Indicators of Environmental Degradation in the Blue Nile Basin: Exploring Prospects for Payment for Environmental Services

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Abstract

The Blue Nile Basin (Abay in Ethiopia) covers wide range landscapes and climatic zones in Ethiopia and Sudan. Different agricultural production systems, in the basin, evolved in response to those diverse landscapes and climatic zones, and the attendant human decision dynamics that responds to changing livelihood opportunities. Many production systems studies recognized only mixed agriculture in the highlands and pastoralism in the lowland areas. Now it is widely recognized that several other factors such as land-use, vegetation cover, and different land and water management practices are important in defining production systems. These study approaches help to capture the diverse water and land related livelihoods of the farming communities in upstream and downstream parts of the basin and their impact on their respective environments. In this review, we follow a similar approach but focus at the basin scale to define and characterize major production systems and associated subsystems specifically: small grain cereals-based mixed crop-livestock and maize-sorghum-perennials systems and their associated subsystems. We then focus on water management practices in rainfed and irrigated systems. We also synthesized impacts of those production systems on the environment and upstream-downstream linkage using erosion, sedimentation, livestock and crop water productivity, soil nutrient balances as indicators. Evidences suggest that natural ecosystem services (e.g. regulation services such as nutrient recycling and redistribution) are severely threatened in the Blue Nile basin. On-site and off-site effects of pedogenic processes like sediment removal, transportation, redistribution and attendant environmental impacts (e.g. nutrient balances and water productivity) are highly correlated with dominant farming practices and attendant anthropogenic interventions. Indicators such as water productivity and soil nutrient depletion and farmers' activities to replenish the lost nutrients are also strongly related to the degree of the farmers' resource endowments. In view of initiating the upstream community to invest more on land and water management, options for payment for environmental services (PES) must be sought and, interventions that enhance sustainable ecosystem management must use integrated approaches and farming system/subsystems as entry point.

Key words: *Production systems; environmental degradation; upstream downstream; Blue Nile basin; water productivity, payment for environmental services (PES)*

1 Introduction

The Blue Nile Basin (called the Abay in upstream, Ethiopia) covers approximately 0.31 million km^2 (ENTRO, 2006). Its source, the Gish Abay, is in the Ethiopian plateau from which it flows northward into Lake Tana. From Lake Tana it exits from the southeastern corner and cuts a deep gorge first south then westwards. Along the way it is joined by a number of tributaries (e.g., Beles, Dindr) emerging from a range of different landscapes and climatic zones in Ethiopia (MoWR, 1998). In the downstream areas, the river flows across wide clay plains of unconsolidated sediments that might have been delivered by flood and deposited there over time.

Different farming systems in the basin evolved in response to these diverse landscapes and climatic zones, and the attendant human decision dynamics that responding changing livelihood opportunities (Westphal, 1975; Dixon, et al., 2001; Malcom et al., 2001). In Ethiopia many farming systems studies recognized only mixed crop-livestock agriculture in the highlands and pastoralism in the lowland areas (e.g. Getahun, 1980). In contrast, Westphal (1975) recognized several factors such as land use, vegetation covers, and different land and water management practices. Westphal's (1975) approaches help to capture the diverse water and land related livelihoods of the farming communities upstream and downstream in the basin. Using similar studies approaches, but focusing on cereals-based mixed farming system of Gumera watershed (Blue Nile basin, Ethiopia), Haileslassie et al. (2007, unpublished) identified three distinct subsystems: rice-based cash crops (downstream); teff-millet; wheat-barley and barley-potato (upstream) systems in the.

In this review, we attempt to follow a similar approach but focus at the basin scale on major farming systems and associated subsystems. We focus on cropping systems; specifically small grain cereals-based mixed farming systems and maize-sorghum-perennials systems and their associated subsystems (e.g. livestock). We then focus on water management practices (rainfed systems and irrigated systems).

The major objectives of this review are to characterize major farming systems in the Blue Nile basin; to review implications of the magnitude of different ecosystem degradation indicators such as erosion, nutrient balance and water productivity; and to appraise major determinants of investment in land and water management.

2. Description of Farming Systems

2.1. Small grain cereals based mixed farming systems

Small grain cereals-based mixed farming system[1] covers major parts of the upstream areas of the Northern Highlands (1500 to 3000 masl[2]) in Ethiopia, but is not found in the Sudanese Blue Nile. Subsystems, hereafter called systems, in this region can be further categorized by specific cropping patterns. In the following section we will consider the wheat-barley and teff-based cereals (MoWR 1998; Westphal 1975; Bourn 2002).

2.1.1. The wheat-barley system

Wheat-barley system is a typical of subsistence farming and mainly occupies the upstream areas: upper altitude ranges above 2500masl (e.g. the Beshilo, Durame and Middle Abay sub-basins (Figure 2.1)). This system is invariably rainfed agriculture, drawing only on green[3] water resources and characterized by land fragmentation and shortage of arable land. For example, an average farm size of 1.3ha (only for Amhara region) is reported by ENTRO (2006). It is also very common to see pulses (e.g., horse bean, pea) and potatoes as components of this system. The importance of those crops increase with increasing altitude

[1] Small grain cereals refer to: teff, wheat, barley, oat
[2] masl is Meters Above Sea Level
[3] That fraction of rainfall that is stored in the soil and available for the growth of plants

(Haileslassie et al., 2007, unpublished). In steep slope areas, where altitude allows, some maize and sorghum cultivations are also reported.

Livestock are well integrated into the crop production system, with both complementary and competitive interactions between crop and livestock enterprises. They are complementary in that livestock are used for nutrient recycling and sources of traction power, while crop production provides residues for animal feed. But at the same time livestock and crop production compete for space and thus drive land use change. Haileslassie et al., (2006) reported that, in this system (e.g., in Gumera watershed), farmers lack cash crops and livestock play an important role to overcome households' cash constraints. There are few alternative income opportunities (e.g., non-farm employment) and thus farmers prefer to have more small ruminants (e.g., sheep) for frequent off-take.

Communal grazing lands are one of the important land uses in the wheat-barley system. In most parts of the wheat-barley system over stocking and closely related over grazing of those land use unit are frequently reported. Such land management practices are criticized for contribution to increased run off, erosion and sedimentations. It becomes also evident that crop lands are contributing a significant quantity of sediment in the basin and farmers are focusing a niche approaches for farm land management. For example the fertilizer inputs vary between crops and fields (home and distant fields). This has implication for the quantity of biomass produced and related process of water and land productivity.

Depending on the rainfall pattern the wheat-barley system can be classified as single or double cropping. Double cropping areas are usually on the higher elevations and confined to the mountain ranges separating the Tekeze, Awash and the Blue Nile basins. In those areas there is a bimodal distribution of rainfall and farmers can produce two harvests per year.

Delayed and early withdrawal of rain (in both the short and long rainy seasons) is one of the major production constraints of the wheat-barley system.

High population pressures and attendant livestock density and cultivation on steep slopes have resulted in severe soil erosion and land degradation (Mwender 1997). This is one of the major challenges in wheat-barley system. For example erosion rates ranging between 25-84 ton ha^{-1} yr^{-1} are reported for the Gumera watershed (Haileslassie et al., 2006): a value closer to the estimate of ENTRO (2006). This can be also viewed in terms of the cost of maintaining soil fertility (on site effects on upper stream areas) and nutrient inflow and soil fertility enrichments in the downstream areas (off site effects). In both cases, the consequences are already seen in the form of low soil fertility and crop yields upstream, and sedimentation of canals and irrigation infrastructures in downstream areas (Eltahir 2006; SMEC 2007). At the local level, such ecosystem disruptions are also frequently reported (IFAD 2002). In most cases, according to ENTRO (2006), there are permanent grain deficits in this upstream farming system: ranging between 240 and 580 kgs of grain per family.

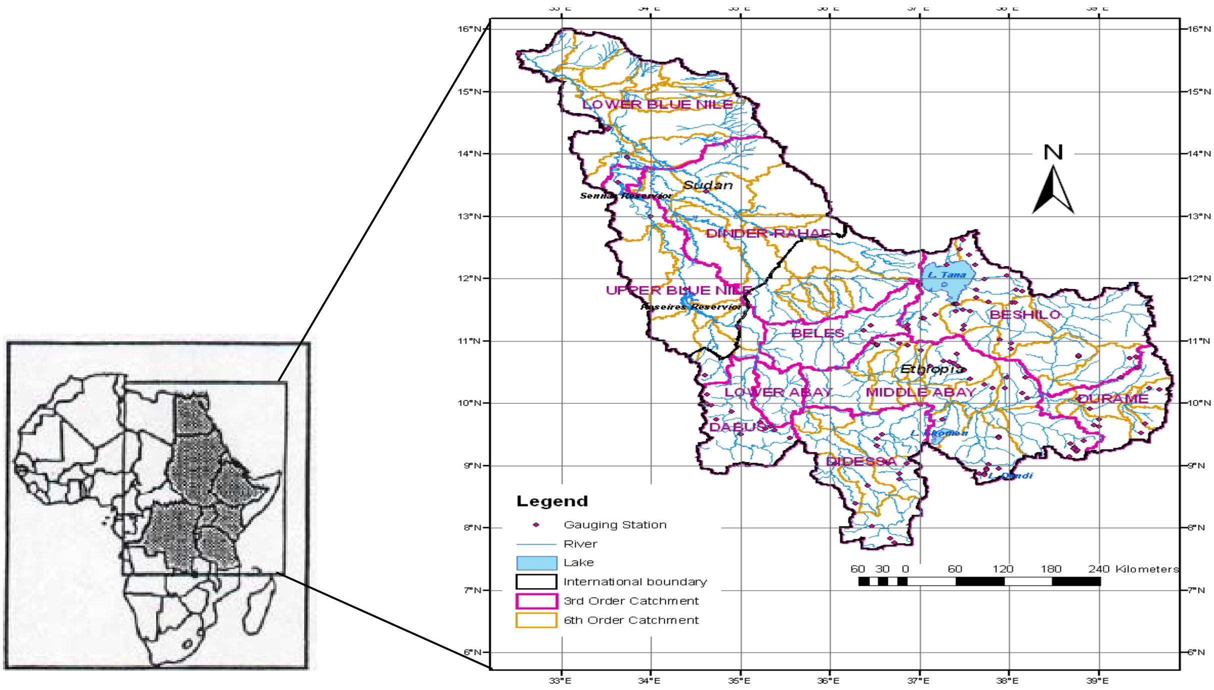


Figure 2.1. Location, sub catchments of order catchments of the Blue Nile basin

2.1.2. *Teff based cereals farming*

This is one of the dominant systems in the upstream areas (1,500 masl to 2,300 masl). For example, this system can be observed in parts of the Beshilo, Durame and Tana sub-basins (ENTRO 2006; MoWR 1998 (Figure 2.1.)). Teff can withstand water logging and thus is a dominant crop for flat lands and vertisols. Where soils are better drained, maize and sorghum are also extensively cultivated (Bourn, 2002). Depending on the biophysical settings, farmers tend to adopt different crops combination strategies, such as a teff-maize-sorghum complex or a teff-wheat-sorghum complex. In this system, pulses (e.g., chick pea and rough pea) and oil crops (e.g., niger seeds) are important cash crops. Teff is a principal staple food and also cash crop in some areas.

Teff systems are rainfed, and therefore like in barley-wheat systems, green water management is important. The productivity of crops (e.g. associated sorghum and maize), in this farming system, is higher than the wheat-barley system, but very low compared to the global average. According to ENTRO (2006), teff-based cereals farmers (on average) produce a surplus over subsistence requirements. Despite the claimed surplus productivity of those areas, the investment capacity of farmers to enhance green water productivity is limited and most likely the sustainability of ecosystem provision services are questionable under current practices (ENTRO 2006; SMEC 2007).

The livestock is important component of this system and is fully integrated, but with different herd structures and composition as compared to wheat-barley system. For example, the major purpose of livestock in teff-based cereals farming is draft power. This is closely related to the relatively bigger land holding size that requires sufficient traction power. Average farm sizes ranging between 2.07ha (in western Amhara), 1.26ha (in eastern Amhara) have been reported (ENTRO 2006). Livestock feed scarcity is a major problem in teff-based cereals farming and crop residues are therefore an important feed source (MoA 2002).

The major challenges to crop production in this system are erosion and soil nutrient depletion, driven by land use changes. Haileslassie et al. (2005), for example, reported very strong nitrogen depletion (>120 kg N ha^{-1} yr^{-1}) for cereals-based farming systems in Ethiopia. In contrast to the generalized notion of the Ethiopian highlands as a source, and the downstream areas (e.g. Sudan plains) as a sink for sediment, localized sediment redistribution within and between different systems are reported (Haileslassie, 2006). For example sediment flux to Lake Tana, which is located in a teff-based cereals farming system, has been estimated to be 10x106 m^3 yr^{-1} Assuming a trap efficiency of 50%, the Lake will lose 6% of its effective storage within 100 years (MoWR, 1998). Recent studies by SMEC (2007), give a higher estimate on the amount of sediment load into Lake Tana: the total annual sediment load from the upper catchments is estimated at 9.61 million tons yr^{-1}. The average annual outflow from Lake Tana (at Bahr Dar) carries an average annual sediment load of 1.04 million tons yr^{-1}. This means 8.57 million tons of sediment will settle annually in the Lake and wetlands.

2.2. Maize-sorghum-perennials complex

This farming system covers very large area located in the western and southern parts of the Blue Nile basin. The system consists of both intensive farming of maize-based perennial crops in the south, upstream of the Didesa sub-basin in Ethiopia; and extensive farming of maize-sorghum complex in the western lowland valleys of Dabus and Beles, upstream of the Dinder and Rahad sub-basins in Ethiopia. The maize-sorghum complex extends to Sudan where sorghum becomes a dominant crop (e.g. the rain fed semi mechanized farms). An important segment of the maize-based perennial is the maize-wheat; sorghum-teff-maize; maize-enset and maize-teff-coffee subsystems. In the following session we focus only the two major systems: maize-based perennial and maize-sorghum complex.

2.2.1. Maize-sorghum complex of the western lowlands

This farming system is practiced in the western and northwestern valleys of Dabus, Beles, Dinder-Rahad sub-basins (MoWR, 1998; ENTRO, 2006). The major soils are leached Acrisols and Nitosols of low inherent fertility on upslope areas and vertisols in lower plain of the Sudan. In this system, there are segments of sedentary small holder farmers and shifting cultivators and semi-mechanised rainfed farming. The major crops produced in this farming system are sorghum, maize and millet. Sorghum becomes dominant with decreasing rain fall (e.g. in Sudan). In some areas sesame, groundnut, cotton and ginger are produced as cash crops. The topography is almost flat in most parts with very few areas of sloping and undulating land. Compared to other upstream areas, the population in this farming system is sparse (0-10 person km^{-2}) and problems of soil erosion are not apparent (MoWR 1998).

Owing to poor land and crop management, the yield in this system is low compared to the national average, and as a result there is scope for improvement in green water productivity. Slash and burn is the major land management practice for small holders in this system (sorghum and shifting cultivation in Ethiopia by the Berta, Komo and Mao people south of the Abay River), and plowing is limited to recently settled highlanders in the Ethiopian part. Most often plots are cultivated for one or two years and then farmers move to new plots. This could be accounted for by soil fertility depletion (as the results of minimum fertilizer inputs).

Semi-mechanization of the crop land management is reported in this system (e.g. in the Sudan part). It was developed under the auspices of the government of Sudan as a mechanized crop production schemes in 1945. Land is leased by the State to individual investors, whereby each individual is allotted “a farm”. These schemes are managed by both private and government sectors. Within the Abay-Blue Nile basin in Sudan, there are approximately 73.13 million ha of large to medium-scale semi-mechanized farms (ENTRO, 2006).

There is also traditional rainfed cultivation (~ 474,282 ha) in this part of the Sudan. The main difference between the mechanized and traditional cultivation systems is the scale of operation and the use of modern agricultural machineries. Additionally, the traditional cultivation uses simple tools, depends on family labor and is generally limited to subsistence production. In the traditional rainfed farming land holding ranges between 4 and 6 ha (ENTRO, 2006) which likely reflects the poor workability of clay soil and the need for more labor inputs. Better off families hire labor and/or tractors to cultivate more land area. Mechanized cultivation, on the other hand, creates large farms, usually between 400 and 600 ha. Sorghum yields in the traditional crop sector have declined in both systems, and are currently at about 0.4 tons/ha, down from about 0.9 tons/ha in the 1970's. This can be accounted for by low inputs, soil fertility depletion and shortening of fallow periods. In general this suggests low crop water productivity and unsustainable land and water management.

Sometimes, rotation of sorghum, sesame and fallow with or without cotton are practiced, but often a piece of land is cropped with sorghum until the land loses its fertility and then is abandoned completely. In the semi-mechanization segment of Maize-sorghum complex, it is not the whole farm operations that are mechanized. Activities like harvesting of some crops are managed manually. Flat landscapes, a lack of drainage lines over extensive areas and the dominance of vertisols characterize this system. The rainfall ranges between 500-750 mm yr^{-1} and this is the only rainfed based crop production in the downstream areas of the Blue Nile. In contrast to upstream areas in Ethiopia practicing small grain cereals farming systems, erosion and high population pressures are not reported in this system.

Like farmers in the teff and barley-wheat systems, farmers in maize-sorghum complex, are also dependent on rainfed farming. While there is significant irrigable land in these areas, irrigation is limited and small-scale (particularly in Ethiopia). In addition, no significant efforts have been made to enhance farmers' capacity to increase green water productivity (e.g., soil moisture conservation and increased crop productivity).

Despite surplus feed in major parts of this system, livestock are less integrated into this crop production system (MoA, 2002). This could be accounted for the low intensity of the production system and also the prevalence of tsetse fly in the region (e.g., valleys of Didesa (Bourn, 2002)). Other production limitations include the inaccessibility of the area and low farmers' know-how. However, in response to the rapid population growth and settlement (from small grain cereals-based farming), in the Ethiopian parts, this system is evolving into a mixed crop livestock system (MoWR, 1998). For example a number of settlers have started using oxen for draft power and producing livestock as part of their livelihood strategies. Some mechanized rainfed farming is also emerging.

2.2.2. Maize-based perennial crops

This system is entirely located in the Ethiopian highlands and encompasses diverse cropping patterns that can be categorized with major variants: maize-wheat; sorghum-teff-maize; maize-enset and maize-teff-coffee (ENTRO, 2006; Bourn, 2002, MoWR 1998).

In general, the maize-sorghum-based perennial system is characterized by perennial crops such as coffee, enset[4], khat and some fruit trees. Coffee and khat are major cash crops, while maize/sorghum/enset are the staple foods in this system. Cultivation of root and tuber crops is also frequently reported (Bourn, 2002). Considerable variation is seen in the relative importance of enset as a staple food compared to other tubers and root crops and cereals (Bourn, 2002). In some parts of the basin (e.g., the Jima zone) enset is virtually the only food crop, while in other parts (e.g., Illubabor, West Shewa and West Wellega and the upper Dhidessa valley) enset is only a minor source and cereals are the major food source. This system is known for high calorie production per unit area.

[4] Enset (*Ensete ventricosum*), sometimes referred to a 'false banana, is a long-leaved, banana like perennial plant used for food, fodder and fiber in parts of Central Highlands and major parts of southern Ethiopia.

The growing period is the longest in this part of the basin and it ranges from 240 to 365 days. Rainfall in this area is also reported to be the highest in Ethiopia (2200 mm yr^{-1}). Like elsewhere in upstream areas of the basin, this system is rainfed and therefore green water management is important for livelihood improvements.

As suggested by MoWR (1998), about 13 semi-mechanized and state-owned rainfed farms are registered in this farming system. Those farms were first established to takeover the large private commercial farms expropriated at the time of land reform in 1975. The total area covered with annual crops and perennials was 36,754 ha (in 1995) and the major focuses were food crops such as maize. Given its potential, this level of investment was arguably too small. In these upstream areas, the majorities of farmers are smallholders and are still dependent on age-old traditional plowing methods. This is likely a consequence of factors such as the dominant landscape, population pressures, land fragmentation and the fact that commodities, rather than cash crops, are produced.

Following changes in the Ethiopian government and policies after 1991, there was growing interest in investment in mechanized rainfed agriculture, but the priority remained food crop cultivation. As a result, water productivity in financial terms has remained very low. Investment in large and medium-scale mechanized irrigation farming is also quite limited, with the sole example being the Fincha sugar plantation.

Although livestock is typically integrated into crop production in this system, hoe culture is reported in some areas of this farming system, mainly the enset and other root crop cultivation. It is also practiced in khat and coffee cultures when intercropping is required. Tsetse fly is a challenge for the livestock sector (Bourn, 2002).

Though localized erosion problems are reported, compared to the small grain cereals systems, the problem is less severe (Table 3.1). This system is found primarily in high forested areas in the country and is sparsely populated compared to the small grain cereals systems. Under such perennial-annual integrated systems, a positive soil nutrient balance is reported (e.g. Haileslassie et al., 2005 (Figure 3.2.). However in addition to low coffee yields (0.53 Mg ha^{-1} where research recommends 0.6-2.3 Mg ha^{-1} yr^{-1}), coffee berry disease, poor management and fluctuations in the international markets are major production constraints. Seasonal labor shortages during the coffee harvest are also frequently reported. Thus farmers usually hire casual labor, mostly landless farmers and farmers who move from the other areas (e.g., small grain cereals system) for this purpose.

2.2.3. Irrigated sorghum farming in the Sudan

In contrast to upstream areas, irrigation in downstream areas, in the Sudan, is an important component of the agricultural sector. Irrigation contributes more than 50% of the total value of agricultural production and provides employment for more than 80% of the population (FAO, 2000). As these schemes are distributed across the downstream regions of the Blue Nile and its tributaries, they can be designated as a farming system. In this system, in addition to sorghum (the major crop) and wheat, cash crops such as cotton and ground nut are produced. Annually there are sizeable volumes of those commodities for domestic consumption and export. Poor crop performance, and by implication low physical water productivity (kg of yield m^{-3}), characterizes this system and therefore all schemes have been subsidized by the federal government in Sudan.

Several studies reported that irrigation canals and reservoirs in these systems are major sinks of sediments that have been moved from upstream areas in Ethiopia where small grain cereals-based mixed farming is practiced. These irrigation systems are therefore highly capital-intensive, requiring regular maintenance and desiltation. According to ENTRO (2006), the social and economic infrastructure associated with these large-scale irrigation schemes has accentuated the substantial geographical disparities associated with the unequal natural resource endowment among states. Gezira State alone produces more than 50 percent of irrigated agricultural output, including 90% of the nation's cotton and almost half of its wheat.

2.2.4. Irrigated vegetables and cash crops farming in Ethiopia

Irrigated farming has a long history in Ethiopia and is usually operated at a small-scale. Small-scale irrigation of fruits and vegetables (onion, potato, garlic, carrot cabbage) invariably complements the livelihoods of rainfed smallholders, by providing households with cash income. According to MoWR (1998), small-scale irrigation is integrated into most farming systems (e.g. small grain cereals-based mixed farming systems) and is not considered an independent system. Despite the huge areas of potential irrigable land in the Ethiopian part of the Blue Nile basin (~600,000 ha), neither medium nor large-scale irrigated farms are widely seen.

In 1998, 9,300 ha of medium-scale irrigation developments and 31,480 ha of small-scale traditional diversions were reported in Ethiopia. Today these figures could be higher as a result of IFAD supported efforts to improve traditional irrigation in Ethiopia (IFAD, 2006), and current efforts by the Government of Ethiopia (GoE) and NGOs supporting the development of small-scale irrigation. There are also a few medium and large-scale irrigation schemes under construction (e.g., Koga) and under study (e.g., Rib and Gumera). IFAD (2006) reported that the productivity of irrigated crops in Ethiopia is below both potential and global averages, despite the important role it plays in improving the livelihoods of farmers (Table 3.3). This low productivity is mainly associated with shortages of vegetable seed, market/infrastructure and farmers' know-how. Like rainfed farmers, irrigated farmers are reluctant to apply agricultural inputs such as fertilizer and pesticides. This is associated with farmers low investment capacity and risks mitigation strategies. The repercussion is low water productivity and water shortages. This in turn leads to local and potentially international conflict (IFAD, 2002).

2.3. Pastoralist and agro-pastoralist in the Sudan

As suggested in ENTRO (2006) a substantial proportion of population in the Blue Nile live and work on the large irrigation schemes and semi-mechanized farms. In the past many of them followed pastoralist and agro-pastoralist livelihoods, but for one reason or other lost their livestock and became sedentarized. Despite changes related to frequent drought and expansion of large scale farms, many people retained their original way of life. For example the Rufa'a al-Hoi is an Arab speaking Muslim nomadic people with sheep, cattle and camels. Following loses of many of their animals due to the 1984 drought; increasing number of sedenterization of Rufa'a al-Hoi people is reported. Deteriorating the power of the Rufa'a al-Hoi through introduction of the federal structure has also significantly contributed to this transition of the system. A study suggests also occasional conflict between different pastoralist groups. For example Kenana (are also Arab speaking pastoralists) usually comes into conflict with the northern Badiya group of Rufa'a el-Hoi along the Blue Nile. Major problems in those pastoral areas are lack of drinking water supply for livestock. It is also noted that in such system water supply and feed availability are not synchronized and thus lead to either overgrazing (in available drinking water areas) or under utilization of animal feed (in areas where there is no drinking water. Problems related to erosion are not frequently reported.

3. Environmental Indicators and Prospect for PES

Evaluation of environmental degradation and sustainability is complex because it can not be measured directly. Several approaches have been proposed (e.g. to use indicators) to evaluate sustainability. Apart from crop productivity, soil quality, nutrient balance and water productivity has been used as one of the important indicators of sustainability (e.g. Nambiar et al., 2001; Bell and Morse, 1999). In the following sections we will present cases studies related to those indicators in the basin or similar agro ecosystem and discuss implications for the different farming systems in the Blue Nile basin.

3.1. Environmental Indicators

3.1.1. Erosion and sedimentation: implications for upstream downstream linkages

Erosion is one of the most important and indicator of land degradation process. The most widely applied erosion estimation approaches involves different land management parameters. For example USLE estimates the annual soil losses as a function of rainfall erosivity (R), soil erodability (K), slope gradient (S), slope length (L), vegetative cover (C) and land management (P). Those parameters (e.g. land management and land cover) associated strongly with the kind of farming systems. Slope classes and soil erodability factors are also a function of farming systems. For example in the cereals based farming systems, there is a continuous cultivation and repeated cultivation practices to prepared fine seedbed. This enhance soil aeration and as the result oxidation and decomposition of organic matter and strong stronger erodability factor.

In the Blue Nile basin, there are no farming system specific erosion studies. But from number of basin-wide studies the magnitude erosion across the different production systems is summarized in Table 3.1.

From Table 3.1, it can be realized that the barley-wheat systems is under very strong erosion process. Highest frequencies of grid cells with strong magnitude of erosion are observed in this system. Most erosion estimation model lacks mechanisms to estimate the sediment redistribution. Therefore the amount of sediment that temporally deposited within the system and this systems contribution of sediment to the downstream region could not be estimated. In terms of the magnitude Haileslassie et al., (2006) reported similar severity of erosion in wheat barley systems of the Gumera watershed (Blue Nile basin). According to ENTRO (2006); and Tafesse (2006) steep slopes around Mount Choke in East and West Gojam, the steep cultivated slopes around Mounts Guna (South Gonder) and Molle (South Wello) stand out as a significant area with a high erosion hazard. All those sites are either fully within the wheat-barley or in the transition zone to teff based cereal systems.

As suggested in ENTRO (2006) another more restricted area is found in the upper Jema sub-basin in South Wello on the high hills north and west of Debre Birhan. Though situation is aggravated by the type of farming systems, the landscape and the rainfall patterns are reported to be the major drivers.

An equally important farming system, in terms of erosion and arguably sediment sources, is the teff based cereal farming system. This can be accounted to the fine seed preparation required by teff and also the late coverage of the land with vegetation. This system is characterized by major part of it having erosion rates ranging between 0-50 tha^{-1} yr^{-1}. ENTRO (2006), identified north and east of the Abay River in the Lake Tana Basin as the important areas in terms of important hot spot areas.

It is widely recognized that maize –sorghum- perennial systems also contribute to the overall sediment sources in the Blue Nile: but with lesser magnitude compared to the small cereals system. Particularly the erosion areas with magnitude ranging between 12 and 1000 t ha^{-1} yr^{-1} are only few. The highest magnitude of erosion (50-100 t ha-1 yr-1) is located mainly south of the Abay and encompasses the upper and middle steep and cultivated slopes of the Middle Abay Gorge Sub-basin in East Wellega. According to ENTRO (2006) there are two subsidiary areas with a high erosion hazard can be seen in the Upper Didessa Valley.

In terms of distribution, across the different land use land cover within a system, it is frequently indicated that cultivated land contributes about 46% of over all sediment. The differences are claimed to come from the non cultivated lands mainly communal grazing lands. This has strong policy implication in terms of equity and trends of management of this land use type. The major point to be underlined is the tendency of tolerable soil loss rates (< 12.5.t ha^{-1} yr^{-1}) in the wheat-barley and parts of the teff based cereal systems.

Table 3.1. Frequencies of grid cells with different magnitude of erosion across different farming systems (loss exceeds soil formation or 12.5 tons/ha/yr are unsustainable Haileslassie et al., 2005; ENTRO, 2006)

Major farming systems	Magnitude of erosion (t ha^{-1} yr^{-1}) and respective frequencies of grid cells [5]						
	0	0-6.5	6.5-12.5	12.5-25	25-50	50-100	>100
Wheat-barley	few	few	frequent	V. frequent	V. frequent	V. frequent	few
Teff-based cereals	V. frequent	V. frequent	V. frequent	frequent	frequent	few	few
Maize-sorghum	V. frequent	V. frequent	few	few	few	few	none
Maize perennials	V. frequent	frequent	frequent	few	few	few	none
Pastoral	V. frequent	none	none	none	none	none	none

According to ENTRO (2006), the most important off-site negative impacts of soil erosion are sedimentation of streams and water storage infrastructures. In contrast to the generalized notion of the Ethiopian highlands as a source, and the downstream areas (e.g. Sudan plains) as a sink for sediment, localized sediment redistribution within and between different systems are reported (Haileslassie, 2006). For example sediment flux to Lake Tana, which is located in a teff-based cereals farming system, has been estimated to be 10x106 m^3 yr^{-1}. Assuming a trap efficiency of 50%, the Lake will lose 6% of its effective storage within 100 years (MoWR, 1998). Recent studies by SMEC (2007) give a higher estimate on the amount of sediment load into Lake Tana: the total annual sediment load from the upper catchments is estimated at 9.61 million tons yr^{-1}. The average annual outflow from Lake Tana (at Bahr Dar) carries an

[5] Frequency classes are > 100 grid cells as very frequent; 50-100 grid cells are frequent 0-50 grid cells are few and 0 none

average annual sediment load of 1.04 million tons yr^{-1}. This mean 8.57 million tons of sediment will settle annually in the Lake and wetlands.

High sediment loads in streams pollute water supplies, and cause siltation of dams, reservoirs, water-harvesting structures and irrigation canals, reducing their effective capacities, shortening their service lives, and incurring high maintenance cost, at national, community and individual levels. As suggested in ENTRO (2006) the two main dams in the Blue Nile Basin are Roseires completed in 1966 with a storage capacity of 2.4 km^3 and the Sennar completed in 1925. Currently both infrastructures are affected by siltation. A loss as high as 38.3 % of the designed capacity of the reservoirs is frequently reported. In addition to the reduced volume of water for irrigation, impacts are observed on hydropower generation, damage to turbine blades. The same sources further elaborates in 1991 some 9.78 million m^3 of silt entered the irrigation canal system of which 62% is deposited in the canals with the remainder being deposited in the fields. Desilting of the 17,244 kms of irrigation and 10,650 kms of drainage canals in the Gezira scheme alone is an enormous and expensive operation.

3.1. 2. Water productivity in the view of scarce water in the Blue Nile Basin

It is regularly reported that the water conflict in the Nile Basin is much related to the allocation of water quantity between the various countries. With a limited amount of river water and increased demand due to population growth, one can hypothesize that water shortage and as the resulting tensions over water allocation will increase in the future (Mason, 2003). One of the most frequently suggested options is the enhancing agricultural water productivity.

In general, productivity can be estimated as the ratio of the outputs of an economic unit and the inputs (Renault and Wallender, 2000). Customarily, crop water productivity is based on the ratio of mass produced (actual yield) to water consumed (evapotranspiration (Kijine et al., 2003). The more comprehensive approach to water productivity is application of economical values (Molden et al., 1998). Livestock water productivity is a new concept but theoretically follow similar approaches. There is no basin wide or farming system wide water productivity estimation for the Blue Nile. In the following paragraphs, we will present case studies in Gumera watershed (Blue Nile basin) and discuss basin wide implications.

In view of the above discussed water productivity estimation approaches, the interpretation of the relation between dry matter production and evapotranspiration is difficult since only above ground dry matter is usually measured and do not consider the root biomass. Many experiments, including the case study we presented here, are concerned with the economic dry matter production only (e.g. seed, tuber, fruit and etc...); therefore, the paritioning between economic yield and total dry matter yield is not often reported (Andrea 1999).

With this context, globally, there is significant variability in the amount of water required to produce dry matter of different crops. Results of the case study presented here are within the global ranges (Hoekstra et al., 2002, (Table 3.2.). At the basin scale, the crop water productivity values for the case study site are in lower range of the reported values. For example in Gezira, in Sudan, the productivity of sorghum ranged between 0.15 and 0.41 kg m^{-3}, wheat water productivity between 0.07 and 0.27 kg m^{-3} (irrigation). This indicates the current low level of yield and water management practices and the potential to improve this. Haileslassie (2007 unpublished), suggested that relation between livestock and crop water product is an indication of farmers' livelihoods strategies (Table 3.3.).

Table 3.2 Crop water productivity under different land use in Gumera watershed for selected crops and feeds

Farming systems	Crop groups	Area (ha)	CWP* (kg m^{-3})	CWP (kg m^{-3}) **	CWP (kg m^{-3}) ***
	Rice	5378	0.6	0.7-1.1	
Rice-based cash crops	Teff	2201	0.2		
	Pulses	5300	0.6	0.5	
	Onion	67	1.5		
	Garlic	21	0.9		
	Grass and wetlands	6442	0.6		

Maize-small cereals	Sorghum	6587	0.3	0.6-1	0.3
	Millet	14169	0.5	0.2-0.7	0.2
	Teff	29400	0.4		
	Maize	15040	0.5	0.8-1.6	0.4
	Wheat	3184	0.2	0.8-1	0.2
	Potato	176	1.8		1.4
	Grass and wetlands	8312	0.7		
	Barley	2811	0.4		0.2
Cereal-pulses-potato	Wheat	787	0.2		
	Triticale	4667	0.4		
	Pulse	2138	0.2		0.1
	Potato	2811	1.5		
	Grass and wetlands	1579	0.6		

CWP is crop water productivity and area is only for grazing land and crop land, ***values are national average and modified from Hoekstra et al., 2002;** global values* values are our estimates.

Table 3.3 Livestock water productivity (LWP) and crop water productivity (CWP) for Gumera watershed (UDS m^{-3})

Farming systems	LWP	CWP*
Rice-based cash crops	0.08	0.41
Maize-small cereals	0.26	0.39
Cereal-pulses-potato	0.52	0.28
All farming systems	0.23	0.32

It is generally revealed that farmers' lack of capital (e.g., improved biomass yield, water harvesting and soil moisture conservation) some of the determinants of increasing water productivity. According to Haileselassie et al., (2007, unpublished) there is a very close and positive relation between water productivity and farm households' level of asset endowment and access, which suggests that poverty reduction, must be one of the major areas of intervention to enhance the water productivity of crop and livestock enterprises. Similarly, downstream in Sudan decisions to adopt sustainable land management technologies depend on households' asset endowments. This is particularly of relevance in areas of shifting cultivation and the need for labor for frequent clearing to access land of better fertility as well as for weeding (ENTRO 2006).

The overall trends of low water productivity in the Nile basin can be also realized from Table 3.3 as water productivity and yields positively correlates positively (Figure 3.1). But the yield values between the upstream and downstream counties should not be used as good indicator of better water productivities of the downstream regions as the two cropping systems are located in different region and enjoys different climatic parameters that affect the evapotranspiration and water productivity in general. But upstream and downstream region commonly share one important point of actions: they have the potential to improve the water productivity so as to reduce the mounting pressure of water shortages.

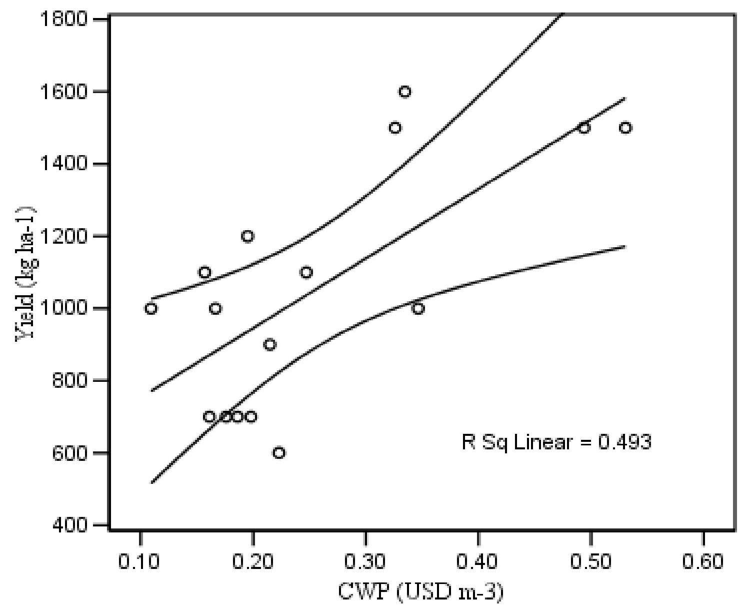


Figure 3.1. Relation between crop yield and water productivity (Blue Nile basin, Gumera watershed, Haileslassie et al., 2007, unpublished)

Table 3.3. Average yield (T/ha) and yield % of main crops in the Blue Nile and World average, 2005 (ENTRO 2006).

Crop type	Yield by crop type, counties and world		
	Sudan	Ethiopia	World
Wheat	2.6	1.37	2.91
Rice, Paddy	3.8	1.85	4.02
Barley		0.99	2.44
Maize	4.4	1.95	4.72
Sorghum	1.3	1.33	1.31
Potatoes		10.53	17.20
Sweet Potatoes		10.00	14.78
Cabbage		10.13	21.68
Tomatoes		12.5	27.47
Onions	17.4	12.9	23.14

Garlic	14.8	12.88

The question is what links water productivity and farming systems? A farming system is a complex interrelated matrix of soils, plants, animals, implementing labor and capital, interdependent farming enterprise. As indicated in the preceding section of this review, water productivity also involves those different elements of a farming system. This means interventions aimed at altering any of those system elements has linkage to the magnitude of water productivity. A good example is biomass productivity and dominant crop type. In case of considering the financial water productivity the market values of crop produced also matter s (e.g. cash crops like coffee). For example the market value of most vegetable is higher compared to the cereals. Therefore, farming systems focusing on vegetable production could have better water productivity.

This example could be applied to the concept of livestock water productivity. System that integrates crop and livestock production would be benefited from enhanced water productivity. Those systems are known for multiple uses of livestock (traction power, manure, meat, milk etc...) for the similar quantity of water inputs (water for feed production). In this perspective, it can be realized that those production systems, where livestock are fully integrated, have better water productivity than those system exclusively dependent on livestock or crop. In conclusion system scale water productivity could give better picture of water productivity and pertinent sustainability of a particular system than single enterprises water productivity values.

3.1.3. Nutrient balances

Nutrient cycling in all terrestrial ecosystems, whether they are natural (forests, rangelands, grasslands) or managed (agroecosystems, pastures, plantations), follows similar pathways. However the size of nutrient pools, fluxes and transformations in these systems may vary by several orders of magnitude (Hornung, 1990). The question, whether nutrient inputs and outputs are balanced or not, is closely related to the issue of sustainability (Smaling et al., 1996). In natural ecosystems, processes that govern nutrient cycling like primary production, uptake and decomposition tend to be balanced. However, when ecosystems are managed, and food production is one of the major objectives, nutrient transfers are influenced not only by the conditions and process within the system, but also by circumstances and controlling forces outside the system (i.e. anthropogenic effects). As a result, unequal transfers between nutrient pools may cause the system to accumulate or deplete nutrients.

In these section case studies of nutrient balances in Ethiopia showing how different cropping systems affect the magnitude of balance will be indicated and implications for different farming systems in the Blue Nile basin discussed.

In the full balances calculation, full ranges of inputs (mineral fertilizer; atmospheric deposition; organic inputs, nitrogen fixation, sedimentation, irrigation) and outputs (harvested products; resides removed, leaching loss, gaseous loss and erosion) are considered. Large differences occurred between crops grown on field plots and crops grown on homestead plots. Permanent and vegetable crops had positive balances while all other cropping systems had strong negative full balances. Erosion was one of the major outflows that affect the positive partial balances mentioned in this study (Figure 3.2.).

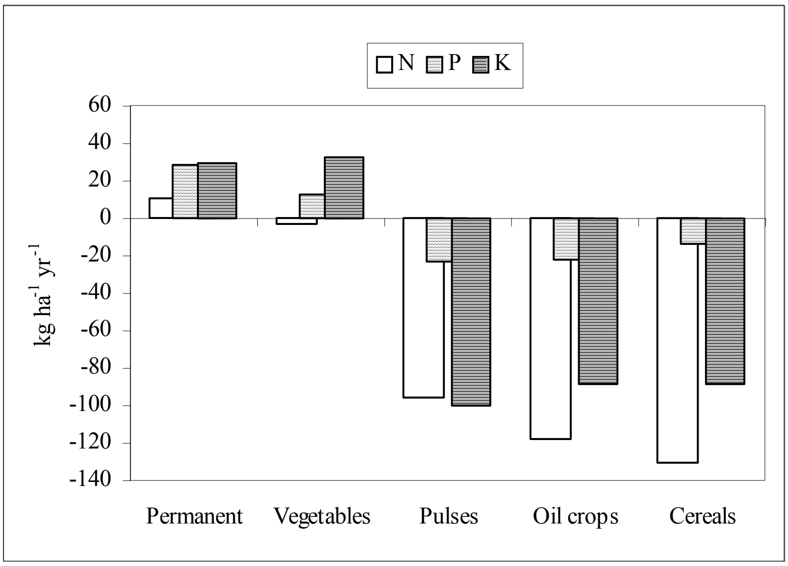


Figure 3.2. Full nutrient balances in Ethiopian smallholders' mixed farming by cropping systems (production year 1999/ 2000)

As permanent crops can cover the soil and intercept falling raindrops at and close to the surface, this cropping system is less susceptible to erosion losses. Hence permanent crops had positive full balance (Figure 3.2). Similar trends of nutrient depletion in field and homestead plots have been reported for the Southern Ethiopian Highlands (Tilahun *et al.,* 2001; Elias *et al.,* 1998). This is closely related with the erosion assessment in the previous section. This means also that the cereal production systems in the upland Ethiopia suffered not only from erosion but also the nutrient stock mining. In terms of nutrient depletion determinant studies by the same author, on Ethiopia highlands, suggested a contrasting differences of nutrient depletion determinant between crops on fields (cereals, pulses and oil seeds) and on homesteads (vegetable and permanent) (Table 3.4.). Under the permanent and vegetable cropping systems, nutrient losses were caused mainly by leaching, denitrification and the removal of harvested products. Erosion played a more prominent role under annuals as compared to permanent crops (Table 3.4.). Here it worth mentioning that such nutrient mining, on major farm lands (i.e. cereals), can ultimately drive land use changes and therefore contributes to erosion and downstream sedimentation.

Table 3.4. Determinants of nutrients depletion under different cropping systems in Ethiopian smallholders' mixed farming systems (% share in depletion)

Crop groups	Harvested products			Residues removal			Leaching		Denitrification	Erosion		
	N	P	K	N	P	K	N	K	N	N	P	K
Cereals	10.0	19.4	6.0	4.0	5.0	11.0	9.0	17.0	3.0	74.0	80.0	66.0
Pulses	14.0	16.8	13.0	4.0	3.0	8.0	8.0	17.0	2.0	72.0	84.0	62.0
Oil seeds	1.0	1.0	2.0	1.0	4.0	5.0	8.0	20.0	2.0	88.0	96.0	73.0
Vegetable	21.0	30.4	25.0	19.0	31.0	34.0	22.0	22.0	12.0	24.0	44.0	19.0
Permanent	16.0	24.9	14.0	40.0	67.0	70.0	27.0	13.0	14.0	3.0	10.0	2.0

3.1.4. Level of poverty and vulnerability to ecosystem's services disruption

According to MoFED (2002), the proportion of the population below the poverty line in Ethiopia is 44%. This value is high compared to the Africa standard (FAO, 2000). Basin farming system data indicating the level of poverty are scarce. But estimates for the regional states (in the basin) are fairly comparable with this national trend although of lesser magnitude (ENTRO, 2006). For example, using a basket of food items sufficient to provide 2,200 kcals adult^{-1} day^{-1} and considering a non-food component, the poverty line represents ETB 1,070 (according to 1995/96 prices). Accordingly, 55% the population in the Benishangul Gumz region (i.e. maize-sorghum complex of the western lowlands) live below poverty line. Oromiya (38%) and Amhara (32%) regional states have a lower share of population living below poverty line. According to ENTRO (2006), for the last 10 years the proportion of the rural population living below the poverty line has dropped, while that of the urban population has increased steadily (in Ethiopia).

For the downstream areas (in Sudan) directly comparable poverty line data are lacking. As reported in ENTRO (2006), the percentage of population below the poverty line is higher than in Ethiopia. For example in Gederafi state a range of 41-60% is reported. The difference in proportion of the population living with poverty across upstream and downstream regions of the basin could, however, be ascribed to the methods used in determining the poverty line. The trend across farming system may vary but could be by low magnitude of order as agriculture is the major livelihood strategies in all cases.

The question is: how does this poverty level relate to communities' capacity to invest in ecosystems conservation and management, to what degree is the community vulnerable to the disruption of water delivery and water-related ecosystem supporting (e.g.

purification of water) services, and how significantly will disruptions in upstream areas affect the downstream areas.

According to Brady and Weil (2002), ecosystem services (preserving services, cultural, supporting, regulating and provision*)* are fundamental to life. Nevertheless, there is real evidence suggesting that those services are severely threatened in the Blue Nile basin. The major drivers are growth in the scale of human enterprise and a mismatch between short-term needs and long-term societal well-being (FAO, 2000). The effects are already sensed in different farming systems of the Blue Nile basin in general. For example, the regulation services of the ecosystem (in terms of soil erosion) are disrupted and hence in addition to the common water resources, the Blue Nile basin countries are linked by the problems of soil erosion in upstream areas and sedimentation in downstream areas (Mason, 2003).

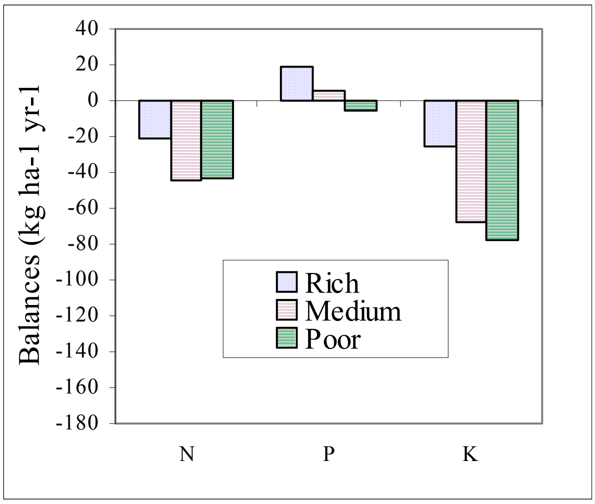
Both erosion and localized sedimentation are a major threat in upstream areas (Ethiopia), whilst sedimentation is a major challenge in downstream areas (e.g. Sudan). Both on site and off site impacts of erosion are widely recognized. On-site there is serious nutrient depletion, and farmers have very low capacity to replenish the lost nutrients using fertilizers. For example, the application of 16-28 kg of fertilizer ha^{-1} yr^{-1} that is currently applied in upstream areas does not match with the magnitude of nutrients depleted under cereals. This is accounted for the capacity of farmers to invest in fertilizer (e.g. Figure 4.1 and 4.2)

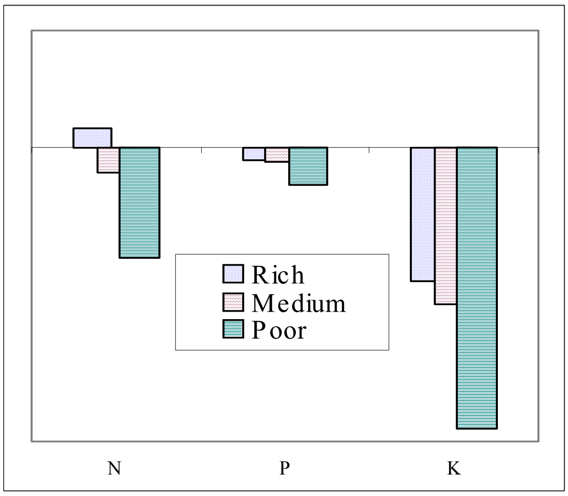
Yield loss and low productivity of grain and animal feed and are all observed results of erosion. For example, Sertsu (1999) estimated a yield loss of wheat equivalent to 46 US$ ha^{-1} yr^{-1} (in areas of low soil loss) and 544 US$ ha^{-1} yr^{-1} in areas of high soil loss. At national scale (in 1994) a loss of US$106 million or about 3% of agricultural GDP was estimated. In the Amhara region the annual reduction in grain production, as the results of soil losses on cultivated land for the year 2007, was estimated at 100 thousand tonnes of grain (BoFED, 2006). Soil erosion has strong implications not only to the above mentioned provision of ecosystem services (e.g., food, fiber, fuel), but also on the status of green water productivity in upstream areas in general.

The challenge is farmers' low capacity to replenish those losses and in turn to diminish their vulnerability to the impacts. Haileslassie et al. (2007) also reported such chains of poverty, land degradation, low investment in natural resources and vulnerability to these effects. According to those authors, soil nutrients depletion and farmers' activities to replenish the lost nutrients are strongly related to the degree of the farmers' resource endowments (i.e., level of poverty (Figure 4.1 and 4.2.). A similar trend was reported for livestock water productivity across farm households of different wealth group (Table 4.1)

Table 4.1. Livestock Water Productivity across farm households of different wealth classes in Blue Nile basin

Water productivity (UD$/m3)	Economic status	N	Mean	Std. Error
Crop water productivity	Rich	34	0.51a	0.05
	Medium	62	0.40b	0.02
	Poor	75	0.34c	0.01
	Total	171	0.38	0.01
Livestock water productivity	Rich	34	1.04a	0.13
	Medium	62	0.98a	0.05
	Poor	75	0.81b	0.04
	Total	171	0.89	0.03

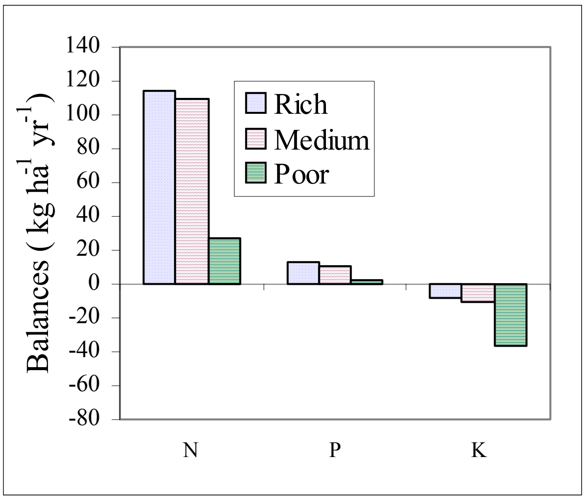


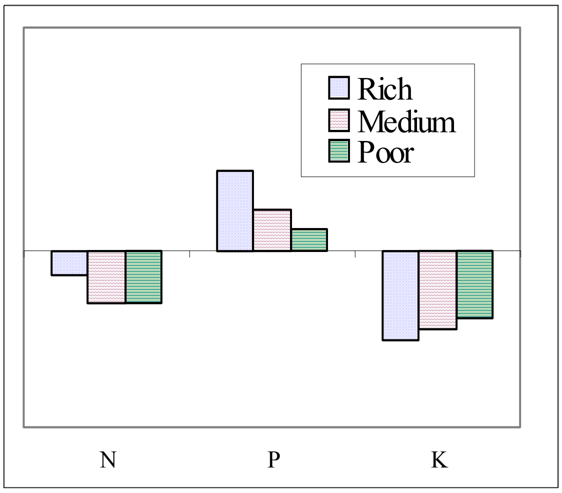


b)

a)

Figure 4.1. Full nutrient balances on teff (a) and maize (b) fields of case study farms under different wealth groups (Haileslassie 2005)





a) b)

Figure 4.2. Full nutrient balances on enset (a) and barley (b) fields of case study farms under different wealth groups (Haileslassie 2005)

3.2. Prospects of payment for environmental services (PES)

Environmental conservation is pursued as an investment to create the necessary conditions for sustainable development. Payments for Environmental Services (PES) are component of a new and more direct conservation paradigm and an emerging concept to finance conservation programs by fostering dialogue between upstream and downstream land users. Those kinds of approach are, particularly, useful if applied in basins where irrigation schemes are emerging and the service life of reservoir and irrigation canals, in downstream areas, are threatened by the sediments moved from upstream region. In the following section we report the result of research results undertaken on the determinants of willingness to pay (WTP) by the down stream water users and willingness to accept (WTA) by upstream water users for improved watershed conservation practice in the Blue Nile basin (Gumera and Koga watersheds, Ethiopia)

3.2.1 Households' willingness to pay

As part of this study, households' WTP in cash or spent time for improved land and water management practices was evaluated. Of all sample farm households 64.92 % showed willingness to pay to pay in cash. The remaining 35.08% were not willing to pay in cash. For similar observation in upstream and downstream strata, our result revealed that 66.67% of the upstream and 53.08% of the downstream sample farm households WTP money for improved land and water management activities. Bane (2006) reported similar results on his study of valuating domestic uses of irrigation water in upper Blue Nile basin. Farmers' WTP in labor, for improved land and water management, showed stronger magnitude (97.23% of the total sample farm households). Our result was in good agreement with Asrat (2002) who reported farmers' perception on soil conservation and their willingness to pay more in labor than in cash. Our result also showed a significantly higher Mean Willingness to Pay (MWTP) by upstream users. MWTP in cash was 1.08 and 1.36 USD/month for up stream and downstream farmers respectively. While MWTP in labor was 3.3 and 3.9 person days/month for upstream and downstream farmers respectively. Perhaps most interesting point will be comparing the investment cost for land reclamation and those MWTP. In connection with this, MoWR (2002) reported an estimated watershed management cost of 760 USD/ha (for implementation and maintenance). On basis of the current mean land holding, a farm household may require about 1365 USD to implement improved land and water management on his plots. As the values of MWTP can not cover this cost, a coordinated effort by all stakeholders (government, upstream and downstream community) must be a strategy.

It is very clear that those farmers enthusiasm, to invest in land and water conservation for sustainable water use and ecosystem services, emanates mainly form maintenance of soil fertility in upstream areas (upstream farmers) and mitigation of siltation (downstream). Grasping those interests and implementation at watershed and basin scale would be a good scene in efforts toward attaining sustainable land and water management in the Blue Nile basin. Perhaps, most relevant points of discussion can be: why not all farmers were willing to pay and what were the limitation to implement this before? How strong is mean values of WTP compared to the total cost required to undertake conservation?

3.2.2. Determinants of farmers' willingness to pay in cash

In this section, selected explanatory variables were used in the interval regression model to analyze determinants of farmers' WTP for land and water management. A total of 23 explanatory variables (14 continuous and 9 dummy) were included in the model. Only significantly related variables are presented in Table 1. The maximum likelihood estimate of the interval regression model shows 15 explanatory variables to significantly determine farmers' WTP. Though 8 explanatory variables were not significant in explaining farmers' WTP, clear trend of relation between the dependent and independent variables could be traced.

Table 1: Estimate of the interval regression model

Explanatory Variables	Downstream users			Upstream users			All samples		
	Coeff.	SD.E	P>z	Coeff.	SD.E	P>z	Coeff.	SD.E	P>z
Educational level	-1.87	4.67	0.69	-11.24	3.79	0.00***	-6.29	2.91	0.03**
Age of the household head	-0.45	0.19	0.02**	-0.19	0.15	0.22	-0.33	0.12	0.01**
Start Bid ~y	0.60	0.17	0.00***	0.46	0.14	0.00***	0.55	0.11	0.00***
Financial and technical assistant	5.37	3.95	0.17	4.31	3.48	0.22	5.76	2.64	0.03**
Training	-3.99	3.95	0.31	6.81	3.78	0.07*	1.78	2.72	0.51
Own cultivated land	-0.26	0.42	0.54	0.35	0.18	0.06*	0.17	0.17	0.33
Access to credit	1.98	4.11	0.63	5.31	3.69	0.15	4.73	2.65	0.08*
Number of trees owned	0.00	0.00	0.04**	0.00	0.00	0.86	0.00	0.00	0.03**
Distance to output market	-0.08	0.53	0.88	-0.42	0.49	0.38	-0.54	0.28	0.05**
Distance to nursery site	-0.18	0.78	0.82	-0.74	0.42	0.08*	-0.63	0.37	0.08*
Distance to agricultural office	-0.78	0.35	0.02**	-0.72	0.64	0.26	-0.77	0.29	0.01**
Livestock owned in TLU	0.67	0.58	0.24	1.22	0.45	0.01**	0.74	0.34	0.03**
Slope of the parcel	9.91	13.74	0.47	7.74	4.54	0.09*	10.44	4.29	0.02**
Adult male in the household	2.80	1.52	0.07*	-1.19	1.36	0.38	0.56	1.00	0.57
Adult females in the household	-1.20	1.82	0.51	-3.23	1.57	0.04**	-2.25	1.20	0.06*
Constant	7.88	18.13	0.66	12.25	12.64	0.33	12.01	9.65	0.21
Lnsigma	2.99	0.08	0.00***	2.90	0.09	0.00	2.99	0.06	0.00***
Sigma	19.79	1.64		18.18	1.59		19.89	1.19	

a) ***, ** and * indicate significant level at 1%, 5% and 10% respectively. b) All samples: Number of obs=325; LR chi2 (25) =103.70; Prob > chi2=0.0000; Log likelihood = - 409.16806; 135 left-censored observations; 1 uncensored observation; 0 right-censored observations; 189 interval observations. c) Upstream users: Number of obs=175; LR chi2 (23) =74.79; Prob > chi2=0; Log likelihood = -186.71088; 83 left-censored observations; 1 uncensored observation; 0 right-censored observations; 91 interval observations. d) Downstream users: Number of observation =150; LR chi2 (24) = 37.11; Prob > chi2=0.0317; Log likelihood = -212.27658; 52 left-censored observations; 0 uncensored observations; 0 right-censored observations; 98 interval observations.

Pender and Kerr (1996), reported that farmers' ability to acquire, process and use information could be increased by education. According to those authors, education reflects acquired knowledge of environmental amenities. This was in good agreement with our results and suggests that keeping the influences of other factors constant, every extra year of schooling increase in the predicted farmers' WTP in cash by 6.29 (Table 1). From the model results it was also evident that farmers' economic status determines WTP. This was clearly explained by the positive and significant relation between livestock, size of arable land and number of tree owned by the sample farm households and their WTP (Table 1). In line with this, Peden et al. (2007) indicated that more livestock and arable land ownership is considered as more asset possession. Those in turn lead to farmers' investment decisions. It is also clear that when farmers own large livestock population, they need to have land and water available at their vicinity to provide their livestock population with feeding and drinking water. The size of cultivated land is often associated with a means that might help ease the needed liquidity constraint. From field observation and discussion held with farmers, we also realized that Eucalyptus tree is a major means of income for farmers in the two watersheds. This can explain the reason why farmers with more number of trees were willing to pay. With the assumption of ceteris paribus, the probability of being willingness increases by 0.74, 0.35 and 4.73 for livestock ownership, land ownership and access to credit service increased by 1 unit respectively. In addition to the household economic status, the model showed access to information, financial and technical assistance as strong explanatory variable for farmers WTP. For example explanatory variable like distance to the offices of agriculture showed significant and negative relation with WTP. This means as the time a household needs to walk to get the agricultural office increases their WTP decrease as farmers would have less access to information and awareness. From the model we realized that, keeping the influences of other factors constant, farmers' willingness to pay decrease by 0.77 as distance of office of agriculture increases by 1 kilometer. Stronger relation was observed for assistance to land and water management practices: the probability of farmers' willingness increase by 5.76 as assistance in land and water conservation practice increase by one unit, keeping other factors constant. Understanding and implementing policy instruments related to those explanatory variables is important to use PES as a tool for improved land and water management in the Blue Nile basin.

5. Key messages

In view of the current trends of production systems and related sustainability indicators used in this review the following preliminary conclusion can be drawn

- Barley-wheat and teff based cereal farming systems are the major sources of sediment in the Blue Nile basin. However the significance of their contribution to the downstream region needs further investigation as there is sediment redistribution within their systems;

- Though there can be niche level nutrient accumulation (e.g. homestead), barley-wheat and teff based cereal cropping have strong magnitude of nutrient depletion and thus their sustainability could be questioning;

- In addition to water bodies in the downstream region, localized sediment redistribution in wet lands and foot slope areas are major sinks of the sediment and thus local scale sediment sinks management should not be neglected ;

- Case studies show that both crop and livestock water productivity shows lower values. Given the current level of low livestock and crop productivity, there is a great potential to increase water productivity and mitigate the impacts of water shortage in the Blue Nile basin ;

- Farmers' investments on land and water management for sustainable ecosystem functioning are determined by their access to resources and thus farmers capacity building and focusing on technologies that could be afforded by the poor farm households should be one of the major strategies to internalize the land and water management externalities. In the view of initiating small farmers interest to invest in natural resources management and thereby reduce on- site and off-site effects of erosion and sedimentation mechanisms of payment for environmental services (PES) must be explored.

- Sharing the costs and benefits of environmental conservation, on an equitable basis among all stakeholders, improves the prospects of sustainable environmental management in the Blue Nile basin

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