can be insignificant in terms of individual components at lower scales. Thus, as is often noted within systems, the whole is more than the sum of the parts (Checkland and Scholes, 1990). For a system to survive in a changing environment it has to adapt, and therefore *communication* and *control* between the hierarchical scales are vital.[6] Within rural systems, the predominance given to the market mechanism has led to a greater reliance on prices to provide information, but as the previous section has made clear, prices have not given sufficient feedback on social and ecological parameters, leading to instability within these spheres. In order for rural systems to develop in a sustainable manner, information on changes in all relevant components needs to be effectively transmitted to provide the opportunity for balanced adaptation. Over time both price and non-price transmission mechanisms have tended to become less effective at reflecting social and ecological factors. Giampietro (1994) draws attention to the shift in type of resource input from renewable to non-renewable and notes that although this has removed immediate natural resource constraints, it has made economies relatively immune to feedback via productivity effects. He concludes that this makes social feedback mechanisms all the more necessary. However, it seems that many of these too have become weakened as economies have engaged in greater trade. One of the consequences of market expansion has been that businesses have become less integrated with the local economy and less entwined with the social community within which they operate. While higher levels of material wealth have been realised because of *gains from trade*, the prices of resources and products have become less related to local conditions. Furthermore, with a lower degree of economic interdependence between people living within a locality, the extent of social interaction has been lessened, reducing the likelihood of non-price information being informally transmitted and accommodated. Thus the system gravitates towards becoming more influenced by exchange values, and less sensitive to other values.

To counter destabilising effects within rural systems, it is clearly necessary, within the system, to have both good information flows and responsive mechanisms. It is not so immediately clear how this can be achieved as rural systems are composed of an amalgam of micro level ecosystems, of businesses, and of individuals and communities. Together they make up an elaborate system, which is itself part of and influenced by a wider ecological, economic and social system. Furthermore, rural systems are expected to fulfil a variety of functions.

Traditionally they are viewed as suppliers of primary products, food, timber, minerals, but recently their significance as suppliers of ecological services has been acknowledged. Ecological services have value not only at the local level, but also at higher levels up to the global. For example, woodlands can contribute to balance within a regional ecosystem, while the carbon-fixing properties of tree growth are beneficial to the global carbon cycle. Similarly, biodiversity at lower levels within the system can be important for local resilience, and at the same time have considerable implications for maintaining the gene pool at the national and global level. Rural systems also have an important role as a place where humans can interact with the natural world, either on a temporary basis as visitors, or more permanently as residents. If the residential population is not to be dominated by retired people with outside sources of income, or commuters engaged in business elsewhere, then the rural system needs to be able to provide the means for earning a livelihood. The livings that are derived from the primary and near-primary industries may be considered of particular value because they are a principal determinant of the distinctive culture of rural areas. Rural social goals thus may be interpreted as not only a commitment to fairness, to ensuring adequate living standards, but also the achievement of modes of living that interact and are in balance with the natural environment.

3.1. A hierarchical framework for rural systems

Hierarchy theory was initially developed to study ecological systems by observing them as a series of nested scales, defined both spatially and temporally, but it has since been extended to social systems (see for example, Checkland and Allen). The strength of a hierarchical framework within the rural context is that it can include economic phenomena, but, unlike economic models does not focus exclusively on them. Instead it emphasises the need to comprehend not only the physical, chemical, biological, intellectual and emotive attributes of components at each scale, but also the ‘rules of the game’ that determine interactions among them (Weston and Ruth, 1997).

Within this approach, components are identified within hierarchical scales, recognising that they are made up of smaller parts (for example, a farm is composed of a collection of enterprises) yet are also part of a greater whole (the farm is a component of the national agricultural sector). This dual dimension of components gives them *multi-factoriality*, which means that they can both be changed by other components, while themselves acting as a change agent (Clayton and Radcliffe, 1996). Friction can occur within the system because the identity of a component has to be secured in competition with others at the same scale, yet the competitive process can destabilise other scales within the system on which it depends (Giampietro, 1994). While stability is desirable, nonetheless, stability is not synonymous with immutability, but rather refers to the ability of entities to maintain self-organisation while evolving. Indeed, evolution occurs precisely as a result of interactions between the scales (Weston and Ruth, 1997).

By adopting a hierarchical perspective, some clarification can be achieved. Scaling brings recognition that different levels within the system function in different ways; an appreciation of this can contribute to more effective management. Sometimes there are trade-offs between scales, with often a change desirable at one level causing losses at another. For example, a reduction in the price of agrochemicals at the world market level might lead to higher food output and lower food prices at the national level, but destabilise local ecosystems. The standard economic approach for dealing with trade-offs is to assign money values to each effect, and aggregate them to assess the value in monetary terms of each possible outcome. Thus in the case of an agrochemical price reduction, the benefits of lower product prices less the estimated cost of ecological damage are estimated and the change is considered beneficial if the net benefits are positive. Such an approach has allowed the continued application of optimising models favoured by economics, but the results have limited value because of the significant information loss.[7] Opportunities for considering whether output might be increased with less environmental damage are forsaken; they are not included within the choice framework. For improved social decision-making, where trade-offs exist, but there is a need for stability at various scale levels, knowledge and information on the relationships between the scales is vital and can stimulate more creative problem solving.

While the hierarchical scaling approach may have superiority over the purely economic approach in providing more information and thus cultivating more options, it needs to be recognised that the defined scales are constructs, reflecting the perceptions of the hierarchical model builders (Wilby, 1994) and hence may themselves be restrictive. On the same grounds, Curry (1995) has warned of the dangers in the use of Geographical Information Systems when they rigidly define context and thereby limit discourse. This pitfall is potentially avoidable if hierarchy theory is approached as a methodology rather than as a technique. Checkland and Scholes (1990) argue for a distinction to be made between hard systems analysis and soft systems methodology. A hard systems approach assumes that the world *is* made up of clearly definable scales, and uses techniques to solve problems (see Midmore (1996) for a critique of their use in agricultural economics); by contrast, soft system methods use system models as a means of creating cyclic processes of enquiry; their main purpose is to help to articulate and operate a learning cycle from understanding to purposeful action, without imposing a rigid technique. Crucially important for the success of a soft systems approach is inclusiveness within the learning cycle. With regard to rural systems, the involvement of rural populations in the development process is critical for resource management because it is only in the detail at the local level that imaginative resolutions can be found to achieving complementarity between economic, ecological and social goals. Sustainable development objectives challenge societies to adjust the way in which they operate, so that they are fully inclusive. Asby and Midmore (1995) have argued that planning for economic vitality in marginal regions can only be attained through an effectual structure that provides for 'empowerment' of local communities. This is required all the more to counteract the disempowering effects of market liberalisation on rural economies. Market liberalisation has meant that, via the price mechanism, higher scales within the system have had greater predominance over the lower. In general, the primary sectors, so significant in defining the character of rural areas, have been subject to declining terms of trade. The resulting cost-price squeeze has pressed primary producers, perhaps most noticeably farmers, to adopt new, typically capital-biased technologies. Capital-biased technological change is relatively easily transferable between regions, in contrast to technology more reliant on labour and local natural resources, and consequently its propagators have benefited from expanding markets. With such developments, ecological conditions have become a less significant influence on income levels, and thus have been subject to neglect, while market conditions have become more important. The farm scale has been, in effect, a channel through which forces originating from higher levels in the system have impacted at a lower level on the ecosystem, with insufficient regard paid to maintaining stability.

Pressures similar to those driving change within the agricultural industry have also been brought to bear on other primary and near-primary production activities, with similar destabilising effects on rural areas. Capital-biased labour-saving technologies have reduced the opportunities for livelihoods to be gained from natural resource management and have caused environmental damage. With fewer opportunities to generate a livelihood in rural locations, migration has been inevitable. Furthermore, the shift to capital-intensive technology within the primary and near-primary sectors has not only reduced the demand for direct labour, but also increased the amount of spending on inputs from businesses outside the region. Consumer spending on goods outside the region has also increased, as reduced transport costs have made rural economies more open: local multiplier effects accordingly diminish. Thus while market liberalisation and technical change have raised production in the economy as a whole, they have altered the distribution of income both within rural areas and between rural and urban areas. Aggregate prosperity at the country level has been gained at the expense of certain groups and at environmental cost. If areas are to become more demographically sustainable, attention needs to be paid to the resource and financial flows within rural regions and between them and their urban poles (Saraceno, 1994). Crucially, attention needs to be given not only to the level of prices, but also to the way in which economic activity is organised, the *rules of the game* within the system.

3.2. Changing the rules of the game

In order to counter destabilising market forces, suitable action needs to be taken at the appropriate social and geographical scale. Rosser (1995) emphasises the necessity of having institutions that operate at relevant levels within the ecological hierarchy. Similarly, institutional structures are required for addressing social and related economic issues. A frequent cause of instability is the lack of integration of local information and objectives into higher level decision-making (Wolf and Allen, 1995). Knowledge from grassroots-based organisations not only needs to be incorporated, but to be empowered, those organisations also need access to knowledge produced in other parts of the system (Harris et al., 1995). Partnerships that encompass local, regional and national levels of government and their agencies are vital for establishing the necessary links between the different scales.

Rural populations might want to consider changing the rules of the game with respect to trade. They might consider engaging in more local trade, reducing dependence on outside markets where current prices may be more favourable, but in the long term, less robust. Such an idea challenges conventional wisdom that holds that greater trade not only raises wealth, but also reduces the vulnerability of small economies, as they are less affected by local shocks. Nevertheless, while a degree of trade can be beneficial, high levels of trade can result in economies becoming over-specialised and thereby overexposed to increased levels of external competition and variable market conditions. Thus if stability within a rural economy is valued, means for promoting more local trading might be explored (Douthwaite, 1996). Furthermore, local production for local use can bring a wider range of benefits if the producers and consumers share community goals of fairness and respect for the surrounding environment.

Another rule of the game that can be challenged is the mode of technology. Mainstream economics has tended to assume that market conditions will determine the most efficient technology, but as Arthur (1989) has argued, dynamic increasing returns to an embedded technology can crowd out a superior technology. The effect of the increasing returns can be so great that small changes to prices provide insufficient inducement for superior technologies to emerge (Goodstein, 1995). A consequence of this is that for the path of technology to alter, a conscious choice has to be made. This needs to be accompanied by the introduction of institutional changes and possibly short-term subsidies to stimulate the development and uptake of alternatives. In the case of agriculture, farming in balance with local ecosystems is likely to require technology that makes greater utilisation of natural endowments rather than external capital inputs. Since natural endowments vary between locations, this would necessitate more regionally based research and the input of the local knowledge of farmers.

These forms of approaches, which involve the rural population and concentrate on the modes of economic activity, contrast with traditional economic policy measures to deal with environmental and social problems, which have tended to focus on adjustments to market signals (Schütz, 1999). Typically, when negative environmental effects of market activity have been identified and market failure acknowledged, economists have advocated policy instruments such as taxes or subsidies to internalise the external market effect. Thus, what were previously non-market effects are fed back into the private decision-making arena so that, supposedly, confidence can be placed in the market again. This type of approach can be powerful for disseminating information relevant for achieving goals at higher levels in the system. For example, price adjustments at the country level can be appropriate for achieving country level targets, such as raising agricultural output, or increasing countrywide tree cover. In addition, price signals can have a place in providing continuous incentives for encouraging adaptation towards ecocyclic principles (Ring, 1997). But for attaining specific goals at lower levels in the system, price adjustments are normally inadequate because implementation costs prohibit the high degree of variation required to tailor the policy instrument to diverse local conditions. With insufficient information transmitted through market signals, the response is deficient at the local level. Neither are price adjustments adequate for dealing with social problems, as agricultural price support has demonstrated. Government intervention to uphold agriculture product prices in the wake of declining terms of trade has not been able to prevent a decline in farm incomes (Harvey, 1991).

The hierarchical framework does not reveal a clearly definable desideratum for sustainable development in rural areas, but instead draws attention to the need to adopt an integrative systems approach. This involves making conscious choices to take appropriate action to guide development and promote stability. Through scaling, the hierarchical framework begins to clarify some of the complexities within the system, helping to identify the links between multiple goals and the sources of destabilising pressures. The need for better information flows and institutional change to provide opportunities for betterment is emphasised. While this approach contrasts with a reliance on the market mechanism to achieve optimal welfare levels, it does not deny the role of economic factors, both in contributing to and solving problems. Furthermore, as the next section demonstrates, a methodology derived from economics can be useful in generating some of the information requirements necessary for making more informed social decisions.

4. An empirical framework for analysis of rural sustainability

Economic analysis is notable for a consolidation of its spatial focus around just two major perspectives, the aggregate functioning of the overall system (macroeconomics) and the basis for individual decision-making as consumption and production units, mediated by markets (microeconomics). This dichotomous approach lacks coherent connection, a source of historical controversy.[8] Nevertheless, although ecological economists have made substantial efforts to distance themselves from neo-classicism, it must be recognised that any evolution of this kind is a mixture of original and existing concepts, and their literature can be characterised by similar divisions. For example, Daly (1991) has set out the elements of an environmental macroeconomics in which the notion of global carrying capacity figures strongly. Others, for example, El and El, have designed systems of accounting that encompass both financial and natural resource flows. The construction of an Index of Sustainable Economic Welfare by Daly and Cobb (1990) provides a defensible alternative to transactions-focused measures of aggregate activity. At the individual decision-making level, substantial effort has been made to assess the value of environmental resources for public decision-making purposes, mainly through contingent valuation methods (though by no means exclusively: some of the issues surrounding evaluation founded on human assessment are explored by Blamey et al., 1995).

In terms of developing insights from hierarchy theory for rural systems, however, the ecological economics approach lacks scope for integration over a range of spatial scales. This section explores the potential that an intermediate, but less emphasised approach — based on the method of input–output analysis of Leontief (1951) — might offer for development within this context as a framework for improved understanding. A full description is outside the scope of this discussion[9]; however, in essence the method involves an unravelling of sales and purchases of production units in an economy (rather than netting them out to calculate aggregate value-added), demonstrating interdependence between the economic sectors comprising the entire economy. It is possible, by extending the basic technique, to investigate regional[10], social and environmental dimensions. The relevance of each dimension is examined in turn, below, to appraise the scope of input–output methods for analysis of the hierarchical relations that affect rural issues. In particular, drawing on the analysis of the previous section, we examine appropriateness of the approach for insight into the instability between hierarchical levels.

4.1. The regional dimension

Whilst decomposition of national economic performance was an initial focus for input–output analysis, its use in a regional context rapidly followed. However, to link relationships between different levels of the hierarchical system, the 'ideal'[11] inter-regional framework (Isard, 1960) permitted analysis of interdependence between several regional, or even local, economies. Recent applications of this type of regional input–output analysis have highlighted issues discussed in previous sections (for a review, see Midmore et al., 1997). Robison (1997) sets out the most important requirements for an input–output approach tailored to the needs of rural areas. It must convey an individual community focus; definition of the household sector must specifically capture the great openness of rural community economies; there must be a degree of closure that provides an assessment of the community economic base; and the model must be defined to include estimates of inter-community trade, and inter-community multiplier effects. Douglas and Harpman (1995) examine the job impacts of expenditures derived from non-market recreational benefits, concluding that the outdoor recreation sector of the economy is relatively labour-intensive. However, poor local economic structure leads to swift leakage of expenditures; Keith and Fawson (1995) concluded that the impact of expenditures of wilderness users in Utah were not sufficiently large to significantly influence the local county economies.

4.2. The social dimension

The standard input–output model, and its extension to regional economic interaction, primarily concentrates attention on flows between productive economic sectors or industries. The Social Accounting Matrix (SAM) approach extends this basic framework to recognise the importance of distribution of value-added between enterprises, households and the state, allowing issues relating to distributive justice to be explored.[12] Hence, for example, Marcouiller et al. (1995) showed the differential impact of natural resource management programmes and policies on timber development on three groups of household, by income level. Its flexibility allows development over a range of spatial scales. At one extreme, the SAM of Parikh and Thorbecke (1996) identifies interdependencies within a rural village in India; at the other, the investigation by Roberts (1995) of linkages between UK agriculture and the wider economy reveals the magnitude of benefits leaking from the farm sector. The SAM of Leatherman and Marcouiller (1996) for a small rural region in Wisconsin concluded that local policy could influence distributional patterns through targeting specific economic sectors for growth.

4.3. The environmental dimension

The input–output system is based, in principle, on physical interactions between economic sectors; it may thus be extended to account for 'external' flows such as pollution and natural resources utilisation (for a review, see Briassoulis, 1986). In practice, to provide consistent accounts, shadow prices must be calculated to accommodate the monetary framework normally used, or it must be entirely recast to reflect the underlying physical flows. The nature of interchanges within the ecological system causes further problems: they are synergistic, non-linear, and dynamic, and do not adapt easily into the fixed coefficient, static (or at best, comparative static) input–output modelling context. Yet unless these can be satisfactorily described, the model cannot be closed to provide a coherent analysis of the economy/environment linkages.

Analysis of this type thus tends to be less ambitious, simply accounting for pollutant emissions activities (see Hafkamp (1991), for a review of this approach). Others have followed the approach of Leontief (1970) in estimating the 'footprint' of defensive expenditures: Nestor and Pasurka (1995) use the inputs of anti-pollution economic sectors to link abatement costs to derived demands through the rest of the US economy. Relatively few studies of this kind specifically identify rural pollution or natural resource issues. Marcouiller et al. (1995) has been referred to above: Schroder (1995) models Danish agricultural energy and materials balances within an input–output framework, determining impacts of reduced nitrogen emissions. Wernstedt (1995) combines an input–output and income allocation matrix (a hybrid input–output/SAM approach) to estimate the distributional consequences of regional level environmental policy decisions that enhance fish populations in the Columbia River Basin. Harrison-Mayfield et al. (1998) use an input–output model to identify both the backward and forward linkages of conservation policies in agriculture, suggesting that effects for English rural areas are positive, whereas negative impacts are dispersed through the dominant urban economy or capital-intensive agricultural supply and food industries.

4.4. Problems of an integrated perspective

This brief, somewhat selective review suggests the possibility of extending the input–output approach to encompass hierarchical relationships. Its appeal for 'systems thinking' economists is in relating subsystems (industrial, institutional, regional) at a high level of spatial disaggregation, and its extension to the natural environment. It could guide policies to strengthen internal linkages of rural economies, developing resilience toward globalisation pressures. It can also trace out indirect, and possibly unanticipated, feedbacks from ostensibly rational goals. Yet there are several serious problems, two of which are considered here. Firstly, the ability to transcend boundaries in the disciplinary framework is acquired at the cost of considerable reductionism. Secondly, accounting within a common framework for the multiple, complex nature of inter-regional, inter-institutional, human-environment interaction is clearly a task of heroic (and costly) proportion.

The linear algebra used in input–output models requires assumptions of fixed relationships between inputs and outputs, and zero price and income inelasticities of demand. Whilst these circumscribe realism and explanatory capacity, they do not inevitably demand support from neo-classical axioms concerning psychology or ethics. Thus, the approach can serve as an incremental stage in investigating the real entities and structures constituting the material and social world, through further scrutiny and development (Lawson, 1989), although the integrated perspective required for developing sustainable rural systems suggests an enlargement of present scope. Attempts at limited combination of different approaches involve significant and erratic compounding of error structures. Midmore (1993), investigating the regional agricultural forecasting ability of a combined input–output/econometric approach, found that unless final demand were forecasted accurately, overall performance was poor. Conversely Rey (1997), and Rey and Dev (1997), exploring embedding of regional input–output within dynamic econometric models, concluded that all various possible integration approaches are sensitive to errors associated with the input–output components.

It may therefore safely be presumed that extension incorporating more dimensions will require greater accuracy and detail from the data sources on which the approach is based, and this leads on to the second complication, the volume of data required. Difficulties in obtaining data in sufficient detail and quality increase disproportionately, as the scope of the modelling framework is extended. Harrison-Mayfield (1996), attempting to disaggregate the UK input–output table into rural and urban components in order to appraise spatial interdependency, concluded that due to prohibitive costs involved in collecting supplementary data, it may be preferable to concentrate on local case-study areas than attempt to model the rural economy as a single entity.

Norgaard (1994) (pp. 19–20) has identified seven increasingly comprehensive levels of regional analysis on which an operational definition of sustainable development could be based. These begin with agricultural and industrial activity within a region, and progress outwards through the footprint produced by interdependencies outside the region itself. Before even arriving at the fourth level, the range of diverse transactions requiring monitoring, in compound regional systems with intricate socio-economic structures, becomes overwhelming:

> “One of the challenges of sustainable development … would be to devise ways of keeping track of multiple flows without all of the labor force working full time as energy and materials accountants … This line of inquiry has clearly gotten out of hand. There is no way that societies could keep track of all of the flows that are quantifiable, no way they could make sense of them if they did, and no way to keep track of the unquantifiable flows at all.”

This assessment has discouraging implications for an economics that aims to incorporate hierarchy theory into the understanding of rural relationships, both internally and with other structures. Nevertheless, whilst in practice the costs of such a full accounting are excessive, the theoretical framework itself is useful, in terms of emphasis on inter-relationships. Although the research discussed in this section is remarkable for its fragmentary nature, as a whole it can contribute to an intuitive understanding of the relations between different levels of the spatial hierarchy. A suitable ambition for economic inquiry might be to influence, rather than determine, the outcome of decision-making processes. Hence it would not be necessary to construct an all-embracing, exact representation of the structural characteristics of the rural system. Indeed, doing so (as, hopefully, we have demonstrated) can actually be harmful because it curbs the scope for creative adaptation. The multiple goals and complex relationships involved in rural sustainability require only general policy direction, not exact policy goals. Instead, recognising the rhetorical role of economics and the importance of its value structure, a shift in its emphasis is required.

5. Rehabilitating economics for rural sustainability

Our survey of the literature on rural change clearly identifies that increasing commercialisation and technical change have led to developments that under various criteria might be regarded as unsustainable. Thus we consider that economic advice for promoting the sustainable development of rural regions needs to be more circumspect in its advocacy that rural areas should be more open to trade. With an acceptance that market values are not representative of all values, economics needs to adopt a more unassuming position, advising society on how it might creatively meet its aspirations, rather than pedantically asserting that society must adapt to an anarchic market. Obviously market forces cannot be ignored, and economic analysis can provide some understanding on how they condition behavior, and how their effects ramify through the system. Nevertheless, this should not require acceptance of the view that we are completely beholden to them. After all, market forces are simply an emergent property of an anthropogenic system. Market prices result from an amalgam of influences that can be crudely identified as a mixture of preferences, technology and institutional arrangements. It is these factors that need to change over time in order to develop more sustainable systems, and in the long run will have an impact on prices. A current challenge is how to begin to make those adjustments while conditioned by existing prices.

Given the weight ascribed to both economic analysis and prescriptions by the policy-making community, it is important that the rhetoric of economics is encouraged into a more evolutionary idiom, acknowledging the social context of economic values and the range of opportunities for long-term development. There needs to be a shift away from an identification of problems as purely ones either of market failure or of unfortunate distributional consequences, typically addressed by adjustments to the market mechanism in the former case, and by transfer payments in the latter. In place, more emphasis should be given towards developing systems that avoid the creation of environmental problems, and which are socially fully inclusive. This requires a more integrative approach to development.

The concept of integrated rural development is not new, but finding ways of achieving integration has remained a perpetual challenge, particularly to the intellectual community, and none more so than economists, whose tools are chiefly designed for solving clearly limited problems within defined parameters. Inevitably integration is in practice a messy process, which requires the actors within the system to explore potentialities. The role of the intellectual community should be analogous to providing maps, rather than designed solutions. Economics can contribute to this map-making with the application of input–output frameworks that explore linkages between levels of the spatial hierarchy. It can be used not only to identify the economic ramifications of change within a regional economy, but also to track environmental footprints and explore redistributive consequences. Economics also can assist also in the design of policies to transmit information and influence behaviour.

The idea of developing a perspective on the desired direction of development rather than accepting free market outcomes marks a return to the classical economic approach espoused by Schumpeter (1954). More recently, Costanza et al. (1996) have asserted the need for a practical shared vision of both the way the world works and of a sustainable society is as a vital element in achieving a sustainable system. The specific destination may be unknown, and the actual journey is one of exploration. Adopting a systems method of thinking encourages a more considered and reflective exploration.

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[1] There are notable exceptions, including Chavas (1993) on sustainability and survival strategies; Toman (1994) on a consensus definition of 'social capital' and safe minimum standards; Green (1994) in the context of low-income countries; and Yiridoe and Weersink (1997), who use choice theory to achieve sustainable agroecosystems.

[2] Earlier, the Physiocrats attempted to locate value in what today might be termed 'resource content'; modern counterparts include Hannon et al. (1986) and, in the context of this discussion, see also Owens (1994).

[3] Critical scrutiny of the concept of equilibrium has been wide-ranging and includes, for example, Leijonhufvud (1968), attacking the incorporation of Keynesianism into mainstream neoclassical economics. Kornai (1971) has criticised its adverse effect on systems thinking, and Amir (1994) portrays the influence of 19th century mechanistic thinking on economic discourse as malign.

[4] This has been noticed more or less throughout the industrialised world since the late 1960s and early 1970s. In the UK, for example, rural populations increased between the population censuses of 1961 and 1971 for the first time since the census procedure had been undertaken. This trend has continued in more recent censuses; see Halfacree (1994) and Green (1996).

[5] However, poverty, as narrowly defined here solely in income terms, does not necessarily accord with quality of life.

[6] Neither the use of the term ‘hierarchy’ nor ‘control’ implies the need for authoritarianism. ‘Hierarchy’ is used in the technical sense and ‘control’ refers to an ability to manage the system.

[7] See Vatn and Bromley (1994) for a full discussion of the information losses occurring with monetary valuation.

[8] See Weintraub (1979) for an attempt to impose a uniformly neoclassical view, with considerable resonance for the ‘new classical’ school of macroeconomists.

[9] There are a number of good, basic introductory texts. See, for example, Otto and Johnson (1993); the regional dimension is covered thoroughly in Dewhurst et al. (1991); and for a comprehensive introduction, see Bulmer-Thomas (1982).

[10] Whilst lack of correspondence between administrative regions and the appropriate framework for such analysis, the bioregion, should be noted, it falls beyond the scope of the present article (however, see, for example, McTaggart, 1993).

[11] So-called, because it requires information on transactions between regions which is, in practice, difficult to obtain.

[12] Pioneers of the approach, examining estate, agricultural and urban households in Sri Lanka, were Pyatt and Roe (1977); see also Pyatt and Round (1979).

3. Materials and methods

3.1. Description of the Study Area

The study was conducted during the 2006/2007 academic year in Farta Woreda of South Gondar, which is one of the woredas of the ANRS where food insecurity is a chronic problem for the majority of the rural population. The town, Debretabor is located at about 100 km north east of Bahir Dar the capital of ANRS, along the Woreta-Woldya highway. The Woreda lies between the coordinates of 11^{0}32’ to 12^{0}03’N latitude and 37^{0}31’ to 38^{0}43’E longitude, and covers an estimated area of 1118 km^2.

Altitudes of the study Woreda varies between 1900 and 4035 meters above sea level, and in terms of topography, 45% of the total area is gentle slope, while flat and steep slope lands account for 29% and 26%, respectively. In terms of land use pattern, an estimated 65% of the area is cultivated and planted with annual and perennial crops, while area under grazing and browsing, forests and shrubs, settlements and wastelands account for about 10, 0.6, 8 and 17% respectively.

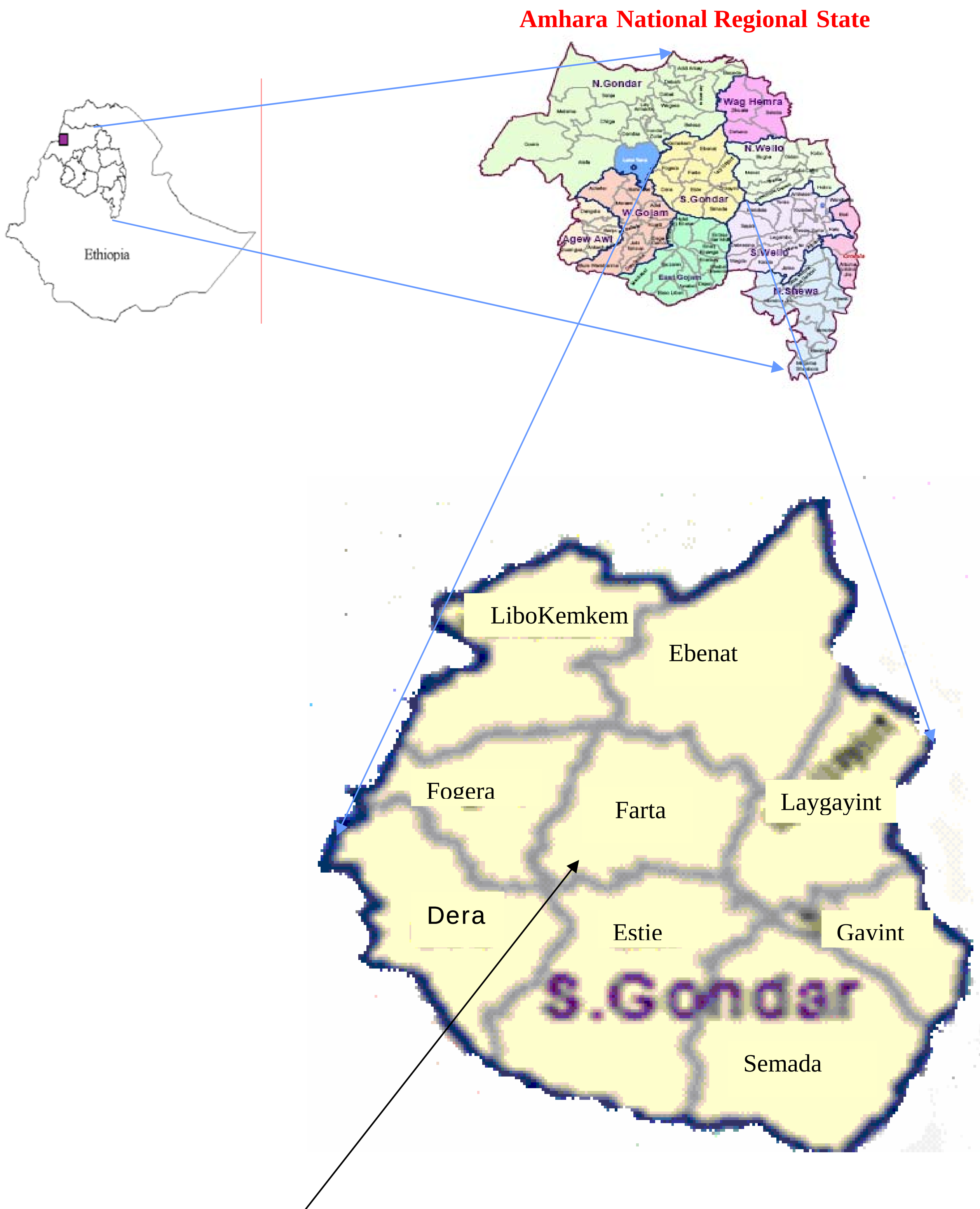
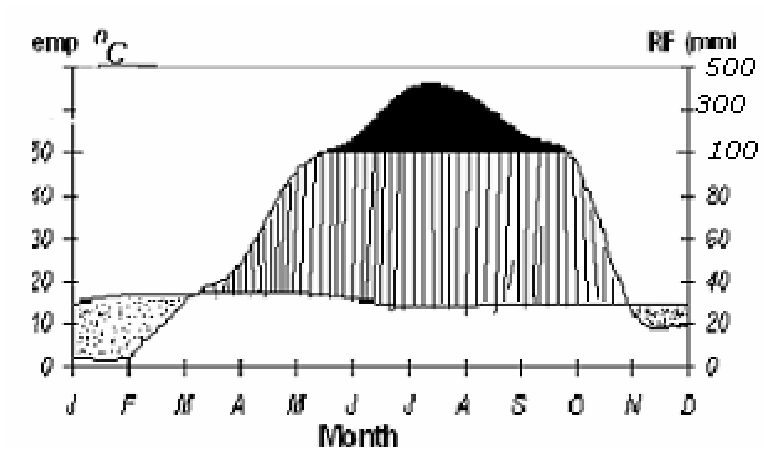


Figure 1. The Location of the Study Woreda ***Farta***

Agro-ecologically, about 44% of the Woreda is classified as Dega while the remaining 56% is considered as Woina Dega. The average annual minimum, maximum and mean temperatures are 9.7 ^{0}C, 22^{0}C and 15.5 ^{0}C, respectively (Figure 2). The rainfall pattern is unimodal, stretching from May to September. Annual rainfall ranges between 1097 and 1954 mm with a long term average of 1448 mm (Tamene H/Giorgis, 1997).



■ Wettest season ▥ Relatively wet season ▨Dry season

Figure.2: – Klimadiagramm of the study Woreda from Debretabor station.

Cambisols, Regosols, Lithosols and Andosols are the predominant soil types while the rest are found scattered through the woreda (Anonymous, 1997). The agricultural households are engaged primarily in crop-livestock mixed farming systems. Barely, wheat, teff, sorghum, maize, field beans, peas, and potatoes are dominant crops while chickpeas and some oil crops are also grown. Reported yield levels of cereals revolve around 1t/ha for cereals except for maize that reaches 1.5 t/ha. Limiting factors that were reported for South Gonder Zone also apply for the study woreda. It is evident that with such yield levels, prevailing land use patterns, and population size; the woreda is not food self-sufficient. Yet another reason for the region to be food - insufficient is the loss of topsoil due to erosion and hence depriving of nutrients for crop growth. Most obvious is the soil loss due to water erosion, which is estimated to about 119million tons per year in Amhara region, amounting 70%of the total soil loss in the country as a whole (Tamene H/Giorgis, 1997). With this condition in the region there are only a few NGO’s working towards alleviating the problem. GTZ-Integrated Food Security Program is one of them that is acting in South Gondar. The rehabilitation program is implemented in 6 woredas of south Gonder zone rehabilitating a total of 14watershed areas with about 300hectars each. The four study gullies are found in two of the watersheds.

The study gullies are located in four PAs of the Farta Woreda, which are called Werken Gashajagre, Worken Adura, Eshim wofena and Tsegur eyesus. Among the study gullies Werken Gashajagre gully is situated at 11^{0}49.301’N latitiude and 37^{0}59.533’ E Longitudes and at an altitude of 2460 masl and on the other end at 11^{0}49.167’N latitude and37^{0}59.401’E longitude at an altitude of 2351masl. Where as Eshim wofena gully which is (Y) shaped is situated at 11^{0}46.638’ N and 37^{0}58.015’ E at an altitude of 2048masl and the left side of the gully 11^{0}47.028’ N latitude and 37^{0}57.973’E longitude at an altitude of 2106masl also the right side 11^{0}46.936’N latitude and 37^{0}58.119’E longitude at an altitude of 2120masl. The Tsegur Eyesus gully is situated at 11^{0}53.443’N latitude and 37^{0}58.443’E longitude at an altitude of 2481masl and 11^{0}53.587’N latitude and 037^{0}58.301’E longitude at an altitude of 2442masl. Finally the Worken adura gully is found at 11^{0}49.721’N latitude and 37^{0}58.591’E longitude at an altitude of 2301masl and on the other end 11047.918’N latitude and 37058.733’E longitude at an elevation of 2349masl.

In the last two decades, debates on development and resource exploitation have increasingly centred on sustainability issues (e.g. Barbier, 1987; Beets, 1990; Katerere et al., 1991; World Commission for Environment and Development, 1987). Often the debates have lacked an economic component or, where the debates included economic arguments, these were over simplistic and incorporated little more than marketed output, and the capital and labour invested for this output. Generally, no economic value was assigned to changes in natural resource stocks

(Repetto, 1992). Furthermore, the economic analyses in developing countries paid scant attention to subsistence production and to labour (the latter was 'surplus') (Repetto, 1992).

With such poor analytical tools, it is not surprising that policy decisions regarding development options have often had no positive impact on society and, in extreme cases, have resulted in wholesale disruption of natural systems (e.g. Browder, 1988; Mahar, 1988; Sinclair and Fryxhall, 1985). One example in Zimbabwe from the early 1980s is the US$7.3 million investment in the rural afforestation programme, which was made in the context of a fuelwood crisis without almost any analysis of the value of natural woodlands and trees to rural households (World Bank, 1990). The outputs from this programme have probably had little positive impact (World Bank, 1990). In addition, one small component of the programme saw the replacement of indigenous woodland of arguably high value with eucalyptus plantations of arguably no value (pers. obs.; World Bank, 1990).

In the last few years, there has been a massive increase in awareness that analyses for decision-makers about development and resource exploitation have to incorporate accounting for environmental assets (Repetto, 1992; Scoones et al., 1992; Swanson and Barbier, 1991). In this paper, I look at the efforts to value tree-based resources in Zimbabwe. Other data from the region are reviewed, but these are mostly non-existent. Most of the work on tree-based economics in the region has focused on alley cropping systems (see Swinkels and Scherr, 1991), which are not at present common in the region (Campbell et al., 1991a). Resource economics in the tropics has centred on moist tropical forest (e.g. Hecht et al., 1988; Rasoanaivo, 1990; Peters et al., 1989). In this paper, the focus is on dry tropical savanna-woodlands (miombo, mopane, teak and Acacia woodlands - White, 1983). In these woodlands, only wildlife values have received much attention and here the focus has been on direct use values (e.g. Barbier et al., 1990; Jansen et al., 1992; Swanson and Barbier, 1991).

The essential question that requires answering is how much is the woodland worth, and to whom? The results of the few studies are reviewed and a research agenda for future work is outlined. To place the Zimbabwean work in context, the first sections deal briefly with why valuation is necessary and methodological approaches to valuation.

2. Why value natural resources?

Numerous fora have identified the need to value natural resources and to develop appropriate valuation methodologies. For instance, one of the recognised priorities for forestry and agroforestry policy research is the development of mechanisms for: (i) a balanced valuation of environmental benefits in national accounts and (ii) valuing trees and forests from a local perspective to complement national valuations (Gregersen et al., 1992). One of the four programme areas that make up Chapter 11 of Agenda 21 deals with 'capturing forest values' (Ayling, 1993). Within the body of literature devoted to non-wood forest products, it is recognised that there is a need to improve the valuation of the social and economic benefits derived from these products (de Beer and Mcdermott, 1989; FAO, 1991; Scoones et al., 1992).

In the Zimbabwean context, attention has been drawn to the fact that the valuation of natural resources has been inadequately dealt with (Bojo, 1993; Campbell et al., 1991b; Moyo et al., 1992).

There are a number of reasons why tree-based resource valuation is necessary in Zimbabwe and most other developing and tropical countries. At the global scale, the following question remains unanswered: What is the value of woodlands in terms of recreational values, biodiversity conservation and impact on climate? (Bojo, 1993). At the national level, valuation is required as a key input to decisions about land allocation and land use (Bojo, 1993; Moyo et al., 1992; Scoones et al., 1992), for instance:

> (i) Given the proposed land reform programme to address the gross inequities in land distribution (Katerere et al., 1991), how can woodlands be appropriately valued? What are the costs and benefits associated with the loss of woodlands (Grundy et al., 1992) that will occur in the resettlement areas? If land taxation is used as an instrument to increase the supply of commercial farmland for the land reform programme (Murphree and Cumming, 1991), on the basis of what value should the large tracts of indigenous woodland on this farmland be taxed? (Bojo, 1993; Moyo et al., 1992).

(ii) Roughly 10% of Zimbabwe's woodlands are managed by the parastatal, Forestry Commission. Conservation of these State Forests is often justified on the basis of protection of watersheds and conservation of biodiversity. However, what are the costs and benefits of conservation? (Bojo, 1993; Moyo et al., 1992).

(iii) In tree-based development programmes, where should the emphasis lie? Do rural households need investment in woodlots, fruit tree orchards or fodder trees? How valuable are non-wood forest products? Conventional resource planning is biased in the favour of commercial harvest and has undervalued other goods and services (de Beer and Mcdermott, 1989; Scoones et al., 1992).

(iv) Much has been written about resource degradation (e.g. Katerere et al., 1991; Campbell et al., 1988). What are the costs associated with woodland degradation? In particular, what are the off-site downstream impacts of degradation? How can the costs of negative externalities be internalized to enhance efficient and sustainable use of resources (Moyo et al., 1992).

(v) Ultimately, one must ask whether it is possible to have an amended system of national accounts incorporating information about changes in natural resources? (Bojo, 1993).

3. Potential valuation methodologies

From the outset, it should be stressed that the present paper deals with monetary valuation, but that there are a wide range of non-monetary indicators of value that can be used (de Beer and Mcdermott, 1989), such as frequency of consumption of forest products, frequency of collection, and percent of household time-budgets devoted to forest-related activities. Many of the indicators need to be collected for certain approaches to monetary valuation.

Values of tree-based resources can be classified into three classes: values associated with use (use value); values related to potential use (option value) and values associated with mere existence, for instance the benefit associated with knowing that some woodland type exists (existence value) (Bojo, 1993; Krutilla, 1967; Scoones et al., 1992; Weisbrod, 1964). What goods and services of trees and woodlands should be considered? Traditional economic analyses of forestry activities have concentrated on the use values of wood. The full range of non-wood forest products have to be considered. Furthermore, analyses have focused on marketed goods. Most woodland products are in fact used for subsistence (Campbell and Brigham, 1993), and hence there is a need to incorporate nonmarket use values. In addition, it is necessary to include option and existence values in valuation exercises. Finally, how can woodland service functions (indirect use values), such as climate modification, soil fertility improvement and biodiversity maintenance, be valued?

In the absence of organized markets, an intuitively appealing approach to revealing the preferences of individuals is the use of contingent valuation methods (CVM) (Davis, 1963; Mitchell and Carson, 1989). These techniques use a hypothetical market situation to obtain bids from individuals indicating their willingness to pay (WTP) for a commodity. Despite the widespread use of these methods, the reliability of values obtained using CVM is vigorously debated (e.g. Bishop and Heberlein, 1979; Brookshire and Coursey, 1987; Knetsch and Sinden, 1984).

Many tree-based goods and services are closely linked with conventional markets, e.g. tree litter for fertility maintenance can be replaced (at least, partially) by inorganic fertilizers, off-site impacts of woodland clearing in terms of downstream siltation can affect crop output through reduced irrigated production. Hence, it is possible to value tree-based resources by tracing their link with organized markets. Bojo et al. (1990) identify a number of major classes of techniques in this group, two of which are relevant here: that based on production values, in which the losses or gains to production are estimated and valued, and that based on replacement costs, i.e. the cost of replacing tree-based goods and services with those from organized markets.

4. Results from resource valuation exercises in Zimbabwe

Contingent valuation of tree-based resources

The most comprehensive attempt to date to value woodland resources in Zimbabwe is that of Campbell et al. (1991b), in which two approaches were used, one based on CVM (Lynam et al., in prep.) and one based on a mixture of production values and replacement costs, to value goods and services derived from miombo woodland by residents in communal areas.

In the CVM approach, ten cards representing commodity categories of trees and two cards representing commodities not related to trees were explained to respondents, and respondents ranked and distributed 50 matches among the cards to reflect the relative importance of each category of commodities. The two extra cards showed a hand pump and a well-known design of latrine. The CVM was based on the willingness of respondents to pay for a fifth share in a borehole with a hand pump. Values were derived for all tree commodity categories by standardizing the points allocated to the categories against the points allocated to the borehole and then multiplying by the expressed willingness to pay (WTP). Direct questions of value about tree resources were considered inappropriate because of the 'inexperience of most respondents in dealing with monetary valuations of tree resources' (Lynam et al., in prep.), and hence a borehole was selected for valuation.

To check the validity of the WTP estimate, (i) actual costs of building and installing a borehole with hand pump were compared with the WTP estimate; (ii) respondents were asked what compensation they would be willing to accept if the hypothetical borehole were to be destroyed, and this was compared to the WTP estimate; (iii) respondents were asked, in a set of dichotomous questions, to choose between a shared borehole and five common commodities decreasing in value from about Z$35000 (a tractor) to Z$90 (in mid 1991, at the time of the analysis, Z$1.00 = US$0.32); (iv) the calculated value of the latrine derived from the points allocation was compared to actual costs of building and installation, and (iv) hypothesised trends in WTP with mean annual rainfall and with present kind of access to water were compared with stated WTP. In general, the validity checks supported the use of the WTP estimate, but sharing of a borehole was based on five sharing households and a linear demand curve was assumed. It would have been preferable to have investigated the nature of the demand function.

The mean values elicited by the CVM for different tree commodities are shown in Table 1. Direct material inputs to major productive practices are the most valuable categories of commodities that households obtain from tree resources (Lynam et al., in prep.). These include wood for fuel and wood for construction, inputs to crop production (woodland litter, scattered trees in cropping areas) and animal feed (dry season browse). It is somewhat surprising that fuelwood is regarded as so important, and that food products from trees (e.g. fruits) are not placed in this top grouping, considering that many other studies have indicated that tree planting by households is based on fruit trees, with planting of trees for fuel being a very low priority (Grundy et al., 1992; Campbell et al., 1993; Bradley and Dewees, 1993). One must ask the question as to whether it is present utility that householders are basing their valuation, and whether it would be more desirable to value the potential utility of trees? (Bradley and Dewees, 1993).

CVM is an important technique because it can be used to obtain values for various service functions of forests. Respondents valued 'ecological services' of trees relatively highly (Table 1), these being regarded as soil fertility maintenance, soil erosion control, climate control and maintenance of stream flow. Other such intangibles are much less important commodities (Table 1). These include shade, health (medicinal plants) and social services (embracing cultural and spiritual values). Cash income from tree products is also relatively unimportant.

The values derived from the CVM are regarded as capital values, and can be converted to annual benefits using an appropriate discount rate. Using rates between 5 and 20 %, annual benefits derived from tree resources amount to between Z$84 and Z$336 per household per year. Lynam et al. (in prep.) suggest that the benefits derived from tree resources could be equivalent to between 12 and 160 % of off-farm and agricultural production incomes in the different study areas.

Table 1. Values derived for various categories of tree-based goods and services using a contingent valuation method (Lynam et al., in prep.). The categories are arranged in order of importance. Mean values which differ significantly at p = 0.05 are shown by different alphabetic superscripts. The ranking of the categories by the replacement-production method (Table 3) are also shown (see text, data from Campbell et al., 1991b).

	Contingent valuation		**Ranking of categories by replacement-production valuation**
	mean value Z$ HH^{-1}	**median value Z$ HH^{-1}**	
Fuel	373^a	500	2
Farm/house materials	290^b	400	3

Crop production	222[c]	333	5
Animal feed	181[c]	144	4
Ecological services	175[c]	257	not assessed
Food	136[c]	200	1
Shade	102[d]	150	not assessed
Cash income	82[d]	125	6
Health	71[d]	100	not assessed
Social services	46[e]	47	not assessed
Total	1678	2256	

Z$1.00 = US$0.32 in mid 1991, at the time of the survey.

Lynam et al. (in prep.) argue that the values can be used to gain insight into behaviour as regards resource use and technology adoption. Using the example of fuelwood, they show that with annual benefits of only Z$37 per household (assuming a 10 % discount rate) and with eucalyptus wood for a year costing roughly five times this value, it is not surprising that farmers seem reluctant to invest in eucalyptus woodlots. However, the same conclusion may be reached for fruit trees, which is not the case, as householders are interested in planting fruit trees. Such calculations need to be carefully interpreted as they clearly depend on the discount rate chosen and the meaning attached to value by the respondents (Bradley and Dewees, 1993).

Replacement-production valuation of tree-based resources

In the other approach of Campbell et al. (1991b) to value tree-based products, a mixture of replacement cost and production value methods was used (Table 2). The economic valuation is crude by necessity: the available data do not allow for accurate economic accounting (Campbell et al., 1991b). In most cases the estimated value is calculated simply from a knowledge of the quantity of goods derived from trees multiplied by the 'farm gate prices' of these goods or the 'replacement cost'.

Table 2. Methods used to estimate value for different tree-based goods and services in the replacement-production valuation (Campbell et al., 1991b).

Fruit	Production data for fruit trees, market values of replacements, indigenous fruits on a per hectare basis, exotics on household plantings
Other wild foods	Consumption data for households, market values of replacements
Fuelwood	Consumption data for households, market values of replacements
Construction wood	Consumption data for households, market values of replacements
Craft wood	Household output of marketed products
Livestock production	Value of livestock, extra benefit provided by trees compared to absence of trees, on a per hectare basis
Crop production	Litter from woodlands - consumption data for households, market value of inorganic nitrogen Fertility improvement from scattered trees - nitrogen improvement using simulation model, market value of inorganic nitrogen, per hectare basis

By using farm gate price of a subsistence product, they assigned value on the basis of exchange value. Replacement cost is the cost a producer would have to pay to replace the subsistence product. Because of the use of farm gate price or replacement cost for goods which, in fact, are mostly not bought and sold, there is an overestimate of local use value (Campbell et al., 1991b; Bojo, 1993), as: (i) in most cases, the financial constraints facing small-scale farmers do not permit them to switch to a marketed product; (ii) small-scale farmers would probably not choose to buy the marketed replacements if the necessary financing were made available to them unconditionally; and (iii) the prices used do not take into account 'diminishing marginal utility' (if all the fruits were taken to the market place, the price per fruit would drop dramatically).

That the data base is limited is evident by a recalculation that has been done for the present paper for the value of leaf litter to crop production. On the basis of new litter consumption data (Nyathi and Campbell, 1993), the new estimate of value is 20 % of the estimate in Campbell et al. (1991b) (Table 3). On the other hand, recalculation of income from craft work from data from

Brigham (in prep.) support the previous estimates. The model SCUAF (Young and Muraya, 1990) was used to simulate fertility improvements by scattered trees. Since then, testing of that version of SCUAF demonstrated serious flaws (Vermeulen et al., 1993), but this is unlikely to make large differences because of the small number of trees in fields.

Another problem related to data limitations, is that some categories of value were estimated on a per hectare basis while others were estimated on a household basis (Table 2). For instance, value of wood was based on household consumption, whereas value of fruit from indigenous trees was estimated on the basis of per hectare production from woodland and from scattered trees in cropping land. In order to express value on common scales, it was assumed that the average area of woodland available to each household (HH) ranged from about 3.5 ha HH^{-1} to 5.6 ha HH^{-1} in the three study areas covered by the work (calculated on the basis of areas of communal woodland and 1991 projected population figures) and that the area of cropping land averaged 3 ha HH^{-1}. Using these conversion factors, value can be expressed either on a per hectare basis or a per household basis, but an additional source of error is introduced.

The point to be made is that the figures produced have to be used with caution because of the poor data base. Some skeptics would probably discount the method entirely for the reason of poor data. One partial solution is to ensure reporting of statistical variability, but this itself is not simple, as the estimates for different categories are based on different kinds of data. In the present paper, ranges are reported where possible (Table 3).

Woodland produces goods to the value of about Z\$200 ha^{-1} yr^{-1}, while scattered trees in fields value at about Z\$10 ha^{-1} yr^{-1}. In total, trees produce goods to a value of nearly Z\$1000 HH^{-1} yr^{-1} Our valuation is mostly based on household consumption data. If current consumption is in excess of sustainable levels of production, the values we obtain, especially for fuelwood and construction wood, do not account for environmental degradation as a result of non-sustainable use. Generally, if progressive decline of the woodlands is occurring, the key issue is likely to be the future effects rather than current value as determined here.

There is a major difference in the ranking of categories derived from the two valuation techniques in regards the placing of food from trees (Table 1). Firstly, the differences in the rankings could be due to the poor data used in the replacement-production valuation to calculate the value derived from indigenous fruits. The valuation was based on very poor production data. It would be simpler to obtain household consumption data and base the valuation on this. Secondly, it should be noted that some differences are expected, as the two techniques estimate different components of value. The CVM estimates capital values, which then have to be converted to annualized benefits using a selected discount rate, which could vary among different categories. The replacement-production valuation estimates annual gross benefits. Net benefits could be calculated if the costs of using the different resources could be quantified. This mostly relates to labour and transport costs.

Table 3. Gross values of tree-based goods and services, expressed as value to a household (HH) and woodland value. Data derived from Campbell et al. (1991b). Cash income for households and value of woodland for cash income are shown separately, as this component of value is included where appropriate in the product categories.

		Value to a household (Z$ HH^{-1} yr^{-1})	**Value of woodlands[1] (Z$ ha^{-1} yr^{-1})**
Fruit	Indigenous fruits in woodland	230-360	65
	Indigenous trees in cropland	10-44	
	Planted exotics	12	
Other wild foods		63	11-18
Fuelwood		183	33-52
Construction wood	Buildings	114	20-33
	Implements, utensils for own use	16	3-5
	Craft wood income	7-18	1-5
Livestock production		100-168	30

Crop production	Litter from woodlands[2]	17	3-5
	Fertility from scattered trees	15	
TOTAL		767-1010	166-213
Cash income	Exotic fruits	17	
	Wild fruits	2	<1
	Craft wood[3]	7-18	1-5

[1] Only those products obtained from woodland are included in this column, thus excluding products from planted exotics and indigenous trees scattered in cropping land and homesites.
[2] Recalculated on the basis of 0.38 tonnes per user household per annum of litter used (Nyathi and Campbell, 1993, for Masvingo communal areas).
[3] Data from Campbell et al. (1991b). Using recent estimates of craft trade and income from Brigham (in prep.) would result in similar overall figure.

The same methodology to the above was conducted to value Acacia savanna in South Africa (Milton and Bond, 1986). These authors arrived at a similar total value, but the relative value of various commodities was different. Gumbo et al. (1989) looked at the value of Sclerocarya birrea trees in Southern Zimbabwe. They used a replacement cost method to derive a value for the trees. The direct value of the products (fruit, wine, wood products, nutrient inputs) over time far exceeds the value realised by chopping the tree down, hence they provided an economic rationale for maintaining the trees.

There are very few other studies of relevance, and most of these have concentrated on marketed products. Brigham (in prep.) investigated the marketed output of all woodland products in one communal area in Zimbabwe, while Cunningham (1990a, 1990b) measured incomes derived from palm wine production in South Africa and described the trade in medicinal plants in southern Africa. The study of Campbell et al. (1991b) also recorded income levels from tree-based resources. As can be seen, these are relatively insignificant by comparison to the total value of tree-based resources (Table 3).

Valuation of livestock and wildlife

Although livestock and wildlife are not strictly tree-based resources, they rely heavily on trees for the provision of browse, and the value of cattle calculated by Scoones (1992a) was used as an input to the calculation of the overall value of woodlands by Campbell et al. (1991b).

There are a number of examples of the economic valuation of cattle in communal areas, all based on calculating value using replacement costs, because most commodities derived from cattle are not marketed. These valuations have been reviewed by Jackson (1989) who highlights the assumptions that have been used and states that it is unclear as to whether the different valuation results are due to different farming systems or different assumptions. He concludes that valuing the economic benefits of livestock within communal areas is at a very rudimentary stage. The different results have different policy implications, and therefore there is a need to resolve the differences. For instance, in one of the valuations manure production is seen as five times more valuable than milk production whereas in another valuation, the opposite is recorded.

Perhaps the most detailed valuation is that of Scoones (1992a). Data on biological productivity, milk production, sales and slaughters, manure production and work rates are presented for cattle and goats. The economic valuation is more complete than that for tree-based resources described above, as it includes the costs of production (veterinary support and stock herding), and thus gross and net benefits can be calculated. Furthermore, the data on which the entire analysis is based are more reliable than those available for valuation of tree-based resources. Lacking from the valuation is the social value of cattle, in particular for bridewealth. It would be of interest to pursue contingent valuation for such intangibles, as farmers rank the bridewealth function third after transport and draught (Scoones, 1992a).

The gross value for cattle is around Z$800 yr^{-1} $adult^{-1}$ (Z$1.00 = US$0.66 in 1987), and the net economic value of communal area cattle and goat systems is Z$104.50 ha^{-1} yr^{-1} (Scoones, 1992a). Patterns of investment in livestock are discussed in relation to the valuations made. In communal lands the rate of return on investment is high for cattle and goats and returns to grazing land are considerably higher than in conventional beef ranching, as long as the full range of livestock products and services are accounted for. Perhaps one flaw in the analysis relates to the use of actual stocking rates rather than officially recommended stocking rates (which are two to three times lower), in the absence of any calculation of the environmental costs of maintaining such high stocking rates, a subject of hot debate (e.g. Sandford, 1982; Scoones, 1992b; du Toit and Campbell, 1989; Child 1988, 1990; Taylor and Child, 1991). Using more conservative stocking rates, reduces the net economic value to about Z$30-Z$40 ha^{-1} yr^{-1} (see for example Barrett, 1991). Jansen et al. (1992) provide an estimation of the cost of overstocking (see next section), but there estimate is for commercial livestock systems.

Jansen et al. (1992) provide the most detailed account of the value of commercial production of wildlife and livestock. In a survey of 89 commercial farms in the drier regions of Zimbabwe, they compare the financial and economic profitability of cattle ranches, wildlife ranches and mixed system ranches. They include in their analysis all sources of income and all costs (including labour, capital, cost of degradation). It appears that wildlife only ranches are the most financially viable and have an average return on investment of 10.5 % compared to only 3.6 % for mixed enterprise systems and only 1.8% for cattle only ranches. Similar conclusions are arrived at for economic profitability.

In comparison to this very detailed valuation of wildlife on commercial farmland, there has almost been no work on wildlife values on communal land. Murindagomo (1988) showed that for a remote community, the value of subsistence hunting was Z$8.2 ha^{-1} yr^{-1}, while commercial safari hunting yielded Z$1.54 ha^{-1} yr^{-1}. There is also scattered data available on the amounts of income realised by wildlife schemes in communal areas (e.g. Cumming and Bond, 1991), but very little detailed valuation work has been undertaken.

Costs of environmental degradation

There are only two studies in Zimbabwe which have explored the costs of environmental degradation, that of Elwell and Stocking (1988) which investigated the regional effects of soil erosion in relation to the cost of replacement of the lost nutrients, and that of Jansen et al. (1992) which estimated the cost of overstocking by livestock and wildlife. In both studies, the influence of trees on the degradation dynamics was not investigated.

The valuation by Elwell and Stocking (1988) is limited to the extend that it is based on erosion simulation models, which are most applicable to cropped land and not grazing land and woodlands. They calculated that the annual cost of soil erosion to Zimbabwe was Z$2.5 billion (1985 prices).

Our understanding of the degradation process by livestock and wildlife is incomplete and hence any attempt at valuation is problematic. Jansen et al. (1992) base their estimate on the work of Child and Taylor on a commercial range (Child, 1988; Taylor and Child, 1991), thus the estimate is of little value for communal systems. Using long-term data, they have calculated the loss in productivity due to overstocking as an average annual productivity loss of 0.32 kg livemass ha^{-1} yr^{-1}. Using carrying capacity estimates and actual stocking rates, they were able to calculate the productivity loss per overstocked livemass. With estimates for livemass prices, they then converted productivity losses to costs, which amounted to Z$0.113 per kg of overstocked livemass per hectare per annum. This cost and an estimate of the degree of overstocking (calculated from known stocking rates and carrying capacity estimated from relationships between rainfall and biomass), were used to estimate the cost of overstocking on the 89 ranches they studied. The estimates are crude but the methodology is innovative and would be worth further investigation.

Avoidance cost valuation of carbon sequestration

Bojo (1993) made a preliminary valuation of the carbon sequestration function of woodlands in Zimbabwe. Valuation is regarded as hypothetical as there are at present no binding international agreements to limit CO_2, and actual monetary transfers will have to take place from developed countries to underdeveloped countries, as it is unlikely that decision makers in Zimbabwe will be much impressed by the fact that somewhere in the industrialized world costs are being saved by the decision to preserve indigenous Zimbabwean woodland.

Bojo (1993) bases his calculation on the data in Nordhaus (1991) which gives costs of reducing emissions per quantity of carbon. Given an average of 42 t ha^{-1} of wood in the remaining woodland (from Bradley and McNamara, 1990), the value of woodland from a carbon sequestration point of view would be about US$200 ha^{-1}, which would could be paid as a lump sum or as an annual, infinite payment of US$20 ha^{-1} (assuming an interest rate of 10%) (about Z$140 ha^{-1} in mid-1993).

Value of tourism

Tourism in the region is said to be based on the wildlife resource (Buetzler, 1990), which in turn is centred on the woodlands of the region. However, in Zimbabwe the outstanding tourist attraction, Victoria Falls, also accounts for considerable tourism revenue. There have been no detailed analyses of the value of tourism, and the data available are scattered (e.g. Cumming and Bond, 1991; Jansen et al., 1992). The tourism industry is considered the third most important source of foreign currency behind mining and agriculture (Jansen et al., 1992), and thus detailed analyses of it are particularly needed.

Comparative valuation of different land-uses

There is now a growing literature on the comparative economics of different land uses. Previous analyses have compared communal livestock systems with commercial livestock systems (e.g. Scoones, 1992a) and compared livestock and wildlife systems (e.g. Jansen et al., 1992), but the only attempt to place trees in the centre of such an analysis is that of Bojo (1993), who has used much of the data presented above. Because of the data limitations, it is perhaps premature to make many strong conclusions, but it does appear that indigenous woodlands, particularly in the drier regions, compete well with other land uses (Bojo, 1993). One of the chief limitations restricting comparison is that the estimates for tree-based resources represent gross incomes, not gross margins, because no costs of production have as yet been included in the valuation.

5. Outlook

The review indicates that a modest start on resource valuation has begun, but that research on many topics is required before resource valuation is going to contribute meaningfully to decision making. The questions posed in the earlier sections remain unanswered: How much is the woodland worth, and to whom? What is the value of woodlands in terms of recreational values, biodiversity conservation and impact on climate? What are the costs and benefits of catchment conservation? How can resource valuation be incorporated in an amended system of national accounts?

Some of the major lines of research that are required are outlined below:

(1) Contingent valuation methods

CVM needs further methodological development and use. How can option and existence values, social services (e.g. bridewealth, conservation of sacred groves) and woodland service functions be incorporated in such analyses? Is it possible to obtain WTP bids directly about tree commodities, rather than using proxy commodities such as boreholes (as used by Lynam et al., in prep.). The actual meaning of the values solicited need investigation (Adamowicz, 1988; Adamowicz and Phillips, 1983; Bradley and Dewees, 1992) -- What are the appropriate forms of questioning? What does the value reflect: present utility or potential interventions?

Moyo et al. (1992) argue that willingness to pay may be better based on such questions as what monetary wage a communal area individual would be willing to accept in formal employment, or what income the individual would accept from his agricultural enterprises in order to forego reliance on tree cutting in preference for purchased formal sector substitutes. In this way, Moyo et al. (1992) argue, CVM will allow for consideration of entitlement and consumption patterns, not in situ, but in a dynamic long-term context.

(2) Willingness to pay

Valuation is based on willingness to pay (WTP), either as expressed in consumer's own preferences in conventional markets, or in hypothetical markets (as in CVM) (Bojo, 1993). Using the WTP concept raises four major problems: imperfect knowledge, externalities, skewed income distribution and market imperfections (Bojo, 1993; de Beer and Mcdermott, 1989).

While householders in the small-scale sector undoubtably have a wealth of 'indigenous technical knowledge' about trees and tree utilization, and act rationally in making resource use choices (Shepherd, 1992; Campbell et al., 1993), they are likely to be poorly informed about certain natural resource processes and are likely to undervalue off-site downstream impacts (externalities). To take an extreme example, they are unlikely to value woodland destruction in terms of its impact on global climate change.

It has been argued that WTP data are not only an expression of preference, but also reflect wealth and income distribution (Bojo, 1993). This is especially a problem in such countries as

Zimbabwe, where income distribution is highly skewed. Even within the small-scale sector, there are wide differentials and skewed income distribution (Jackson 1989; Jackson and Collier, 1988; Moyo et al., 1992). There is a need to investigate the relationship between WTP and wealth, and a need to develop a system of weighting to ensure that the WTP of the wealthier sectors do not dominate any analysis (Bojo, 1993).

Markets do not necessarily reflect the true preferences or values of society where the property rights governing access to the resource are non-exclusive (Lynam et al., in prep.; Randall, 1983). In the smallholder sector in Zimbabwe, access to tree-based resources is a mixture of private and communal (Wilson, 1989; Nhira and Fortmann, 1993). Behnke (1985) has explored the shortcomings of valuation exercises in that they fail adequately to reflect the real value of some goods. Bradley and Dewees (1993) note that farm-gate prices and willingness to pay exercises may tend to over-value some commodities and undervalue others. Whether one is using actual or hypothetical markets there is a need to investigate the nature of willingness to pay estimates. What is the nature of demand functions? To what extent do market prices overestimate the value of products not commonly marketed or replacement products not frequently purchased? The relationship between WTP data and access roles also need investigation.

(3) Replacement production methodologies

Firstly, it is obvious that the major need is for better, more site-specific data to allow for detailed differentiated analyses (Scoones et al., 1992). The previous valuation was based on scattered bits of information from many systems throughout the country (Campbell et al., 1991b).

Production costs need to be incorporated in such analyses, particularly the labour costs. There is almost no data on labour required to exploit tree-based resources. The valuation of labour is problematic. For some activities, for instance craftwork, the net benefits would be negative if labour was given much value. On the other hand, labour inputs in the small-scale sector have often been underplayed or even ignored (de Beer and Mcdermott, 1989; Moyo et al., 1992; Southgate, 1988). Labour availability varies throughout the year, with severe bottlenecks in certain periods (Gumbo et al., 1989; Zinyama, 1988). Labour requirements for resource management need to be quantified, valued and incorporated into resource valuation.

The current examples of replacement-production methodologies have largely based the valuation on household consumption; the long term costs of changes in resource stocks have not been incorporated into the analyses (Moyo et al., 1992).

(4) From individuals to society

How can values assigned by individuals be weighed together to obtain an aggregate value which can guide social choice? (Blackorby, 1990; Bojo, 1993). In the first instance, research should compare how individuals assign value to commodity categories in comparison to the assignments of community groups and outside 'experts'. In this direction, the CVM described earlier included a comparison between the rankings of householders and experts (Campbell et al., 1991b). In general, there is a problem of scale, the wider the group of beneficiaries, the more difficult it is to obtain a valuation (Bojo, 1993).

In moving from the valuations of individuals to policy making, Moyo et al. (1992) argue for two approaches to be taken, termed the 'positivist' and 'normative' valuation approaches. They argue that the current valuation exercises have concentrated on the positivist approach, with valuation being based on current use patterns and the assumption that patterns of ownership, access and use of land and labour resources remain substantially unchanged. They argue that what is missing are any examples of valuation using a normative approach, in which policy makers are informed of the relative merits of different options of resource use entailing fundamental structural changes in the historical legacy of the present ownership and use. The two approaches involve different shadow pricing assumptions and a normative approach may preclude some methodologies such as CVM, which Moyo et al. (1992) argue rely on revealed preferences based on existing resource use, precluding valuation under alternative economic arrangements.

(5) Values in time and space

Generalised estimates of value and aggregate analyses are now available, but what is sorely needed is information that clarifies how value changes in time and space, in relation to such variables as season, year, environment, tenure, gender, wealth and age (Scoones et al., 1992; de Beer and Mcdermott, 1989). Valuation should tell us about changing uses of woodlands over time and about differential values amongst users. Most studies treat the rural population as an undifferentiated homogenous population: there are few studies of a micro-economic nature (Bradley and Dewees, 1993; Moyo et al., 1992).

(6) The cost of environmental change

Despite widespread concern about environmental degradation, it is clear that there is almost no valuation of environmental change in the region (see Southgate, 1988). The valuation of communal livestock systems by Scoones (1992a) did not take into account any potential degradation in the resource base and the replacement-production valuation of tree-based resources by Campbell et al. (1991b) did not incorporate any cost of the change in the resource base, as the estimates were mostly based on household consumption data: consume more and hence higher value! Hosier (1988) has provided a review of studies on the economics of deforestation in eastern Africa, but finds that only two studies have sufficient data to investigate the subject. He concludes that more information is needed about the resiliency of ecosystems to tree removal and more work is necessary to clarify the proper techniques to evaluate the economic implications of environmental change in developing countries. In the context of Zimbabwe, the cost of degradation is particularly important as the cost to the cost of not undertaking land reform and of not investing in the development of communal lands (Sam Moyo, pers. comm.; Katerere et al., 1991).

(7) Regional value of woodlands for service functions

There are almost no data on the ecological value of woodlands, apart from the CVM described above, which is based on a localized survey. What are the regional consequences of changes in tree cover? What is the value of the state forests in catchment conservation? Bojo (1993) argues that the changes in water flow patterns and/or changes in soil erosion and siltation should form the basis of such a valuation. For instance, as regards water the following techniques would be appropriate: (i) production valuation associated with changed water yields; (ii) contingent valuation on the consumers of water from rivers and dams, and (iii) valuation based on flood damage estimates. There is a vast source of largely unanalyzed hydrological data in Zimbabwe, on which to base valuation, but simulation models would probably also have to be used. As regards soil erosion and siltation, the following techniques need investigation: (i) loss of dam services due to siltation could be valued; (ii) soil loss and the resulting change in production could be investigated using simulation models such as SCUAF, though more empirical data are needed on the influence of trees on soil erosion.

(8) Global value of woodlands for biodiversity

There has been no attempts to value biodiversity in Zimbabwe or the region (Bojo, 1993). There is at least a need to make a preliminary valuation, but I concur with Bojo (1993) that biodiversity values are likely to be minor in comparison with other values. Some preliminary papers have discussed the methodological obstacles associated with the valuation of biodiversity (e.g. Bojo, 1993; Evenson, 1990; Haneman, 1988).

(9) Tourism

There is a need to make a more detailed analysis of the tourism industry, especially in regards the contribution of woodland systems to the benefits accrued.

(10) National accounting

It is clear from the above review of valuation that there has been no attempt to include changes in natural resource stocks in national accounts. There is recognition that the deficiencies in the national accounting system needs rectifying (Bojo 1993; Forestry Commission, 1990, p. 11; Katerere et al., 1991), but little attempt has been made to overhaul the present system. A fairly sophisticated example in which natural resources have been included in the national accounting system is that for Costa Rica (Tropical Science Center, 1991).

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8. Appendices

Appendix-1. Gully Soil Accumulation Data Collected From Each Gully

1.1. Accumulation of the gullies Worken Gashajagrie and Worken Adura

Worken Gashajagrie Gully Soil Accumulation					Worken Adura Gully Soil Accumulation Data				
Width in M	Depth in M	Length in M	Volume in M^3	Mass In Kg	Width in M	Depth in M	Length in M	Volume in M^3	Mass In Kg
6	1.05	42	132.3	165824.8	8	2	24	192	232960
7.2	0.58	16	33.408	41873.59	8.8	1.36	22.6	135.2384	164089.3
5	0.94	10.5	24.675	30927.65	8.1	1.3	11.5	60.5475	73464.3
5	1	16	40	50136	6.7	1.8	16	96.48	117062.4
6.4	1.5	11.6	55.68	69789.31	5	3.6	42	378	458640
5.9	2.55	14.2	106.8195	133887.6	7	2.9	20	203	246306.7
5	2.1	27	141.75	177669.5	10	1.75	12	105	127400
6.5	1.7	30.55	168.7888	211559.8	8	1.85	32	236.8	287317.3
5.7	1.5	12.7	54.2925	68050.22	7.58	0.95	14	50.407	61160.49
5.5	1.1	18.3	55.3575	69385.09	4.3	0.9	19	36.765	44608.2
5.1	1.25	9.2	29.325	36755.96	6	1.7	28	142.8	173264
6	1.5	19	85.5	107165.7	5.4	0.88	15	35.64	43243.2
4	1.55	21	65.1	81596.34	4	2.05	12	49.2	59696
6.6	1.75	12.5	72.1875	90479.81	4.5	1.1	23	56.925	69069
3.8	1.8	18.2	62.244	78016.63	5	1.5	11	41.25	50050
7	1	75	262.5	329017.5	8	2	25	200	242666.7
4.2	1.15	21	50.715	63566.18	6.65	1.05	15	52.36875	63540.75
5.2	1.12	15.7	45.7184	57303.44	5	1.87	10	46.75	56723.33
6.5	0.86	13.4	37.453	46943.59	6	1.6	11	52.8	64064
7	0.85	20.9	62.1775	77933.28	5.55	1.4	24	93.24	113131.2
6.5	0.61	14.3	28.34975	35533.58	3.2	1.25	9.7	19.4	23538.67
6.4	0.9	21	60.48	75805.63	4.45	1.6	9.7	34.532	41898.83
7	2.35	22.7	186.7075	234019.2	5.6	2.1	9.9	58.212	70630.56
7.25	1.9	14.6	100.5575	126038.8	8.1	1.2	22	106.92	129729.6
7.05	2.4	21	177.66	222679	7.5	1.5	10	56.25	68250
5.85	1.65	25	120.6563	151230.5	7	2	15	105	127400
7.3	1.85	50	337.625	423179.2	6	2.35	31	218.55	265174
5.8	2.35	24	163.56	205006.1	9.95	2.2	30	328.35	398398
7	1.5	23	120.75	151348.1	11	0.75	18.1	74.6625	90590.5
7.5	1.7	23.9	152.3625	190971.2	7.8	0.95	14	51.87	62935.6
7	1.23	18.8	80.934	101442.7	9	1.5	8	54	65520
7.4	1.46	23.8	128.5676	161146.6	8.2	1	22	90.2	109442.7
7.2	1	26.7	96.12	120476.8	6.7	1.32	11	48.642	59018.96
7.1	1.65	16	93.72	117468.6	5.4	1.4	17	64.26	77968.8
4.35	1.08	22.1	51.9129	65067.63	5	0.87	4.8	10.44	12667.2
5.5	1	46	126.5	158555.1	3.2	1.58	12.7	32.1056	38954.79
6	0.74	14	31.08	38955.67					

7	2.25	9	70.875	88834.73					
6	2.1	30	189	236892.6					
5	0.77	16	30.8	38604.72					
4.3	2.65	12	68.37	85694.96					
4.5	1.72	9	34.83	43655.92					
5	2.3	40	230	288282					
5.5	1.45	8	31.9	39983.46					
6	1.9	7	39.9	50010.66					
6.5	1.12	23.3	84.812	106303.4					
7	1	26.4	92.4	115814.2					
6	0.99	34.5	102.465	128429.6					
5	1.8	9	40.5	50762.7					
5.75	1.05	10	30.1875	37837.01					
6	1.5	39	175.5	219971.7					
8	1.8	38	273.6	342930.2					
7.2	1.21	16	69.696	87356.97					
6	1.9	13	74.1	92876.94					
5.45	1	10.8	29.43	36887.56					
5	1.8	10	45	56403					
6.68	1.5	23	115.23	144429.3					
7.2	1.34	31.5	151.956	190461.7					
6.65	1.06	10	35.245	44176.08					
6	1.95	19	111.15	139315.4					
7.2	1.25	9	40.5	50762.7					
7	1.03	11	39.655	49703.58					
6.5	0.94	12	36.66	45949.64					
6	2.1	15	94.5	118446.3					
5.5	2	9	49.5	62043.3					
6	1.8	13	70.2	87988.68					
9.2	1.22	10	56.12	70340.81					
12	2.1	5.8	73.08	91598.47					
10	2	21	210	263214					
8.5	1.58	14	94.01	117832.1					
6	1.9	12	68.4	85732.56					

1.2. Accumulation of the gullies Eshim Wofena and Tsegur Eyesus

Eshim Wofena Gully Soil Accumulation Data					Tsegur Eyesus Gully Soil Accumulation Data				
width in m	depth in m	length in m	volume in m3	Mass in kg	Width in m	depth in m	length in m	Volume in m3	mass in kg
9.6	2.18	43	449.952	554940.8	6	1.8	12	64.8	81648
11.53	1.87	43.65	470.571	580370.9	6.25	1.37	8.93	38.23156	48171.77
11	1.75	31.9	307.0375	378679.6	5.5	1.5	20.97	86.50125	108991.6
7.8	2.35	35.8	328.107	404665.3	5.4	2.12	29.85	170.8614	215285.4
7.86	2.3	28.3	255.8037	315491.2	6.9	1.15	17.71	70.26443	88533.18
5.15	1.68	16.3	70.5138	86967.02	5.57	2.87	25.6	204.6195	257820.6
6.78	2.43	15	123.5655	152397.5	7.2	1.8	12	77.76	97977.6
7.2	2	21.9	157.68	194472	6.95	1.75	8.3	50.47438	63597.71

6.61	1.85	13.28	81.19724	100143.3	5.25	2.25	42	248.0625	312558.8
5	1.75	13.9	60.8125	75002.08	6.37	1.86	20.4	120.8516	152273.1
6.1	1.9	29.35	170.0833	209769.3	6.8	2.2	13.4	100.232	126292.3
3.85	1.95	20.67	77.59001	95694.35	7.18	1.83	14.76	96.96877	122180.7
4.69	1.57	30.1	110.8177	136675.1	6.2	1.11	13.5	46.4535	58531.41
7.25	1.35	15.1	73.89563	91137.94	7.39	2.25	24.78	206.0147	259578.6
6.47	1.77	12.6	72.14697	88981.26	5.19	1.74	20.96	94.64069	119247.3
5.29	0.66	19.7	34.39029	42414.69	8.54	2.1	23.9	214.3113	270032.2
5.55	0.78	20.73	44.87009	55339.77	6.8	1.84	15.35	96.0296	120997.3
4.2	2.34	9.2	45.2088	55757.52	4.6	2.17	19.7	98.3227	123886.6
4.45	2.1	16.2	75.6945	93356.55	6.15	1	11.3	34.7475	43781.85
6.23	1.5	19.5	91.11375	112373.6	5.41	1.25	30.7	103.8044	130793.5
7.22	1.95	15	105.5925	130230.8	6.52	1.31	10.5	44.8413	56500.04
5.3	1.3	13.46	46.3697	57189.3	7.2	2	40.4	290.88	366508.8
6.9	1.45	18.65	93.29663	115065.8	6.32	2.1	13	86.268	108697.7
6.14	1.2	14	51.576	63610.4	5	1.89	10	47.25	59535
5.95	1.6	12.7	60.452	74557.47	4.35	1.5	11.5	37.51875	47273.63
7.21	1.3	13	60.9245	75140.22	5.3	3	13	103.35	130221
8.7	1.1	14.2	67.947	83801.3	4.4	2.2	6.2	30.008	37810.08
8.15	1.2	20.9	102.201	126047.9	4.95	1.69	5.56	23.25609	29302.67
7.51	1.6	14.8	88.9184	109666	5.2	2.1	14	76.44	96314.4
5.9	1.7	13.9	69.7085	85973.82	7.2	1	18.1	65.16	82101.6
8.45	1.88	14.5	115.1735	142047.3	6.3	2.5	11.6	91.35	115101
7	2.86	36.5	365.365	450616.8	4.58	1.85	7	29.6555	37365.93
7.2	2.48	12	107.136	132134.4	6.24	2.56	15.4	123.0029	154983.6
7.7	2.43	26.2	245.1141	302307.4	5.33	2.2	15	87.945	110810.7
10.3	1.13	27	157.1265	193789.4	4.6	1.95	14.8	66.378	83636.28
7.1	1.1	25	97.625	120404.2	5.32	1.8	33	158.004	199085
8	2.1	28.8	241.92	298368	5.5	2.8	18.3	140.91	177546.6
10.4	2.28	42.75	506.844	625107.6	6	2.6	12.75	99.45	125307
6.62	2.27	48	360.6576	444811	4.8	2.45	28.8	169.344	213373.4
8.5	1.4	22.9	136.255	168047.8	4.3	2.8	24.74	148.9348	187657.8
12.6	2.45	14	216.09	266511	4.21	2	26.5	111.565	140571.9
10.8	2.2	30	356.4	439560					
8.13	1.95	20.3	160.913	198459.4					
13.75	1.45	26.77	266.8634	329131.6					
9.9	1.4	34.9	241.857	298290.3					
8	1.3	29.6	153.92	189834.7					
9.35	0.8	20.58	76.9692	94928.68					
24.2	1.97	27.37	652.4187	804649.7					
16.5	0.9	27.35	203.0738	250457.6					
14	0.55	39.4	151.69	187084.3					

Appendix 2. Tree Wood and Crown Parameter Collections of Each Gully

2.1. The crown data collected from the field of all the gullies

Species Scientific Name	Frequency of Occurrence	Mean Crown Depth	Mean Crown Diameter	Total Crown Volume
Worken Gashajagrie Gully				
Populus ciliata	659	5.279545	2.574091	6598.337
Acacia angustissima	351	5.076129	3.203548	5221.352
Eucalyptus globulus	382	5.9955	3.2955	7161.09
Sesbania sesban	199	4.885	2.88	2244.484
Acacia saligna	80	4.578571	3.025714	989.9538
Acacia melanoxylon	67	3.631111	2.795556	535.3492
Grevillea robusta	12	8.09	4.5	514.6636
Acacia abyssinica	248	4.8325	3.1925	3460.806
Salix babylonica	628	4.640526	2.698421	5922.439
Worken Adura Gully				
Populus ciliata	390	4.401277	1.988511	2082.769
Sesbania sesban	85	4.504	3.442	1240.056
Salix babylonica	261	3.174857	2.043143	1092.243
Acacia angustissima	138	4.802381	3.038571	1880.679
Acacia saligna	17	3.625	2.4375	103.0985
Acacia abyssinica	78	4.155	4.875	242.5066
Acacia melanoxylon	14	3.337647	2.719412	265.9291
Eucalyptus globulus	19	4.978333	3.048333	815.878
Tsegur Eyesus Gully				
Populus ciliata	279	4.60186	1.724031	1206.792
Acacia angustissima	97	4.805714	3.671143	1766.682
Acacia saligna	325	4.984605	3.417364	5539.983
Sesbania sesban	44	5.251818	3.57	806.5678
Eucalyptus globulus	67	5.188333	2.766667	774.2643
Salix babylonica	48	3.486667	2.116667	280.735
Grevillea robusta	117	4.947	3.1405	1777.477
Acacia abyssinica	202	4.056341	3.963182	3914.537
Acacia baileyana	2	7.03	3.15	36.5237
Acacia melanoxylon	149	4.992454	3.104167	2065.171
Eshim Wofena Gully				
Populus ciliata	550	4.932176	1.897838	3144.985
Acacia saligna	501	5.133333	3.327083	8659.676
Sesbania sesban	1647	5.058729	3.401042	27358.68

2.1. The wood volume data collected from all the gullies

Species Scientific Name	Species Frequency	Mean DBH per Species	Mean Total Height	Mean Merchantable Height	Tree Density	Total AGB	Total BGB	Total Wood Volume
Tsegur Eyesus Gully								
Populus ciliata	279	10.88916	14.52961	9.927752	426	11397.05	2531.719	11.77577
Acacia angustissima	97	8.626198	8.147143	3.341429	548.3	1978.963	468.2669	1.018187
Acacia saligna	325	10.65006	9.197054	4.21245	616.6	11630.78	2617.977	5.694914
Sesbania sesban	44	10.46082	9.980455	4.728636	460	1400.09	312.0855	0.961431
Eucalyptus globulus	67	11.77747	13.92333	8.735	650	4917.07	1011.634	3.066253
Salix babylonica	48	8.010799	7.36	3.873333	385	837.4027	192.0517	0.778113
Grevillea robusta	117	8.86493	10.1015	5.1545	592	3266.662	752.0298	1.849255
Acacia abyssinica	202	14.24798	7.006818	2.950477	683.3	12358.05	2557.209	4.965606
Acacia baileyana	2	10.02676	11.72	4.69	683.3	82.03435	18.46966	0.031107
Acacia melanoxylon	149	9.141094	9.491111	4.498657	740	5103.467	1149.302	2.154472
Worken Gashajagrie Gully								
Populus ciliata	659	6.814725	11.30136	6.021818	426	8696.365	2177.683	7.488
Acacia angustissima	351	7.865335	8.575806	3.499677	548.3	7659.6	1726.767	3.944
Eucalyptus globulus	382	12.32735	14.325	8.3295	650	45777.85	8407.246	28.3424
Sesbania sesban	199	11.20053	8.34625	3.46125	460	6244.339	1396.484	3.705
Acacia saligna	80	8.412476	7.378571	2.8	616.6	1315.047	327.7	0.521
Acacia melanoxylon	67	5.216745	5.677778	2.046667	740	444.8362	120.9647	0.142866
Grevillea robusta	12	7.321127	12.5	4.41	592	242.4791	59.2826	0.093564
Acacia abyssinica	248	14.68204	8.055	3.2225	683.3	28468.58	5128.07	11.79479
Salix babylonica	628	8.443589	7.171053	2.530526	385	7462.651	1878.287	4.42621
Worken Adura Gully								
Populus ciliata	390	6.423764	11.04574	6.644468	426	4540.154	1149.962	4.247233
Sesbania sesban	85	10.32916	7.285	2.781	460	1873.997	437.5897	0.99558
Salix babylonica	261	7.557586	7.694286	4.519429	385	2664.29	685.86	2.724713
Acacia angustissima	138	8.00322	8.140476	3.338095	548.3	2506.031	569.8874	1.2322
Acacia saligna	17	6.92324	6.175	2.55	616.6	168.01	44.2292	0.074851
Acacia melanoxylon	78	6.15087	6.058824	2.721176	740	736.1654	193.6382	0.2834
Acacia abyssinica	19	12.7324	6.4	2.245	683.3	769.4369	170.6625	0.2675
Eucalyptus globulus	14	24.61596	15.08333	10.105	650	5451.577	898.1294	3.6143
Eshim Wofena Gully								
Populus ciliata	550	10.52573	12.54081	7.608635	426	22183.48	4793.434	21.8614
Acacia saligna	501	11.83715	8.345208	3.211875	616.6	24972.53	5230.251	10.20711
Sesbania sesban	1647	9.449825	8.053542	2.994813	460	37861	8644.726	20.6446

Appendix 3. 10 years Metrological Data from Debretabor Station

Mean Monthly Minimum Temperature In °C

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	8.9	9.1	9.9	12.0	10.9	10.5	10.4	10.0	9.4	8.4	8.7	7.7
1995	8.6	9.6	10.2	12.1	11.9	11.3	10.7	10.5	9.2	8.2	8.5	8.3
1996	8.2	9.9	10.7	11.6	10.9	10.1	10.2	10.0	9.5	8.2	8.5	7.7
1997	8.1	8.6	10.9	10.8	10.6	10.5	10.4	10.3	9.8	9.1	8.5	8.5
1998	8.8	9.2	10.9	12.9	12.1	10.9	10.6	10.2	9.8	9.4	7.3	6.6
1999	8.0	9.7	9.3	11.0	10.8	10.3	10.0	10.1	9.3	9.3	7.0	7.7
2000	7.8	9.0	10.2	11.5	10.8	10.1	9.8	9.8	9.2	9.1	8.2	7.6
2001	6.9	9.5	10.5	11.5	11.7	10.3	10.1	10.4	9.0	9.1	7.4	8.0
2002	7.7	8.9	10.5	10.9	11.9	10.5	10.0	9.3	9.0	7.7	7.8	7.4
2003	7.3	9.3	10.4	10.9	11.9	10.7	9.3	9.4	9.1	8.4	8.1	7.6

Monthly mean maximum temperature in °C

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1994	22.8	24.1	25.0	25.8	28.3	20.4	17.1	17.4	19.4	22.4	21.4	22.4
1995	23.2	24.1	24.9	24.2	23.7	23.2	18.2	18.7	20.0	21.8	22.0	21.6
1996	22.6	24.5	24.2	23.4	21.2	19.8	18.7	19.0	20.5	21.8	21.3	21.6
1997	22.0	23.5	23.9	23.0	22.0	20.7	18.3	19.3	21.4	21.0	22.0	21.5
1998	22.9	24.1	24.9	26.5	23.2	22.2	17.7	18.0	19.8	20.8	21.5	22.8
1999	22.3	25.0	24.9	25.3	24.6	23.4	16.8	18.2	20.0	19.3	21.5	22.1
2000	22.8	23.5	25.5	21.8	23.7	22.2	19.0	18.7	19.8	19.8	21.4	22.6
2001	22.8	24.0	24.1	25.2	23.6	20.1	18.3	18.3	20.0	21.8	22.0	22.8
2002	22.3	25.1	24.7	24.9	25.4	22.0	20.2	19.7	20.5	22.9	23.1	22.9
2003	23.7	24.5	24.4	25.4	26.0	22.5	18.5	18.8	20.0	21.9	22.3	22.4

Monthly Total Rain Fall in mm/Hg

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0	0.0	22.7	34.6	100.4	73.0	399.7	403.6	184.9	5.0	23.4	25.3
1996	4.3	1.2	49.4	92.1	146.1	197.0	349.4	373.9	155.3	30.6	76.2	4.4
1997	3.4	0.0	73.7	43.1	197.6	225.1	449.7	359.0	197.0	314.0	12.3	82.5
1998	13.6	0.0	20.8	6.9	203.6	126.2	400.6	410.8	244.8	75.9	0.0	0.0
1999	34.5	0.0	0.0	18.1	41.2	181.4	476.5	345.7	244.8	250.6	11.2	19.5
2000	0	0.3	6.3	118.4	61.1	168.1	423.4	462.4	232.3	137.8	34.8	0.5
2001	0	0.7	17.2	24.0	95.4	197.5	496.2	410.0	184.8	45.6	4.5	7.2
2002	0.4	1.0	60.2	45.1	47.2	203.5	256.6	322.4	122.8	2.9	16.5	18.8
2003	0	13.9	24.1	28.1	10.4	86.2	435.7	396.8	221.7	16.7	33.3	14.7
2004	0	37.6	33.7	71.4	19.1	141.0	333.2	295.2	120.2	85.8	42.5	12.7

Appendix 4. Grass Area and Biomass measured from the fields of Each Gully

Species scientific name	***Total Gully Grass Area Coverage in m^2***	***Biomass in 0.25m^2 and Per Stem mass in KG***	***Total Gully Grass Biomass in kg***
Tsegur Eyesus Gully Grass Species Data			
Pennisetum clandestinum	896.18	0.78	2796.082
Coronilla varia	447.04	0.35	625.856
Pennisetum sp	109.42	3.8	467.248
Pennisetum purpureum x P. typhoides	11.28	1.83333	82.71935
Worken Gashajagrie Gully Grass Species Data			
Pennisetum sp	241.55	3.8	3671.56
Pennisetum clandestinum	1711.12	0.78	5357.314
Pennisetum purpureum	48	1.83333	351.9936
Sambucus nigra	52	1.9	98.8
Arundo donax	888	1.72	1527.36
Enset ventricosum	57	3.54	201.78
Eshim Wofena Gully Grass Species Data			
Pennisetum purpureum x P. typhoides	932.03	1.8333	6834.762
Phalaris aquatica, P. arundinacea	218.85	0.967	846.5118
Arundo donax	56	1.72	96.32
Pennisetum sp	272.5	3.8	4142
Enset ventricosum	100	3.54	354
Worken Adura Gully Grass Species Data			
Pennisetum clandestinum	130	0.78	405.6
Pennisetum sp	659.19	3.8	10019.69
Arundo donax	975	1.72	1677
Enset ventricosum	82	3.54	290.28
Pennisetum purpureum	266.61	1.833	1955.104

Appendix 5. Soil Laboratory Results of all the sites

5.1. Laboratory results of the Worken Adura and Worken Gashajagrie gully

Worken Adura Laboratory Results					Worken Gashajagrie Laboratroy Results				
Sample Spot Name	Organic Carbon (%)	Available Nitrogen(%)	Available P(mg /kg soil)	Available K(mg/kg soil)	Spot Name	Organic Carbon(%)	Available Nitrogen(%)	Available P(mg /kg soil)	Available K(mg/kg soil)
WA-1+2(0-15)	1.03	0.0114	36.8	266.2	WG1+2(0-15)	0.91	0.0142	17.97	212.1
WA-1+2(30-45)	1.35	0.0143	31.28	264	WG1+2(15-30)	1.08	0.0165	22.67	119.3
WA3+4(0-15)	1.26	0.0137	35.65	290.4	WG1+2(30-45)	0.72	0.0139	20.91	132.6
WA3-4(15-30)	1.32	0.0139	34.96	294.8	WG1+2(45-)	1.04	0.0146	33.94	119.3
WA3+4(30-45)	1.26	0.0126	52.38	173.8	WG3+4(0-15)	1.14	0.0137	19.15	238.6
WA3+4(45-)	1.08	0.0128	38.76	178.2	WG3+4(15-30)	0.8	0.0111	16.86	132.6
WAB1-4	1.02	0.0137	33.41	189.2	WG5(0-15)	1.58	0.0139	39.45	463.9
WAB5-8	1.31	0.0143	19.72	187	WG5(15-30)	0.83	0.0102	18.97	172.3
WAB9-13	1.37	0.0163	19.9	180.4	WG5(30-45)	0.97	0.0117	16.61	132.6
WA1 (15-30)	1.31	0.0139	26.68	228.8	WG5(45-)	1.04	0.0137	24.21	132.6
WAS1-4	2.37	0.0213	45.02	292.6	WG6+7(0-15)	1.27	0.01166	32.73	212.1
WAS5-8	2.43	0.0183	38.93	310.2	WG6+7(15-30)	1.2	0.0111	40	291.6
WAS9-12	1.47	0.0166	39.79	281.6	WG6+7(30-45)	1.02	0.0137	37.97	145.8
WAS13-16	2.03	0.0211	29.21	261.8	WG6+7(45-)	0.94	0.00964	60.6	198.8
WAS17-20	1.42	0.0152	36.23	213.4	WG8(0-15)	1.4	0.0137	63.63	424.2
WAS21-24	1.18	0.0139	30.82	202.4	WG8(15-30)	1.2	0.0102	36.97	318.1
					WG8(30-45)	0.73	0.0105	36.97	185.6
					WGB1-4	1.31	0.0116	24.85	159.1
					WGB5-6	1.13	0.01166	33.33	291.6
					WGS1-4	1.43	0.0121	37.57	159.1
					WGS5-8	1.15	0.0111	29.7	172.3
					WGS9-12	1.15	0.0137	35.76	212.1
					WGS13-16	0.93	0.01166	47.27	159.1
					WGS17-20	1.97	0.0162	27.88	278.4
					WGS21-24	2.1	0.01197	42.42	331.4
					WGS25-28	1.85	0.0166	49.09	238.6
					WGS29-32	1.77	0.0144	54.54	331.4
					WGS33-36	1.77	0.0139	52.73	371.1
					WGS37-40	1.89	0.0162	61.21	424.2
					WGS41-44	2.48	0.01685	64.85	530.2
					WG S45-47	1.80	0.01476	60.60	397.70

5.2. Laboratory results of the Tsegur Eyesus and Eshim Wofena gully

Tsegur Eyesus Laboratory Results					Eshim Wofena Laboratory Results				
Sample Spot Name	Organic Carbon(%)	Available Nitrogen (%)	Available P(mg /kg soil)	Available K(mg/kg soil)	SPOT NAME	Organic Carbon(%)	Available Nitrogen(%)	Available P(mg /kg soil)	Available K(mg/kg soil)
TEF1-4	1.35	0.014	55.73	275	Ew-A1+2 (O-15)	0.81	0.0108	24.5	330
TEF5-9	1.39	0.0136	50.92	149.6	Ew-A1+2 (15-30)	0.69	0.01	25.94	217.8
TEF10-14	1.18	0.0119	56.69	143	Ew-A1+2 (30-45)	0.49	0.01	15.85	226.6
TEF20-23	1.38	0.0122	58.13	134.2	Ew-A1+2 (45-)	0.47	0.0097	22.1	226.6
TEN1(0-15)	1.77	0.0177	55.25	272.8	Ew-A3+4	0.84	0.0108	36.51	167.2
TEN1(15-30)	0.69	0.0091	55.25	114.4	Ew-A3+4(0-15)	0.76	0.0103	36.99	266.2
TEN1(30-45)	1.1	0.0103	58.13	178.2	Ew-A3+4(15-30)	0.52	0.0097	20.18	211.2
TEN1(45-)	1.09	0.0116	61.49	136.4	EWA17+18	0.96	0.0103	30.75	231
TEN2(30-45)	1.01	0.0105	58.13	151.8	EWA19+20	1.1	0.119	70.14	226.4
TEN3(0-15)	1.53	0.0123	58.13	261.8	EWA19-22	1.12	0.0131	21.28	206.8
TEN3(15-30)	2.3	0.0125	60.53	156.2	EWB1+2(0-15)	0.92	0.0139	51.88	206.8
TEN3(30-45)	1.11	0.0119	53.33	140.8	EWB1+3(30-45)	1.26	0.0154	55.73	246.4
TEN3(45-)	1.04	0.013	42.28	114.4	EWB3+4(0-15)	0.99	0.014	48.52	279.4
TES1-4	0.99	0.0112	62.93	110	EWB3+4(15-30)	1.12	0.0165	48.04	292.6
TES5-6	1.38	0.0119	61.97	127.6	EWB27-28	1.05	0.0128	58.61	206.8
TES7-10	1.13	0.0109	52.04	114.4	EWB29-	1.09	0.0132	50.92	151.8
TES11-14	1.26	0.0112	45.94	114.4	EWAB(0-15)	0.76	0.0128	50.92	253
TES15-18	1.28	0.012	55.6	129.8	EWAB(15-30)	0.79	0.0126	43.72	259.6
TES19-22	1.44	0.0136	49.16	123.2	EWAB(30-45)	0.88	0.0112	89.36	279.4
TES27-30	1.34	0.0131	47.78	129.8	EWAB1-4	1.31	0.0131	53.33	151.8
TES31-33	1.34	0.0134	42.95	127.6	EWAB5-8	0.85	0.0131	55.25	110
TES35-38	0.86	0.0108	57.04	132	EWA3+4(30-45)	0.45	0.01	30.75	217.8
					EWA5+6	0.8	0.01	37.47	162.8
					EWA7+8	0.83	0.012	30.75	160.6
					EWA9+10	0.96	0.013	33.63	198
					EWA11+12	1.09	0.013	29.31	255.2
					EWA13+14	0.89	0.013	39.87	191.4
					EWA15+16	1.37	0.013	32.67	228.8
					EWB3-4(30-45)	1.03	0.0142	56.69	257.4
					EWB3+4(45-)	1.18	0.0125	65.34	292.6
					EWB1-4	1	0.012	48.52	154
					EWB9-12	1.08	0.0112	60.53	182.6
					EWB13-16	1.51	0.0136	66.3	272.8
					EWB17-20	1.12	0.012	35.07	259.6
					EWB25-26	1.07	0.0131	60.53	162.8

Appendix 6. Gully Soil Loss Parameter Data Measured of Each Gully

6.1. Gully loss in terms of its parts measured on fields of Worken Gashajagrie and Worken Adura

Worken Gashajagrie gully loss measurments					Worken Adura gully loss measurments				
Structure No	Mouth Width	Bed Width	Depth	Gully Length	Structure No	Mouth Width	Bed Width	Depth	Length
1	19	9.98	3.35	16	1	9	5.5	3.63	46.6
2	21	10.9	2.13	14	2	14	2.95	5.05	11.5
3	13	6.45	6	9	3	41	24.9	15	90
4	14.2	5.7	5.5	30	4	48	19	15	32
5	12.15	6.6	4.1	16	5	41	17	11	14
6	8	2.9	2	21	6	55	9.3	15	47
7	8.3	4.4	3	48	7	31	5.9	9.2	15
8	6.2	6.2	2.5	7	8	49	24.9	15	35
9	3	2	1.2	23.3	9	36.6	6.2	9.35	11
10	3.2	1.5	2	26.4	10	16.05	8.25	6.3	25
11	4	2.5	2.5	34.5	11	17	8	5	15
12	16.2	8.15	5.1	9	12	9	5	2.95	10
13	8	2.25	1.5	49	13	13.3	6.75	1.95	32
14	12	5	2.4	38	14	13	6.35	2	15
15	13	4	2.75	16	15	15	8.55	2.1	31
16	15	8.8	2	23.8	16	8.8	6.55	1.73	30
17	11	5.3	1.95	33					
18	17	4.45	2.1	31.5					
19	12	4.8	2.9	29					
20	9	4.7	2.8	20					
21	23	6.4	7	22					
22	19.2	7.6	5.5	37					
23	21.2	6	3.1	26.8					
24	11.35	4.5	3.85	26					
25	40.2	7.4	8	42					
26	25	5.05	6	16					
27	22	16.2	3.4	10.5					
28	18.6	6.4	2.2	16					
29	18.3	6	3.1	25.8					
30	24.675	6.15	5.4	27					
31	36	7.8	10	30.55					
32	38	20.2	5.3	31					
33	10	5.1	2.35	28.2					
34	9	4.45	2.45	21					
35	7	4	0.9	12.5					
36	29	9	7.6	18.2					
37	21.675	8.05	5.4	75					
38	20	6.5	3.9	21					
39	24.95	6.15	5.7	29.1					
40	37.1	7	5.6	35.2					
41	22	7.8	5.95	43.7					
42	15	6.45	5.1	14.6					
43	23.8	8	5.4	96					
44	19.2	8	3.85	24					
45	21	7.25	6.4	65.7					
46	24	8.2	6.4	50.5					
47	15	8	4	68.1					

6.2. *Gully loss in terms of its parts measured on fields of Eshim Wofena and Tsegur Eyesus*

Eshim Wofena gully loss measurments					Tsegur Eyesus gully loss measurments				
Structure No	Mouth Width	Bed Width	Height	Length	Structure No	Mouth width	Bed Width	Depth	Gully Length
1	15.6	11.25	2.84	31.9	1	8.93	6.3	2.28	8.93
2	18	10.16	3.39	43.65	2	13.34	7.33	2.11	20.97
3	17.47	10.11	3.9	43	3	14.5	7.23	3.99	29.85
4	15.75	9.9	3.8	35.8	4	20.7	7.45	5.02	17.71
5	17.25	7.15	4.16	28.3	5	10.6	6.64	3.7	25.6
6	11.95	5.77	4.65	16.3	6	11	5.8	1.7	12
7	13.7	7.75	4.6	15	7	10.8	6.37	1.6	8.3
8	6.4	5.5	2.25	21.9	8	12.35	4.86	2.69	20.4
9	6	4.2	1.1	13.28	9	12.05	7	3.35	13.4
10	5.8	2.2	1	13.9	10	13.8	8	2.88	14.76
11	13.7	7.75	3.9	29.25	11	17.35	13.2	2.69	13.5
12	6.32	3.65	2.92	20.67	12	15.6	9.15	3.39	24.78
13	6	4.1	1.8	15.2	13	10.6	5.42	3.79	20.96
14	12.3	8.9	1	12.7	14	13.3	6.53	4.64	23.9
15	10.3	8.7	1.25	19.7	15	15.93	9.4	4.1	15.35
16	6.7	5.4	0.8	20.73	16	10.05	6.37	2.215	11.3
17	8.9	7.9	1.09	9.2	17	12.3	5.58	2.7	30.7
18	9.4	7.5	1.02	16.2	18	5.3	4.13	1	10.5
19	7.2	5.2	2.5	9.4	19	12.02	8.2	2.06	40.4
20	7.7	6.4	1	19.5					
21	7.2	4.5	2	15					
22	5.3	3.5	1.2	13					
23	5.3	4	1.5	13.46					
24	5.7	5.6	2.1	18.65					
25	7.5	6.5	1	14					
26	9.2	6.6	1.25	12.7					
27	7.8	5.6	1.05	18.2					
28	14.6	11.7	0.98	20.9					
29	15	5.4	2.85	14.8					
30	10.75	6.3	2.8	13.9					
31	10	4.8	3	14.5					
32	17.8	8.05	4.025	36.5					
33	11.5	5.5	4.6	12					
34	12.2	8.7	2.4	26.2					
35	14.9	5.35	3.25	27					
36	12.15	7.84	4.16	25					
37	12	8	3.66	28.8					
38	22.75	11.15	4.63	42.75					
39	19.6	6.75	4.35	48					
40	14.5	6.3	5.6	22.9					
41	16.7	11.35	3.93	25					
42	9.75	9.3	2.34	30					
43	7.8	7	2.1	20.3					
44	11.45	9.45	3.38	26.77					

45	15.65	11.2	1.45	34.9					
46	18.5	12.1	3.2	29.6					
47	7.95	5.25	0.95	20.55					
48	10.5	7.6	1.2	27.37					
49	20.75	18.75	0.45	27.35					
50	12	7.1	1.3	39.4					

Declaration

I the undersigned declare that this Thesis is my original work and has not been presented for any degree in any university and all the resource of materials used for the Thesis have been duly acknowledged.

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