to 5 metres. Kween, Kapchorwa and Sironko districts have steep slopes that go from Mt.Elgon down at around the road connecting Mbale and Moroto. The districts in the downstream stretch of the rivers are generally composed of continuous flat plains although standing gneisses do occur inform of out crops of rocks in some sub-counties. The most striking topographical feature is Mt. Elgon, with its magnificent craters, deep valleys and ridges. But most of the wetlands in the area lie in the flat land terrain with majority of seasonal wetlands.

### 2.1.3 Water Resources

**Surface water occurrence**

Elevation profiles of the Sironko and Sipi rivers are provided in the figures below. The rivers with headwaters in Mt.Elgon are characterized by steep slopes that go down from the mountainous area. Other rivers such as the Lochidimukat and the Apenduru have gentle slopes. The difference may have bearing in terms of incidence of soil erosion.

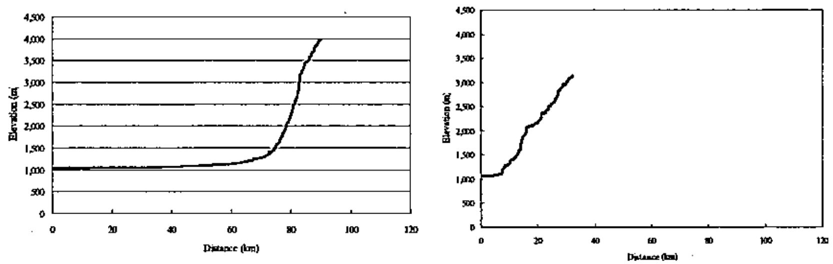



**Fig. R 2.1 Elevation profiles of the Sironko (Left) and Sipi (Right)**

### 2.1.4 Soil Resources

**Major soil class and management options**

The soil class of the wetland system is mainly composed of: 1) Gleysols 2) Vertisols and 3) Histosols. Gleysols are soils frequently developed under depression areas and low landscape positions with shallow groundwater, which therefore render it frequently to be used for wetland rice cultivation. Vertisols are known for its physical properties to exhibit shrinkage and swelling depending on availability of water. The soil class is also fertile in terms of chemical aspects. Histosols composed of soils formed in organic material, frequently under papyrus vegetation. It is desirable to protect and conserve such fragile lands because of their intrinsic value (especially their common function as sponges in regulating stream flow and in supporting wetlands containing unique species of animals) and because prospects for their sustained agricultural use are limited.

The wetland users use wetland soil in combination with dry land soil. The soil class of dry land in the area is also summarised in the tables below. Some of the soil class are presented with formative elements for second-level units. Their definitions in non-technical manner are as follows:

| | |
|---|---|
| Skeletic: | having gravel or other coarse fragments averaged over a depth of 100 cm |
| Lixic: | having a clay horizon with limited soil fertility |
| Eutric : | having a fertile soil layers in the major part |
| Petric: | having a strongly cemented layer |
| Acric: | having a clay horizon with higher soil fertility |



**Table R 2.1 Major soil classes of wetlands in the wetland systems**

| Soil Class and Distribution | Description and Management Options |
|---|---|
| **GLEYSOLS**<br>Majority of riverine wetlands in most districts<br>More specifically Nakapiripirit, Katakwi, Bukedea and Kumi | Gleysols are wetland soils that, unless drained, are saturated with groundwater for long periods to develop a characteristic colour pattern.<br>Gleysols can be well used for wetland rice cultivation. Gleysols can also be put under tree crops only after the water table has been lowered with deep drainage ditches. Alternatively, the trees are planted on ridges that alternate with shallow depressions in which rice is grown. |
| **VERTISOLS**<br>Bukedea, Bulumbuli, Katakwi and Nakapiripirit | Vertisols are churning, heavy clay soils with a high proportion of swelling clays.<br>The soils have considerable agricultural potential, but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence on extensive level plains where reclamation and mechanical cultivation can be envisaged are assets of Vertisols. Their physical soil characteristics and their difficult water management cause problems. Buildings and other structures on Vertisols are at risk, and engineers have to take special precautions to avoid damage due to swelling and shrinkage of the soil. |
| **HISTOSOLS**<br>Bukedea, Kumi, Katakwi and Nakapiritpirit, particuraly around Lake Opeta | Histosols comprise soils formed in organic material found mainly under vegetation of papyrus, and reeds/sedge in the area.<br>In general it is desirable to protect and conserve the area wherever possible because of their intrinsic value (especially their common function as sponges in regulating stream flow and in supporting wetlands containing unique species of animals) and because prospects for their sustained agricultural use are meagre. |

Source: IUSS Working Group WRB. 2007. World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

**Table R 2.2 Major dry land soil class with potential**

| Soil Class | Description and Management Options |
|---|---|
| **NITISOLS**<br>Mountainous part in Sironko, Kapchorwa and Kween | Nitisols are deep, well-drained, red soils.<br>Nitisols are among the most productive soils of the humid tropics. The deep and porous nature and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion. The good workability of Nitisols, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favourably with those of most other tropical soils. Nitisols are suitable for plantation crops such as cocoa, coffee, rubber and pineapple, and are also widely used for food crop production on smallholdings. |
| **PLINTHOSOLS**<br>Mainly Kumi and Bukedea | Plinthosols is an Fe-rich (in some cases also Mn-rich), humus-poor mixture of kaolinitic clay.<br>Plinthosols present considerable management problems. Poor natural soil fertility caused by strong weathering, waterlogging in bottomlands and drought are serious limitations. Many Plinthosols outside of the wet tropics have shallow, continuous petroplinthite, which limits the rooting volume to the extent that arable farming is not possible; such land can at best be used for low-volume grazing. Soils with high contents of pisoliths are still planted to food crops and tree crops (e.g. cocoa in West Africa, and cashew in India) but the crops suffer from drought in the dry season. |
| **FERRALSOLS**<br>Ferralsols occur mainly in the north western part of Nakapiripirit in the wetland system. Other types of ferralsols occur in Kween, Nakapiripirit and Napak. | Ferralsols represent the classical, deeply weathered, red or yellow soils.<br>Most Ferralsols have good physical properties. Great soil depth, good permeability and stable microstructure make Ferralsols less susceptible to erosion than most other intensely weathered tropical soils. Moist Ferralsols are friable and easy to work. They are well drained but may in times be droughty because of their low available water storage capacity. The chemical fertility of Ferralsols is poor; weatherable minerals are scarce or absent, and cation retention by the mineral soil fraction is weak. Under natural vegetation, nutrient elements that are taken up by the roots are eventually returned to the surface soil with falling leaves and other plant debris.. |
| **LUVISOLS**<br>Mainly in Sironko Kapchorwa, Bulumbuli and Kween along Mbale-Moroto Road | Luvisols are soils that have higher clay content in the subsoil than in the topsoil.<br>Most Luvisols are fertile soils and suitable for a wide range of agricultural uses. Luvisols on steep slopes require erosion control measures. The eluvial horizons of some Luvisols are depleted to the extent that an unfavourable platy structure is formed. In places, the dense subsoil causes temporarily reducing conditions with a stagnic colour pattern. Luvisols in the temperate zone are widely grown to small grains, sugar beet and fodder; in sloping areas, they are used for orchards, forests and/or grazing. |
| **ANDOSOLS**<br>Limitedly in the Peripheral area | Andosols accommodate the soils that develop in volcanic ejecta or glasses under almost any climate.<br>Andosols have a high potential for agricultural production, but many of them are not used up to their capacity. The strong phosphate fixation of Andosols (caused by active Al and Fe) is a problem. Ameliorative measures to reduce this effect include application of lime, silica, organic material, and phosphate fertilizer. |

Source: IUSS Working Group WRB. 2007. World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

### Table R 2.3 Other soil classes in the system with limited potential

| Soil Class | Description and Management Options |
|---|---|
| **REGOSOLS**<br>Eutroci Regpsols occur sparsely in Nakapiripirit. | Regosols are very weakly developed mineral soils in unconsolidated materials.<br>Regosols in desert areas have minimal agricultural significance. Regosols with rainfall of 500–1000 mm/year need irrigation for satisfactory crop production. The low moisture holding capacity of these soils call for frequent applications of irrigation water; sprinkler or trickle irrigation solves the problem but is rarely economic. Where rainfall exceeds 750 mm/year, the entire profile is raised to its water holding capacity early in the wet season; improvement of dry farming practices may then be a better investment than installation of costly irrigation facilities. |
| **ARENOSOLS**<br>Mainly Katakwi and Western part of Tisai Island in Kumi | Arenosols comprise sandy soils.<br>Arenosols occur in widely different environments, and possibilities to use them for agriculture vary accordingly. The characteristic that all Arenosols have in common is their coarse texture, accounting for their generally high permeability and low water and nutrient storage capacity. On the other hand, Arenosols offer ease of cultivation, rooting and harvesting of root and tuber crops. Low coherence, low nutrient storage capacity and high sensitivity to erosion are serious limitations of Arenosols. Uncontrolled grazing and clearing for cultivation without appropriate soil conservation measures can easily make these soils unstable and revert them to shifting dunes. |
| **LEPTOSOLS**<br>Sparsely in Nakapiripirit | Leptosols are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony. Leptosols are azonal soils and particularly common in mountainous regions.<br>Leptosols have a resource potential for wet-season grazing and as forest land. Erosion is the greatest threat to Leptosol areas, particularly in mountain regions in the temperate zones. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing, the removal of stones by hand and their use as terrace fronts. |

Source: IUSS Working Group WRB. 2007. World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome.

### Table R 2.4 Summary of soil resources in the wetland system by district

| District | Amuria | Bukedea | Bulambuli | Kapchorwa | Katakwi | Kumi | Kween | Nakapiripirit | Napak | Ngora | Sironko | Soroti | Peripheral area | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gleysols | 0 | 161 | 74 | 0 | 464 | 65 | 95 | 873 | 21 | 20 | 5 | 39 | 126 | 1,941 |
| Vertisols | 0 | 170 | 197 | 0 | 377 | 15 | 44 | 709 | 182 | 0 | 10 | 0 | 53 | 1,757 |
| Histosols | 0 | 73 | 26 | 0 | 68 | 78 | 0 | 36 | 0 | 4 | 0 | 27 | 0 | 312 |
| Nitisols | 0 | 0 | 347 | 352 | 0 | 0 | 548 | 0 | 0 | 0 | 136 | 0 | 168 | 1,551 |
| Petric Plinthosols | 0 | 400 | 0 | 0 | 245 | 263 | 0 | 0 | 0 | 46 | 10 | 0 | 0 | 964 |
| Acric Ferralsols | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 61 | 51 | 0 | 0 | 0 | 0 | 139 |
| Lixic Ferralsols | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 589 | 120 | 0 | 0 | 0 | 0 | 710 |
| Luvisols | 0 | 1 | 114 | 3 | 21 | 0 | 69 | 170 | 75 | 0 | 116 | 0 | 15 | 585 |
| Eutric Regosols | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 260 | 39 | 0 | 0 | 0 | 172 | 474 |
| Arenosols | 0 | 0 | 0 | 0 | 423 | 29 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 472 |
| Leptosols | 0 | 0 | 0 | 0* | 0 | 0 | 0 | 55 | 0 | 0 | 0 | 0 | 8 | 63 |
| Skeletic Andosols | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Unidentified | 117 | 0 | 0 | 0 | 0 | 0 | 37 | 589 | 248 | 0 | 0 | 0 | 75 | 1,067 |
| Lake | 0 | 0 | 0 | 0 | 147 | 71 | 0 | 0 | 0 | 24 | 0 | 4 | 0 | 246 |
| Grand Total | 117 | 805 | 758 | 355 | 1,745 | 521 | 824 | 3,343 | 736 | 94 | 277 | 88 | 619 | 10,281 |

Unit: $km^2$

Source: National Wetlands Information System



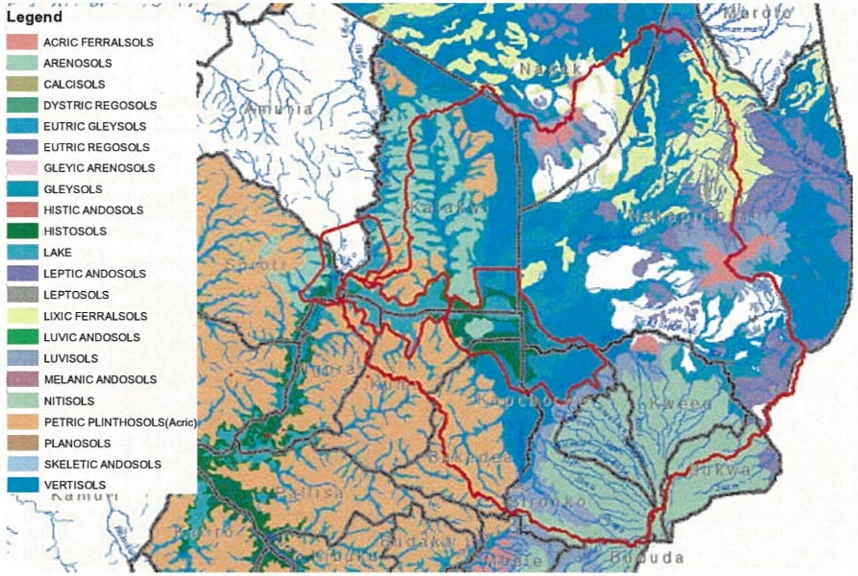


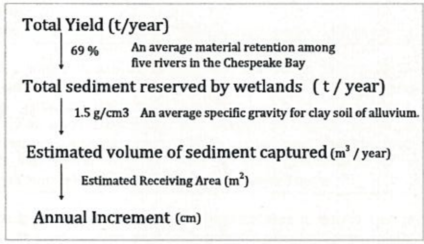

**Fig. R 2.2 Soil map of the Awoja wetland system**

#### Soil erosion

An assessment[4] of soil erosion provided a risk map as given in Fig. R 2.3. The assessment employed an empirical simulation model of the Universal Soil Loss Equation (USLE) to estimate soil erosion from fields in the two catchment areas: Mpologoma and Awoja Basins. The followings are the major findings:

- The most high risk areas (hot spots) are the ones on the slopes of Mt Elgon in the Districts of Kapchorwa and Sironko for Awoja Wetlnad System[5].
- Excluding the mountain area, Mpologoma catchment is at a higher risk of erosion;
- Nakapiripirit has the lowest risk to erosion in the entire study area; and
- The distribution of the risk (with the exception of the mountain region) is more uniform in Mpologoma than in Awoja catchment.

Further, an estimation of sediment yield for each sub-catchment was performed, from which an annual increment of sediment deposition was subsequently derived by the following procedure[6,7].




As a result, an annual incremental depth of sediment deposited in the wetlands extending over

[4] Preliminary Assessment of Erosion Risk and Sediment Yield in Mpologoma and Awoja Basins carried out by the GIS Unit of the National Agricultural Research Laboratories, Kawanda under the National Wetlands Management Project
[5] Districts are as per 2007 boundaries
[6] Quantifying the Role of Wetlands in Achieving Nutrient and Sediment Reduction in Chespeake Bay, Chesapeake Bay Program STAC Responsive Workshop, November 2008, STAC Publication 08-006
[7] Methods and Interpretation of geotechnical test.(in Japanese).

Bukedea, Sironko and Kumi was estimated at 0.41 cm. In the same manner, an annual sediment deposition in the two lakes was estimated at 0.39 cm.

The analysis indicated that the extensive wetlands in Bukedea, Bulambuli function as a sediment reservoir; and thus Lake Opeta is currently being buffered from abrupt alteration of the ecosystem. Due to a long distance of low-lying flat plain with an approximate distance of 28 km from Mbale-Moroto Road to the Tisai Island, larger soil particles would be deposited first and smaller particles subsequently. The wetlands thus provide sieving effects. Finally the soil particles reaching the Lake Opeta are deemed to be those with fine colloidal fraction.

**Table R 2.5 Sediment yield and annual increment of sediment**

| River | Gauging station No. | Total Yield | Total sediment reserved by wetlands | Estimated volume of sediment captured | Estimated Receiving Area | Annual Increment |
|---|---|---|---|---|---|---|
| | | t/year | t/year | $m^3$/year | $m^2$ | cm |
| Namalu | 82228 | 48,682 | 33,591 | 22,394 | 153,344,448 | 0.04 |
| Amaler | 82229 | 71,848 | 49,575 | 33,050 | | |
| Kelim | 82231 | 1,126,685 | 777,413 | 518,275 | 509,296,818 | 0.41 |
| Atari | 82244 | 4,847 | 3,344 | 2,230 | | |
| Sipi | 82243 | 301,943 | 208,341 | 138,894 | | |
| Muyembe | 82242 | 582,260 | 401,759 | 267,840 | | |
| Simu | 82241 | 1,212,763 | 836,806 | 557,871 | | |
| Sironko | 82240 | 1,363,194 | 940,604 | 627,069 | | |

Note (1) An average material retention among five rivers in the Chespeake Bay watershed. (Source; Quantifying the Role of Wetlands in Achieving Nutrient and Sediment Reduction in Chespeake Bay, Chesapeake Bay Program STAC Responsive Workshop, November 2008, STAC Publication 08-006

(2) An average value for clay soil of alluvium. Methods and Interpretation of geotechnical test. (in Japanese). Moist unit weight, which is the unit weight of a soil when void spaces of the soil contain both water and air.


**Fig. R 2.3 Soil erosion risk map of Awoja and Mpologoma catchments**

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*Full Length Research Paper*

# Soil and nutrient losses in banana-based cropping systems of the Mount Elgon hillsides of Uganda: economic implications

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**This study investigated the effect of different farmer cropping and soil conservation practices on runoff, soil and nutrient loss in Bududa district, Uganda. Gerlach troughs measuring 0.6m length, 0.4 m width and 0.5 m high were installed on runoff plots (15 m x 2 m) on farmer's fields under banana sole, banana-arabica coffee or annual crops, with or without soil conservation structures. Soil loss was significantly ($P<0.05$) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t ha$^{-1}$yr$^{-1}$), with values much higher for fields without conservation structures compared to those where there were structures. The total monetary value for NPK lost through erosion was US $ 16,663, 4,404 and 442 ha$^{-1}$yr$^{-1}$ for annuals, banana and banana-coffee fields respectively; with values much higher for fields without conservation structures compared to those with structures (US $ 15,451 vs 6,058). Soil loss values were much higher than the tolerable limit for Uganda which is 5 t ha$^{-1}$yr$^{-1}$ and calls for immediate action to scale up sustainable land management practices.**

**Key words:** Land degradation, management practices, monetary value, soil erosion, valuation.

## INTRODUCTION

Runoff and soil erosion are major land degradation processes in East Africa, contributing immensely to nutrient depletion, declining agricultural productivity and income. In Uganda, soil loss rates recorded in different locations are higher than the tolerable values (Bagoora, 1990) and have raised both ecological and environmental concerns. Highlands occupy around 25% of Uganda's land and contain 40% of the country's population. They are found in the Southwest, East, West and Northeastern regions, have steep slopes, high population densities and most land including marginal lands, is under intense cultivation. Bududa is among the areas badly affected by soil erosion with 75 to 80% of the district affected (NEMA, 2001). There is as yet little evidence that increase in population densities has led to sufficient adoption of land management practices to offset the worsening erosion and nutrient depletion (Nkonya et al., 2002).

Soil erosion has been a major problem since before independence (Carswell, 2002), and continues even today, with severe impacts (NEIC, 1994; Kazoora, 2002). It is estimated that 4 to 12% of gross domestic product (GDP) is lost through environmental degradation (Slade and Weitz, 1991; NEMA, 2001), 85% of this from soil erosion, nutrient loss and changes in crops (Olson and Berry, 2003). The total monetary value of environmental degradation was estimated at U$170 to 460 million p.a.

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in 1991 and by 2003, this was put at 230 to $600 million (Kazoora, 2002).

Removal of nutrient-enriched soil from cropland leads to a decline in per capita food production (Dunne and Dietrich, 1982). This is a serious menace to the future of an expanding and poor population, whose only resource is a small portion of land, exploitable at subsistence level (Sanchez et al., 1997). Land degradation culminates in a vicious circle of low income-low input, low yield and poverty (Crosson, 1995; Berry et al., 2003). At a farm level, declining fertility is worst on fields far from the homesteads since available organic materials such as manure and crop residues, are placed only on fields nearest the homestead.

With arable land per capita expected to decline from 1.1 ha in 1991 to 0.6 ha in 2015 (NEMA 2001), it is critical to both reduce land degradation trends in areas already under cultivation, and ensure sustainable land management practices to prevent degradation in future cultivated areas. Erosion control bunds had been installed by the colonial administration in the Mt. Elgon area and some are still being maintained by farmers. However, attitude towards further expansion is poor partly due to high labour demands. Further, use of inputs, such as chemical fertilizers and manure, is very low.

Runoff and soil loss studies in agricultural lands have shown that the effectiveness of various management practices in reducing soil loss depends strongly on the characteristics of climate, crops and soil (Shipitalo and Edwards, 1998; Wan and El-Swaify, 1999). Use of appropriate management practices can decrease erosion and increase available soil water for crops. Regional differences in soil physical properties partly explain the different results from various runoff studies.

Soil and water losses fluctuate highly between different seasons and years (Majaliwa et al., 2005; Merz et al., 2006). These fluctuations complicate accurate erosion measurement and prediction (Hogarth et al., 2004). Moreover, such intra- and inter-annual changes in water erosion are complex and caused by many synergistic factors (Busnelli et al., 2006), such as variations in rainfall (Wei et al., 2009; Baigorria et al., 2007), slope, land use and soil characteristics. Wejuli (2008) found that soil erosion in Wanale watershed of Uganda was a function of land cover, soil erodibility and the square root of slope. Deforestation, cultivation of steep slopes and other agricultural activities have induced severe erosion and land degradation in huge areas around the world (Gafur et al., 2003). Loss of vegetation cover as a result of human activities such as overgrazing and deforestation leads to formation of soil seals that increase the risk of runoff and soil erosion (Singer and Shainberg, 2004; Snyman and duPreez, 2005).

Understanding runoff and soil erosion processes under different land characteristics and uses, and the impacts of land use, cultivation and slopes, is essential for sustainable agriculture since most annual global soil erosion rates are observed from farmlands (Wilkinson and McElroy, 2007). Appropriate land use and management can increase rainfall infiltration and reduce surface runoff and soil losses. Vegetation restoration can also improve the effectiveness of land cover, consolidate the health and stability of local ecosystems, and reduce the sensitivity of soil erosion and water loss to temporal changes in rainfall (Dunjó et al., 2004; Merz et al., 2006; Eugenia et al., 2007).

Studies by Bamutaze et al. (2010) indicate that current runoff; erosion and sedimentation rates in the Mt. Elgon Manafwa district are generally high. Mean soil loss rates varied significantly ($P<0.05$) from 7.5 in perennial to 24 t $ha^{-1}yr^{-1}$ in annual land uses.

The rates were above the tolerable rate of 5 t $ha^{-1}yr^{-1}$ for Uganda, with annuals on steep slopes generating more sediment. While many studies have quantified soil erosion, the monetary value of soil loss has not been adequately assessed in Uganda.

### Economic valuation method of soil erosion

The effects of soil degradation have been reported in declining crop yields, siltation of water bodies, reduced fish catches, water hyacinth infestation, to mention but a few. Actual yields of grain crops ranged from 51 to 68% of potential crop levels (Bashaasha et al., 2001). Many approaches have been used to establish the economic value of soil erosion (Clark, 1994).

Some of the commonly used methods are replacement cost, rehabilitation cost, contingent valuation, hedonic pricing, market value of soil, production value of soil, opportunity cost etc. Each method operates from different perspectives and has inherent drawbacks (Hacisalihoglu et al., 2010).

According to Jayasuriya (2003) the "market value of soil" method estimates the cost of soil erosion to society as a whole.

The approach is based on soil erosion reducing the productive potential of the soil through depletion of the soil's nutrient content, its physical structure and ecological qualities. Of these factors, only the soil's nutrient content can be valued in terms of marketed proxies (artificial fertilizers).

Therefore, the analysis estimates the value of reduction in soil's productive potential in terms of depletion of the soil's nutrient resource base. It is calculated as the market value of the difference in soil nutrient content between an eroding soil and uneroded soil. The method undervalues the soil from society's perspective. The soil nutrients are valued in terms of their least cost artificial fertilizer equivalents.

The analysis is not based on the soil nutrient replacement cost approach (Jayasuriya, 2003).

**Objectives**

1. To determine the effect of different cropping and soil conservation practices on runoff, soil and nutrient losses.
2. To assess the market value of the nutrient losses incurred under different cropping and soil conservation practices.

## MATERIALS AND METHODS

### Description of the study sites

The study was carried out in Bushika Sub County (Bushiunya, Bumushisho and Bunabutiti parishes) in the Mt. Elgon Bududa district, Eastern Uganda. Bududa district lies between latitude 2° 49' N and 2° 55' N, longitude 34° 15' E and 34° 34' E. The area receives above 1500 mm $yr^{-1}$ rainfall, controlled by the high altitude of 1250 to 2850 m (Kitutu et al., 2009). It has two distinct wet seasons, separated by dry periods during December to February and July (The Republic of Uganda. 2004). Temperature ranges from 7.5 to 27.5 °C. The cropping pattern is dominated by banana, arabica coffee and annuals.

### Soil characterization

Detailed soil description in the study area was carried out on representative soil unit profiles (0 to 1.5 m) of major landscapes using FAO guidelines (FAO, 1990). Vegetation, slope, GPS coordinates, physiography, erosion, topography, stoniness, geomorphic position, and drainage with potential to influence soil properties were also recorded. Morphological parameters considered in soil description included colour, depth, horizon boundary, structure, texture, consistency, compactness, porosity and cementation, slope, land use/cover, stoniness, abundance and diversity of roots and macro-organisms. Representative soil samples were collected from each horizon for laboratory analysis of texture, pH, organic carbon (OC), exchangeable Ca, Mg, K, Al, available P and CEC (Okalebo et al., 1993). For fertility assessment, soil samples (0 to 20 cm) were taken from each experimental plot, dried at 40°C for 3 days, ground to pass 2 mm sieve and analysed for pH, OC, available P, exchangeable Ca, Mg, K, total N and particle size distribution using standard methods (Okalebo et al., 1993).

Three dominant soil units were identified: Rhodic Nitisols, Ferralic Nitisols and Haplic Lixisols Skeletic (data not presented). Rhodic Nitisols and Ferralic Nitisols occupy foot-slope and shoulder positions of the undulating topography, characterized by distinct red colours in the A layer extending into a deep B layer that goes beyond 1.2 m. The A and B horizons are separated by a wavy boundary. Haplic Lixisols Skeletic soils occupy the upslope position and are shallower with a pronounced rocky structure. They are rich in nutrients with a base saturation of 50 to 80% in the surface layer. Soils are susceptible to erosion due to high slopes that characterize the terrain. The identified soil units are in agreement with those reported for this area (Isabirye et al., 2004).

### *Rainfall measurements*

Three rain gauges were installed in each of the three parishes where the experimental plots were located, and the amount of rainfall recorded for each rain event. Daily rainfall was measured using conventional rain gauge with a measuring cylinder (CASELA type 127 mm diameter, Department of Meteorology, 1979). The data collected included: rainfall duration, amount and any special remarks about the storm.

### *Experimental set up*

While it is acknowledged that slope has a very significant influence on soil erosion and runoff, the major focus of this study was to examine the effect of farmers' management practices on runoff, soil and nutrient loss. Study fields were located on slopes ranging from 3 to 45%. The experiment variables consisted of (i) farmers' cropping practices (banana, banana-arabica coffee, annual crops) and (ii) soil conservation structures (terraces) used or no structures used. Farmers were carefully selected to represent each combination of cropping (banana, banana-arabica coffee, annual crops) and soil conservation practices (structures (terraces) or no structures). Twelve (12) farmers were selected from each parish, with each of the three parishes representing a replicate. Gerlach troughs measuring 0.6 m length, 0.4 m width and 0.5 m high were installed onto experimental plots measuring 15 × 2 m, on 36 farmers' fields. Runoff from each plot was collected in the trough every rainfall event. Experimental set up was a factorial combination of cropping practices and conservation practices in a completely randomized design, replicated 3 times (parishes).

### *Determination of runoff, soil and nutrient loss*

Using a steel meter rule, farmers recorded the height (cm) of the runoff mixture collected in the trough after every rainfall event. The mixture was stirred uniformly and a sample of the soil-water suspension taken in a 3 L jerrycan for laboratory analysis. The volume of solution in

**Table 1.** Summary of selected soil characteristics (0 to 20 cm) for the study sites.

| Parish (REP) | | pH | OC | N | P | Ca | Mg | K | Sand | Clay | Silt |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | -------%------ | | -------------- (mg kg$^{-1}$) -------------- | | | | -------------%---------- | | |
| Bunabutiti | Mean | 6.3 | 3.1 | 0.2 | 12.1 | 3193 | 677.9 | 1147 | 33.4 | 52.4 | 14.2 |
| | Standard deviation | 0.7 | 1.3 | 0.1 | 17.1 | 1731 | 317.2 | 800.6 | 15.5 | 16.1 | 4.9 |
| Bumushisho | Mean | 5.9 | 2.3 | 0.1 | 3.2 | 2149 | 527.5 | 464.3 | 50.4 | 40.6 | 9.0 |
| | Standard deviation | 0.2 | 0.9 | 0 | 4.2 | 468 | 113.8 | 516.1 | 9.6 | 12.3 | 3.6 |
| Shunya | Mean | 5.8 | 3.4 | 0.2 | 13.3 | 3181 | 648.2 | 405.6 | 36.7 | 47.7 | 15.5 |
| | Standard deviation | 0.4 | 1.9 | 0.1 | 11 | 1173 | 192.7 | 302.1 | 13.6 | 11.8 | 11.4 |
| Overall mean | | 6.0 | 2.9 | 0.2 | 9.5 | 284 | 617.9 | 672.3 | 40.2 | 46.9 | 12.9 |
| Mean Standard deviation | | 0.4 | 1.4 | 0.1 | 10.8 | 1124 | 207.9 | 539.6 | 12.9 | 13.4 | 6.6 |

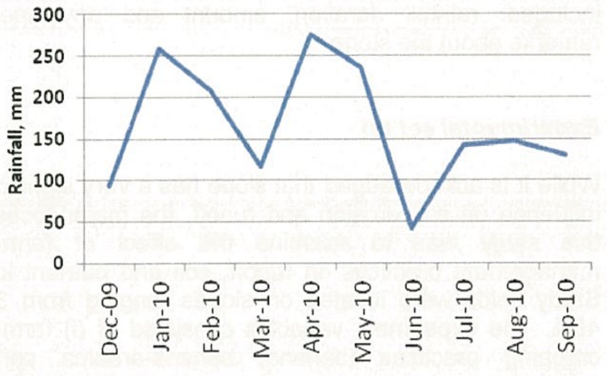


**Figure 1.** Mean monthly rainfall for Bushika sub county, Dec. 2009 to Sept. 2010.

the trough was obtained by converting the height of water (cm) from the 15 by 2 m plot to $m^3ha^{-1}$, and summed up to obtain $m^3ha^{-1}yr^{-1}$ for each land use and conservation practice. The amount of soil sediment within the sampled volume was determined after decanting off the clear water. The sediment was dried, weighed and reported as soil loss in $kgha^{-1}$, then summed up to $kgha^{-1}yr^{-1}$ or $tha^{-1}yr^{-1}$. Nutrient (NPK) loss was calculated by multiplying soil N, P and K content (kg $kgsoil^{-1}$) by soil loss (kg $ha^{-1}$), and later summed up to obtain the kg NPK $ha^{-1}yr^{-1}$. From the market price of N, P and K fertilizers, the monetary value of the lost nutrients was computed.

## Data analysis

Data were processed using Microsoft Excel and statistically analysed using Genstat package version 3.2. Significant differences between means were determined at a 95% Confidence level and means separated using the standard error of difference (sed) procedure. Two means were declared as significantly different when the difference between them was greater than twice the sed value.

## RESULTS AND DISCUSSION

### Soil characteristics

Table 1 presents mean soil characteristics for the study sites. Difference in the three parishes was evident in the soil properties. The soil pH was higher for Bunabutiti compared to the other two parishes. However, pH values were above the critical value of 5.2 for Uganda soils. Soil OC, N and P were higher for Shunya and lowest for Bumishosho. Higher OC, N and P values for Shunya are understandable considering that being adjacent to the park, land in this parish is relatively more recently opened compared to Bunabutiti and Bumushisho parishes which have been cropped for a longer period. Averaged over the 36 farmers' plots, soil $pH_{water}$, was 6.0; mean OC was 2.9% while mean N was 0.14. The P averaged 9.51 $mgkg^{-1}$ (Table 1).

### Rainfall distribution for Bushika Sub County, December 2009 to September 2010

Figure 1 presents mean rainfall distribution during the study period. Data are means of 3 parishes (Bushiunya, Bumushisho and Bunabutiti). Peak rain periods were observed during January and April 2010, with low rainfall periods between June and September 2010. These spatial variations in rainfall would be expected to influence runoff and erosion measurements (Yair and

**Table 2.** Effect of land use and conservation structures on runoff and soil loss.

| Parish (REP) | Soil loss, t $ha^{-1}yr^{-1}$ | |
|---|---|---|
| | No structures | Structures |
| Bunabutiti | 2.34 | 1.68 |
| Bumushisho | 1.56 | 4.39 |
| Shunya | 2.75 | 0.77 |

| Land use | No structures | Structures |
|---|---|---|
| Annuals | 38.5 | 15.5 |
| Banana | 6.6 | 3.2 |
| Banana-coffee | 0.9 | 0.2 |
| sed | 6.07 | |
| CV, % | 18.2 | |

Raz-Yassif, 2004; Nearing et al., 2005).

## Effect of land use and conservation structures on runoff and soil loss

Runoff ranged from 129 to 2,394 with a mean of 858 $m^3ha^{-1}yr^{-1}$. However, this was not directly related to land use or soil conservation practices (data not shown). Soil loss was higher for Shunya parish and lowest for Bumushisho. With the exception of Bumushisho parish, soil loss values were higher for fields with no conservation structures compared to those with structures. Soil loss was significantly ($P<0.05$) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t $ha^{-1}yr^{-1}$), with values much higher for fields without conservation structures compared to those with conservation structures (Table 2). Soil loss values experienced on annual and banana crop fields were much higher than the tolerable limit for Uganda which is 5 t $ha^{-1}yr^{-1}$. Studies by Bamutaze et al. (2011) in the Mt. Elgon district of Manafwa, revealed high runoff and erosion rates, with soil loss being 7.5 $tha^{-1}yr^{-1}$ on perennials and 24.0 $tha^{-1}yr^{-1}$ on annual crops. In the L. Victoria basin Rakai district (heavy clay soils, 914 to 1118 mm rainfall), Majaliwa et al. (2005) reported runoff from annual crop fields to range from 315 to 2,439 $m^3ha^{-1}yr^{-1}$ and soil loss of 27.7 to 86.7 t $ha^{-1}yr^{-1}$, with higher values reported for annual crops than perennials. Data from the present study show that runoff from annual crop fields in the Mt. Elgon Bududa district (light volcanic soils, over 1500 mm rainfall, more steep slopes) could even be higher than that in the L. Victoria basin.

The dependence of runoff and soil loss on land use has been attributed to factors such as rainfall, topography, canopy cover, ground cover, and soil properties (Majaliwa et al., 2005). In this landslide-prone Bududa district, land management systems which leave the land devoid of vegetation cover (e.g. annual cropping) are likely to result in severe erosion, which could aggravate the situation. Banana and coffee present a relatively good canopy cover compared to annuals crop fields which are bare at the beginning of rainy seasons (Majaliwa et al., 2005).

## Effect of land use and conservation practice on nutrient loss

Organic carbon (OC) loss was significantly ($P<0.05$) higher on annuals than banana or banana-coffee systems (1,111 vs 224 vs 24 kg $ha^{-1}yr^{-1}$, Table 3) with values higher for fields without compared to those with conservation structures. The N lost followed a similar trend to that of OC; values were significantly ($P<0.05$) higher for annual crop fields compared to banana or banana-coffee fields (6,581 vs 1,581 vs 185 kg $ha^{-1}yr^{-1}$, $P<0.05$). The mean P lost ranged from 0 to 0.87 kg $ha^{-1}yr^{-1}$. The values were higher for annual crops compared to banana or banana-coffee, however the means were not significantly ($P>0.05$) different between land use or conservation practices. Values for K and Mg lost were also higher for annual crops compared to banana or banana-coffee plots, although not significantly ($P>0.05$) different between land use of conservation practices. According to Hacisalihoglu et al. (2010) nutrient loss from agricultural land in semi-arid (400 mm) part of Turkey amounted to 0.84 to 1.44, 0.67 to 1.30 and 9.42 to 14.90 kg $ha^{-1}yr^{-1}$ for N, P and K, respectively. Results from the present study show even higher NPK losses from the wetter (over 1,500 mm) mountainous Bududa district.

## The monetary value of nutrients (N, P and K) lost due to soil loss

The monetary value of soil loss in the research area was calculated using the method "market value of soil" basing on the lowest nutrients market prices (Hacisalihoglu et al., 2010). Nutrient prices were determined from the lowest fertilizer prices in Kampala as of 2010. The following values were used: urea (46%N, US $ 42.50 per 50-kg bag); triple superphosphate (TSP, 45% $P_2O_5$, US $ 47.50 per 50-kg bag); muriate of potash (MOP, 50% $K_2O$, US $ 45.0 per 50-kg bag). Based on these prices, the cost per nutrient was determined as US $ 1.85, 4.75 and 2.20 per kg of N, P and K, respectively.

Results show that the monetary value of N loss was highest in Shunya parish on fields without conservation structures. This is due to both the high soil and nutrient losses which were highest for this parish compared to others (Tables 2 and 3). However, for P and K, the trends were different.

**Table 3.** Nutrients lost under different land use and conservation practices.

| PARISH (REP) | OC lost, kg $ha^{-1}yr^{-1}$ | | Nitrogen lost, kg $ha^{-1}yr^{-1}$ | | Phosphorus lost, kg $ha^{-1}yr^{-1}$ | | Potassium lost, kg $ha^{-1}yr^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | No structures | Structures | No structures | Structures | No structures | Structures | No structures | Structures |
| Bunabutiti | 7717 | 5904 | 459 | 332.2 | 0.08 | 0.04 | 2.09 | 1.11 |
| Bumushisho | 4875 | 1129 | 329 | 74.9 | 0.06 | 0.00 | 3.24 | 0.28 |
| Shunya | 7452 | 1815 | 544 | 240.1 | 0.04 | 0.01 | 3.19 | 0.23 |
| Land use | No structures | Structures | No structures | Structures | No structures | Structures | No structures | Structures |
| Annuals | 1,111 | 451 | 6,581 | 2,354 | 0.34 | 0.87 | 38.8 | 28.2 |
| Banana | 224 | 101 | 1,541 | 828 | 0.18 | 0.11 | 6.6 | 5.6 |
| Banana-coffee | 24 | 4 | 185 | 54 | 0.00 | 0.00 | 0.40 | 0.10 |
| sed | 191 | NS | 1234.8 | NS | NS | NS | NS | NS |
| CV, % | 27.8 | | 30.5 | | 82.1 | | 39 | |

**Table 4.** The monetary value of nutrients (N, P, K) lost due to soil erosion.

| Land use | Loss through N loss, US $/ha/yr | | Loss through P loss, US $/ha/yr | | Loss through K loss, US $/ha/yr | | Total loss through NPK, US $ $ha^{-1}yr^{-1}$ |
|---|---|---|---|---|---|---|---|
| | No structures | Structures | No structures | Structures | No structures | Structures | |
| Bunabutiti | 849.110 | 614.562 | 0.399 | 0.167 | 4.602 | 2.438 | 1471.28 |
| Bumushisho | 608.723 | 138.665 | 0.292 | 0.005 | 7.131 | 0.623 | 755.44 |
| Shunya | 1006.268 | 444.135 | 0.187 | 0.025 | 7.027 | 0.504 | 1458.146 |
| Annuals | 12,160 | 4,350 | 1.61 | 4.15 | 85 | 62 | 16,663 |
| Banana | 2,847 | 1,530 | 0.83 | 0.5 | 14 | 12 | 4,404 |
| Banana-coffee | 342 | 99 | 0.01 | 0.01 | 1 | 0 | 442 |
| sed | 2,282 | | 1.915 | | 36.7 | | |
| CV, % | 30.5 | | 82.1 | | 38.9 | | |

The value of N lost was significantly higher for annual crops compared to banana or banana-coffee (US $ 12,160 vs 2,847 vs 342, $P<0.05$) (Table 4), with values higher for fields without compared to those with conservation structures. A similar trend was observed for P and K. Cumulatively for the 3 nutrients (N, P, K), a total of US $ 16,663, 4,404 and 442 $ha^{-1}yr^{-1}$ was lost from annuals, banana and banana-coffee fields respectively, through soil erosion. Total nutrient values were much higher for fields without compared to those with conservation structures (US $ 15,451 vs 6,058). Studies by Hacisalihoglu et al. (2010) showed that the economic value loss due to soil erosion from agricultural land in a semi-arid area of Turkey (400 mm rainfall) was US $ 102 $ha^{-1}year^{-1}$. Results of our study suggest even much higher rates for the wetter (>1500 mm rainfall) mountainous district of Bududa.

### Financial implications of soil and nutrient loss

Soil nutrients (e.g. NPK) are contained mainly in organic matter (OM) and clay particles. Since OM is concentrated mainly in the top 0-30 cm part of the soil layer, runoff and soil erosion processes result in loss of these essential plant nutrients. Extensive soil erosion in the mountainous regions leads to continuous loss of essential nutrients, leading to a progressive decline in crop yields. Replacing the lost nutrients necessitates purchase of fertilisers. With the high fertiliser prices in Uganda, replacing the lost nutrients definitely impacts negatively on the resource poor farmers.

## SUMMARY AND CONCLUSIONS

This study investigated the effect of different farmer cropping and soil conservation practices on runoff, soil and nutrient loss. Soil loss was significantly ($P<0.05$) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t $ha^{-1}yr^{-1}$), with values much higher for fields without compared to those with conservation structures. Organic matter, N, P and K losses followed a similar trend to that of soil loss, with higher values observed for annuals than banana and lowest on banana-coffee; higher values were observed from fields without conservation structures compared to those with structures. Cumulatively, the total monetary value for NPK lost through erosion was was US $ 16,663, 4,404 and 442 $ha^{-1}yr^{-1}$ for annuals, banana and banana-coffee fields respectively. The total nutrient values are much higher for fields without conservation compared to those with structures (US $ 15,451 vs 6,058 $ha^{-1}yr^{-1}$). The soil loss values experienced in this study (annual and banana crop fields) were much higher than the tolerable limit for Uganda which is 5 $tha^{-1}yr^{-1}$ and this calls for immediate action to address the situation by scaling up sustainable land management practices in the area.

## ACKNOWLEDGMENTS

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WMP レポート

# WATER QUALITY ASSESSMENT

# OF NAMATALA-DOHO AND AWOJA WETLAND SYSTEMS

## 1. Background

The National Wetlands Management Project (the Project) is a four-year project of the Wetland Management Department (WMD) funded by Japan International Cooperation Agency (JICA) to establish a model of conservation and wise use of wetlands in Uganda. The Project is designed to achieve the purpose by generating five (5) outputs: 1) National Wetland Information System is upgraded and functional; 2) Scientific information on target wetland systems is available; 3) Wetland management plans are prepared; 4) Pilot activities for wise use of wetlands are implemented based on wetland management plans; and 5) Wetland management officers' capacity is strengthened. A geographical focus is given to two (2) wetland systems in the country: Namatala-Doho Wetland System and Awoja Wetland System. The experience in the two wetland systems will be multiplied over the country upon the completion of the Project.

Under the second output, the WMD in collaboration with the JICA Technical Assistance Team (JICA TAT) has developed a sub-project inventory for resource assessment applicable to the two wetland systems. The subprojects in the inventory were identified on the basis of the findings in 1) workshops participated by the relevant district officers in Mbale for Namatala-Doho Wetland System on 6th June and in Soroti for Awoja Wetland System on 8th June 2012; 2) the Reconnaissance Survey conducted from 19th June until 29th June 2012; and 3) follow-up communication with district officers via e-mail to fill the gaps of findings that took place after delivery of the brief report of the survey.

One of the priority subprojects in the inventory is a water quality assessment with three thematic activities with different objectives and therefore different sampling design.

***Paddy Sustainability:*** It is often stated, that compared with Kibimba Rice Irrigation Scheme (KRS), Doho Rice Irrigation Scheme (DRS) has limited sustainability. Water quality parameters that may have relevance with soil fertility were chosen to compare between them.

***Sediments Monitoring:*** The subcomponent is to estimate sediment transport at the existing gauging stations in the two wetland systems to support the findings of the Preliminary Assessment of Soil Erosion and Sediment Yield that is also a subproject in the inventory.

***Nutrients in Lake Opeta and Bisina:*** GIDUDU et al.1 reported significantly pristine water of Lake Bisina with a concentration of nitrate as low as 21 ug/L. On the hand, there is a potential farm land endowed with Vertisols at an upper stream of the lakes and a demand for investment for rice farming. Considering the fact that the irrigation area for rice production in Bulambuli and Kween districts in the upper stream area are begin considered2 as potential irrigation infrastructure development areas, it is of importance to develop baseline information on the current level of water quality.

## 2. Objectives

The general objective of the water quality assessment is to support planning process for management of two wetland systems. More specifically the assessment is designed: 1) to compare water source quality of Doho and Kibimba Irrigation Schemes; 2) to estimate sediment transport at the existing gauging stations in the two wetland systems that will be compared with the findings in the Preliminary Assessment of Soil Erosion and Sediment Yield; and 3) to provide baseline information on water quality of the two lakes that is designated as Ramsar sites.

## 3. Methodology

### 3.1 Paddy Sustainability

***Sampling time:*** Water samples were collected on 1) 2nd May 2013, 2) 3rd to 10th June 2013, 3) 28th July to 4th August 2013 and 4) 10th to 17th October 2013.

[1] B. Gidudu, R. S. Copeland, F. Wanda, H. Ochaya, J. P. Cuda, and W. A. Overholt, Distribution, interspecific associations and abundance of aquatic plants in Lake Bisina, Uganda, J. Aquat. Plant Manage. 49:19-27

[2] The project on Irrigation Scheme Development in Central and Eastern Uganda

***Sampling sites***: Water samples were collected at 1) Doho Head Works (see figure 1) and 2) the most upper part of the irrigation channel, discharge point from the reservoir, of KIS (Figure 2) for the first sampling on 2nd May 2013. The sampling sites were transferred subsequently to the final discharge points of each irrigation area to allow broader comparison among the sites; and also considering apparent tendency of the suspended solid in the periods.

***Sampling method:*** Sample water was collected by single grab sampling at the centre of river using bucket.

***Parameters***: The following ten water quality parameters were measured and compared between the sampling sites: 1) pH, 2)Temp, 3) EC, 4) TSS 100oC, 5) TSS 500oC 6) Nitrates, 7) Ammonia , 8) Calcium, 9) Magnesium and 10) Potassium. The parameters were chosen considering the relevance with crop production and soil fertility.


**Figure 1: Water Quality Sampling sites at Doho irrigation Scheme**


**Figure 2: Water Quality Sampling sites at Kibimba Irrigation Scheme**

### 3.2 Sediments Monitoring:

***Sampling time***: Sediment was monitored over four periods: 1) from 5th to 12th March 2013, 2) from 4th to 11th June, 3) from 29th July to 5th August, and 4) from 9th to 16th October in 2013 at the nine gauging stations spread over in the two wetland systems.



***Sampling sites***: In Doho-Namatala Wetland System, four sampling sites were chosen for monitoring. They were 1) R. Mpologoma at Budumba, 2) R. Malaba at Jinja-Tororo Rd, 3) R. Manafa at Mbale Tororo Rd and 4) R. Namatala at Mbale-Soroti Rd. In AwojaWetland System, five monitoring sites were chosen mainly along Mbale Moroto Road. They were1) R. Sironko at Mbale-Moroto Rd, 2) R. Simu at Mbale-Moroto Rd, 3) R. Sipi at Mbale-Moroto Rd, 4) R. Kelim at Mbale-Moroto Rd and 5) R. Namalu at mbale-Moroto Rd.

***Sampling method:*** Sample water was collected by single grab sampling at the centre of river using bucket.

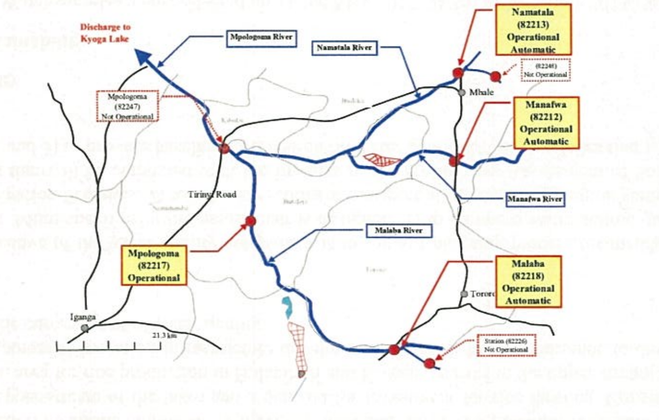



**Figure 3 Sampling sites for Sediment in Doho-Namatala Wetland System**

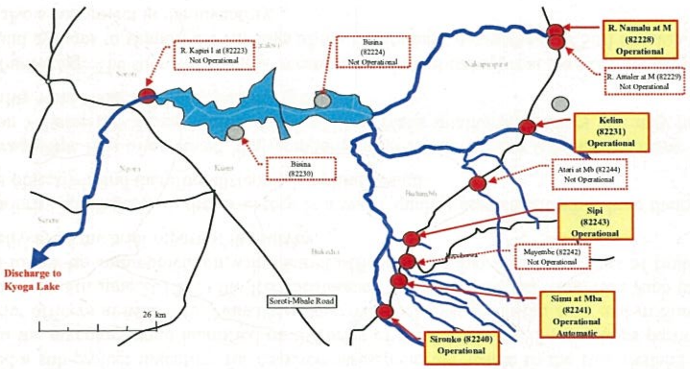



**Figure 4 Sampling sites for Sediment in Awoja Wetland System**

***Parameters:*** The parameters monitored were Total Suspended Solids.

### 3.3 Nutrients in Lake Opeta and Bisina:

***Sampling time***: The monitoring was conducted in two seasons 1) from 19th to 26th April 2013 and 2) from 5th until 12th June 2013 for three parameters: 1) Nitrates, 2) Ammonium and 3) Total Phosphate at six predetermined sites.

***Sampling sites*:** The sampling sites were spread over six sites in the two lakes. Three of them locate in the Lake Opeta, the rest in the Lake Bisina. They are presented in Table 1 and Figure 5.

***Sampling method:*** Sample water was collected by single grab at 50cm using vandon sampler.

**Table 1 Sampling Sites for the study on nutrients in Lake Opeta and Bisina**

| Lakes | Sampling Sites | Coordinate | |
|---|---|---|---|
| | | Latitude | Longitude |
| Opeta | WQ 1 | 1°37'54.52"N | 34°13'8.88"E |
| | WQ 2 | 1°39'2.28"N | 34°10'3.83"E |
| | WQ 3 | 1°38'30.50"N | 34° 7'59.56"E |
| Bisina | WQ 4 | 1°39'48.22"N | 34° 2'7.66"E |
| | WQ 5 | 1°38'10.89"N | 33°56'42.86"E |
| | WQ 6 | 1°40'28.49"N | 33°51'14.42"E |


**Figure 5 Sampling sites for Nutrients in Lake Opeta and Bisina**

***Parameters*:** The parameters monitored were: 1) Nitrate, 2) Ammonia and Total Phosphorus.

### 3.4 Laboratory Analysis

The Principal Water Analyst of the National Water Quality Reference Laboratory in Entebbe undertook planning, field work for sample collection, sample shipment and laboratory analysis.

**Table 2: Water Quality Parameters and Method of Analysis**

| S/N | Parameter | Analysis Method |
|---|---|---|
| 1 | pH | Electrometric method-using a pH meter |
| 2 | Temperature | Electrometric-using a pH meter |
| 3 | EC | Electrometric-using an EC meter |
| 4 | TSS at( 105°C) and TSS at (500°C) | Gravimetric |
| 5 | Nitrates | Spectrometry |
| 6 | Ammonia | Spectrometry |
| 7 | Calcium | Ion Chromatography |
| 8 | Magnesium | Ion Chromatography |
| 9 | Potassium | Ion Chromatography |



Water samples were collected only from the location designated above. Water samples were taken and collected from mid-stream or in the main flow of the river and away from slumping and scouring effects found near the banks, or by using boat from the surface of lakes at designated locations. Appropriate precautions were exercised by adhering to the laboratory sampling and preservation protocols. The laboratory's standard methods for analysis of water and wastewater were used in determination of the water quality parameters. The methods of analysis is summarised in Table 2.

## 4. Results and Discussion

### 4.1 Paddy Sustainability

The results of the analysis in May are presented in Table 3. Other results are shown in Table 4 and 5. From the second sampling, the sampling locations were transferred to a lower part of each irrigation area to allow broader comparison among the sites; and also considering apparent tendency of the suspended solid. It is noted that samples at the lower sites were affected by farming activity particularly in Kabimba Rice Field. For the Doho Irrigation Area, farming activity was not fully started due to the delay of rehabilitation work. The physical disturbance of the paddy field as a result of farming activity may have raised the TSS concentration in the KRS.

**Table 3 Quality of Irrigation source water in May**

| | pH | Temp (°C) | EC (µS/cm) | TSS( 105°) (mg/L) | TSS(500°) (mg/L) | Nitrates (mg/L) | Ammonia (mg/L) | Calcium (mg/L) | Magnesium (mg/L) | Potassium (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| Doho | 6.7 | 24.3 | 264 | 27 | 22 | 0.28 | <0.04 | 29 | 7.7 | 4.2 |
| Kibimba | 6.9 | 28.5 | 309 | 18 | 14 | 0.41 | <0.04 | 120 | 11.8 | 2.6 |

**Table 4 Water Quality Monitoring Paddy -1**

| | pH | | Temp (°C) | | EC (µS/cm) | | TSS 105° (mg/L) | | TSS 500° (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba |
| June | 6.8 | 7.1 | 25.0 | 29.4 | 232 | 372 | 30 | 43 | 13 | 37 |
| July | 6.9 | 7.3 | 24.6 | 28.8 | 235 | 390 | 14 | 179 | 2 | 42 |
| October | 7.1 | 7.6 | 24.0 | 26.7 | 290 | 312 | 4 | 20 | 3 | 17 |

**Table 5 Water Quality Monitoring Paddy -2**

| | Nitrates (mg/L) | | Ammonia (mg/L) | | Calcium (mg/L) | | Magnesium (mg/L) | | Potassium (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba | Doho | Kibimba |
| June | 0.13 | 0.13 | 0.22 | 0.4 | 25 | 35 | 6.3 | 14 | 3.6 | 2.8 |
| July | 2.2 | 4.6 | 0.3 | 0.47 | 25 | 42 | 6.8 | 17 | 5.6 | 3.5 |
| October | 0.09 | <0.02 | 0.45 | 0.53 | 30 | 11.3 | 9 | 12 | 4.4 | 1.71 |

The concentrations of TSS (100°C) were in a range between 14 to 27 mg/L. It was confirmed that the concentration of Total Suspended Solids in irrigation water of Doho Rice Irrigation Scheme (DRS) was almost fifty (50) percent higher than Kibimba Rice Irrigation Scheme (KRS). Practically visual observation of the irrigation water also indicates significantly higher suspended materials at DRS. Since the capacity of the head works is designed as 1.39 $m^3/s$ according to an engineer at DRS, an estimated one (1)

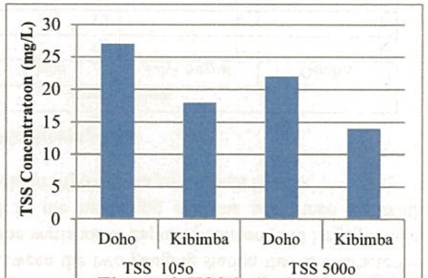



**Figure 6 TSS in Irrigation Water**

ton of TSS (105°) is delivered for eight hours of irrigation water provision.

Contrary to the observation on TSS, the concentrations of cations in irrigation water such as calcium, magnesium and potassium were found to be higher at KRS than DRS. Supply of basic cations through irrigation water is deemed important for maintaining soil fertility. It was also noted that the concentrations of the cations were higher than those generally found in Japan. For instance, Tamie *et al.*[3] reported 5.2 mg/L for Chikuma River and 7.7 mg/L for Tenryu River.

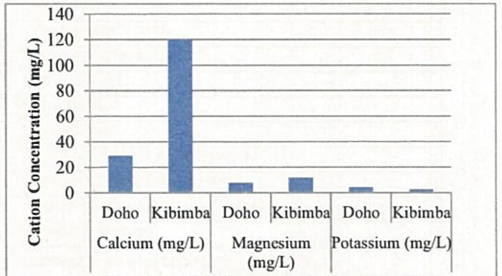


**Figure 7 Cations in Irrigation Water**

At least 1000 to 1500 mm of water is used to irrigate paddy fields in a cropping season. Taking 1000 mm as the minimal water use for one crop, irrigation water with dissolved calcium at 25 mg/L replenish 250kg Ca/ha in one growing season.

Magnesium concentrations in irrigation water were consistently higher at KRS than DRS, while those of calcium were also higher for KRS except October. Although the concentrations of the cations may have been affected by farming practices and application of soil amendments, the quality of the source water may have been the major factor to determine the surface water quality throughout the growing season.

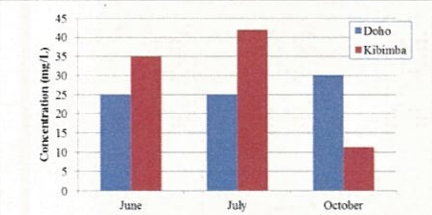


**Figure 8 Changes in Calcium concentrations**

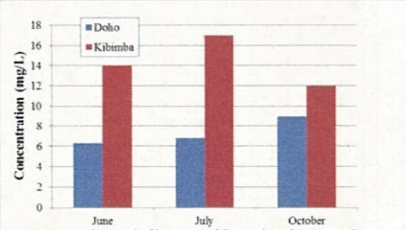


**Figure 9 Changes in Magnesium Concerntations**

## 4.2 Sediments Monitoring

The results of the analysis are presented in Table 6.

The gauging stations at 1. *R. Mpologoma at Budumba* and 2. *R. Malaba at Jinja-Tororo Rd*, are those installed along Malaba River at a lower and an upper parts respectively. Between the two gauging stations, there is a long strip of land that is densely vegetated with papyrus. The concentration of TSS at the upper station exhibited higher values that have plunged to significantly lower values at the lower gauging station except the measurement

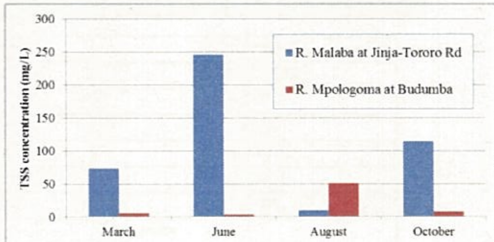


**Figure 10 TSS (100C) along Malaba River**

[3] Tamie Nakajima-Nasu, Ninzo Murayama, Research on Metal Ions of River and Drinking water in Nagano Prefecture, Bull. Environ. Conserv., Shinshu Univ. 7, 1985



in August (Figure 10). The water quality data demonstrates that the papyrus wetland has provided services in removing sediments considering the nature of channel between the two gauging station that is characterized by low gradient and thus slow water movement allowing the wetlands to capture sediment and large particles. This observation is an aspect that was not identified in the modelling analysis performed under the Preliminary Assessment of Erosion Risk and Sediment Yield in Mpologoma and Awoja Basins.

**Table 6 Sediment Monitoring TSS**

| No. | Sediment Monitoring in Gauged Rivers | | Sample Periods | | | |
|---|---|---|---|---|---|---|
| | | | March | June | July- August | October |
| 1 | R. Mpologoma at Budumba | 105°C | 5 | 3.3 | 52 | 8 |
| | | 500°C | - | 3.2 | 45 | 0 |
| 2 | R. Malaba at Jinja-Tororo Rd | 105°C | 74 | 246 | 10 | 114 |
| | | 500°C | - | 209 | 3 | 89 |
| 3 | R. Manafa at Mbale Tororo Rd | 105°C | 2 | 94 | 18 | 24 |
| | | 500°C | - | 86 | 10 | 15 |
| 4 | R. Namatala at Mbale-Soroti Rd | 105°C | 3 | 39 | 1 | 32 |
| | | 500°C | - | 34 | 0 | 13 |
| 5 | R. Sironko at Mbale-Moroto Rd | 105°C | 0 | 10 | 49 | 96 |
| | | 500°C | - | 9 | 45 | 84 |
| 6 | R. Simu at Mbale-Moroto Rd | 105°C | 3 | 28 | 10 | 114 |
| | | 500°C | - | 24 | 3 | 98 |
| 7 | R. Sipi at Mbale-Moroto Rd | 105°C | 3 | 35 | 24 | 10 |
| | | 500°C | -. | 32 | 5 | 3 |
| 8 | R. Kelim at Mbale-Moroto Rd | 105°C | 50 | 67 | 6 | 84 |
| | | 500°C | -. | 59 | 2 | 73 |
| 9 | R. Namalu at mbale-Moroto Rd | 105°C | 2 | 19 | 2 | 2 |
| | | 500°C | - | 17 | 0 | 0 |

Data on TSS 500°C in March is not available.
Unit: mg/l

By comparing the concentration of TSS at Manafwa and Namatala Gauging stations, on the other hand, it is evident that Manafwa is the larger contributor to area's soil erosion incidence. Although the sampling location of Manafwa gauging station is not same with the Doho Head Works of the Paddy Sustainability, the samples were taken from the same river.

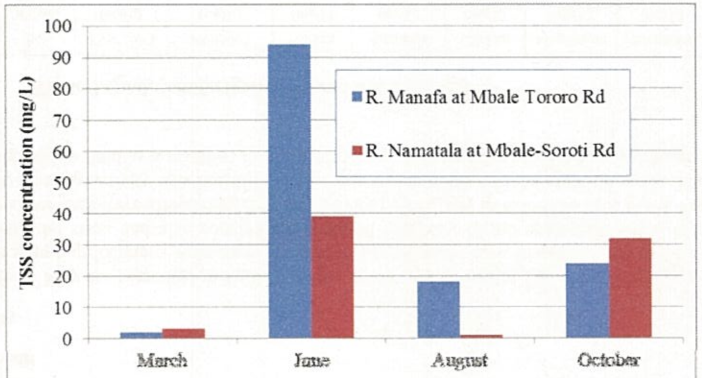


**Figure 11 TSS (100C) at Namatala and Manafwa**

Although, in the Paddy Sustainability, the concentration was determined at 27 mg/L (100°C) in May; it was found that the values ranged from 2 to 94 mg/L.

The discharge of the river in Awoja Wetland System differs significantly due to the varying size of the river profile. It was, however, observed that concentration of TSS significantly differs depending on the location and seasons. The difference may be attributable to the rain-fall pattern of the area, which is becoming more erratic.

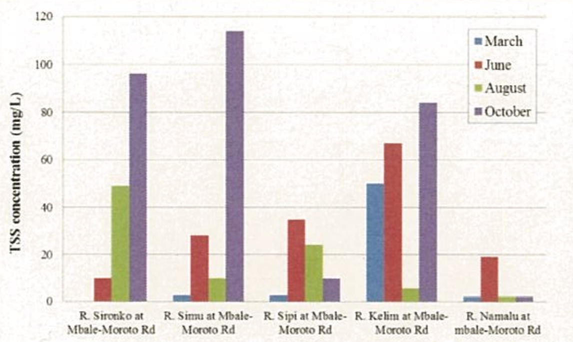



**Figure 12 TSS of the rivers in Awoja Wetland System**

## 4.3 Nutrients in Lake Opeta and Bisina

The results of the analysis are presented in Table 7.

**Table 7 Nutrients in Lake Bisina and Opeta**

| SN | Site | Nitrate (mg/L) | | Ammonia (mg/L) | | Total Phosphorus (mg/L) | |
|---|---|---|---|---|---|---|---|
| | | April | June | April | June | April | June |
| 1 | Lake Opeta poit 1 | 0.5 | <.02 | <0.04 | 3.22 | 0.21 | 0.19 |
| 2 | Lake Opeta poit 2 | 0.09 | <.02 | 0.17 | 2.09 | <0.08 | <.08 |
| 3 | Lake Opeta Point 3 | 0.11 | <.02 | <0.04 | 0.28 | <0.08 | 0.17 |
| 4 | Lake Bisina point 4 | 0.26 | <.02 | <0.04 | 1.17 | <0.08 | <.08 |
| 5 | Lake Bisina point 5 | <0.02 | <.02 | <0.04 | 0.25 | <0.08 | <.08 |
| 6 | Lake Bisina point 6 | 0.02 | <.02 | <0.04 | 0.85 | <0.08 | <.08 |

Nitrate level in the lakes ranged up to 0.26 mg/L over the two sampling period. The concentrations of nitrate in June were below the detection level at 0.02 mg/L at all the sampling points. The concentrations detected in the lakes were well below the most stringent standards at 25 mg/L[4] set forth under the EC Directive regarding quality required of surface water intended for the abstraction of drinking water (75/440/EEC). The toxicity of nitrates to fish is generally low, and 80 mg/ litre is considered to be the maximum admissible nitrate concentration for carp and 20 mg per litre for rainbow trout[5]. The contamination by nitrate of the lakes is, thus, negligible level at the moment. This is mainly due to limited fertilizer use at the upper stream as well as lake shore areas.

On the other hand, the maximum concentration of ammonia was 3.2 mg/L at Opeta Point 1 in June. The ammonia quantified in the assessment exercise indicates rather high level of contamination. The level of contamination would require intensive physical and chemical treatment[6] to serve as sources for drinking water according to 75/440/EEC. This ammonia may have occurred in water bodies arising from the livestock

[4] The Guide value for Category A1 Simple physical treatment and disinfection, e.g. rapid filtra- tion and disinfection.

[5] Zdenka Svobodova, Richard Lloyd, Jana Machova, Blanka Vykusova, Water quality and fish health, EIFAC TECHNICAL PAPER 54, Food and Agriculture Organization, 1993

[6] Extended treatment and disinfection e.g. chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption by activated carbon, disinfection by ozone and final chlorination.



waste. In Australia, 0.5 mg/L is the Protected Environmental Values for Aquatic ecosystem (Fresh water) in its water quality criteria. The value is total as nitrogen so that it should be read as 0.6 mg/L as ammonia.

For phosphorus, the highest level was observed at Opeta poit 1 both in April and June. The values detected in the assessment exercise were, however, well below the problematic level. For instance, the water quality criterion in Australia for fresh water for Aquatic ecosystem is set at 0.5mg/L. The major sources of phosphorus are deemed livestock waste considering the current farming practice. There are also naturally-occurring sources of phosphorus in lakes, such as decaying organic matter, and eroding rocks and soils. When the phosphorus balance in lake is lost and phosphorus levels are too high, the excess phosphorus contributes to excess algal growth. Phosphorus is usually the limiting nutrient in freshwaters. The level of phosphorus is believed to be critical in management and conservation of freshwater systems.

In summary, the current levels of major nutrient contaminants are low except ammonia that may arise from excretion of animals. Limited use of fertilizer at the upper streams contributes to the current level of lake's pristine state. However the lake ecosystem is maintained on a fragile balance depending mainly on lake phosphorus cycles. In other words, the use of chemicals in the upper stream may have significant irreversible impacts on the lake ecosystem.

**Appendix:** Evaluation on Potential Soil Loss from Cultivated Areas and Its Mitigation under Land-use Conversion to the Rice Paddy System

### *1. Introduction*

Soil erosion from cultivated topsoil is a major sediment source for rivers, wetlands and lake basins in Uganda (Wanyama *et al.*, 2012) and such land degradation process involves water-enrichment with sediment load influencing on fish catch to become a severe peril for the livelihood under expansion of the population (De Meyer *et al.*, 2011). Moreover high erosion rates are observed in the heavily populated and intensively cultivated plateau of the Lake Vicoria Basin while lesser or severer ranges observed in the South-western highland and Mt. Elgon in Eastern Uganda (Bamutaze, 2015) though such information/data for lowland area remains very limited. These potential erosion from cultivated land; specially for hilly area, may lead it to depletion of soil fertility to make crop production more critical. In the Project on Irrigation Scheme Development in Central and Eastern Uganda, Phase 2 (hereafter mentioned as PISD-2), it is essential to implement wise use concept in wetland development for proper agricultural production. In this context, it is important to utilize wetland from the perspectives of conservation of natural resources including cropland soil. Therefore, harmonizing the development of stable agricultural production and conservation of natural environment for sustainable utilization of wetland is an important consideration to be achieved. In the *10th Ramsar Convention*, a multi-function of paddy fields was recognized, and paddy field is considered as an artificial wetlands. The PISD 2 intend to utilize multiple functions of paddy fields for development plan of irrigation schemes, such as flood-control by storing rainwater over the field, maintaining of hydrologic circulation by return-flows, and soil erosion control (sediment reduction) in upland area. The multi-function of paddy fields includes the followings.

**Flood control:** paddy fields store rainwater temporarily and this function prevents a rapid rainwater flow, and can prevent or reduce the flood damage in the surrounding/downstream area.

**Diversity:** formed and maintained paddy field have developed ecosystem with rich biodiversity as semi natural system which provides rich habitats for diverse insects, animals and plants.

**Soil erosion control:** paddy fields; surrounded by levee and terraced on gentle sloping, can potentially trap most of sediments to settle down.

**Return flow as for Environmental flows:** Seepage from ditches and levee (bund) surrounding paddy contribute to shallow groundwater recharge and groundwater return flow to the river; while, overflows from paddy pouring into drains to joint with the river flow. Return flow can be utilized as "Environmental flows[1]".

[1]Environmental flows can be described as "the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people" (World Bank), cited from http://water.worldbank.org/topics/environmental-services/environmental-flowss (date last verified 02/Jul/2015)

**Figure:** The photo (left) shows paddy plot developed under the SIAD Project (Sustainable Irrigated Agriculture Development) as JICA's Technical Cooperation, at Nakaloke area of Upstream Namatala Swamps; while the photo (right) shows bare upland soil under ploughing up and downward slope. Directions of ground slope and surface water are indicated by arrows.

## *2. Objective of the Quantitative Evaluation on Potential Soil Loss under Landuse Conversion*

This study aims to compare and evaluate potential soil loss from cultivated areas under different landuse scenarios numerically by applying an empirical soil loss prediction model in order to indicate site-specific potential of erosion and its mitigation due to landuse conversion. The scenario involves the present condition and the future developed-condition; where organized, systematic land development with paddy systems is assumed to be introduced. The output information of the study here will therefore be useful to provide viewpoint on risk of soil loss from farming area hence related negative impact on crop production and areal environmental impact when considering alternative plans of development under the Project (PISD). It is not our intension to present and discuss land degradation (erosion) process to draw specific issues on soil and land management, precisely.

## *3. Study Area*

The study areas are located in the two development-planning areas of Atari (N 1°30'14.32" E 34°26'43.35") and Sironko (N 1°20'50.84" E 34°14'32.15"); where the PISD conducted the Feasibility Study from June 2014 to July 2016, and each site share boarders of 2 or 3 districts of Bulambuli, Bukedea and/or Kween district, the lower-belt of Mt. Elgon region, Eastern Uganda. The landscape is characterized by flood plain area with streams flowing into wetland body with an elevation about 1070 meters above sea level for both sites. In addition, the entire part of each studying site is restricted to the gently undulating topography with intermittent isolated patch of rangeland like landuse (bush, grass and grazing land). Mean annual rainfall is 901-1100 mm (NEMA, 2009). The most extensive area is engaged in rain-fed agricultures except the lowest position in topography where the farmers are enabled to access water from stream or swamp for lowland rice production. Dominant soils over the regions are classified as Vertisols and Gleysols basing on the soil map of Uganda. Further detailed information is available for the Environmental Impact Assessment (EIA) report conducted under the PISD-2.

The regional soil itself was found to have moderate potential of soil loss according to a short-term instantaneous field observation conducted using a runoff plot. The runoff plot[2] measures 0.49 m wide by 5 m long (2.45 $m^2$), with the long axis oriented down the slope with gradient of 4.2 %.

Changes in runoff coefficient, defined as runoff divided by the corresponding rainfall both expressed as depth (mm) over catchment area of the plot, and soil loss are presented in the figures below. Mean runoff coefficient in relation to total soil loss during a 7-month period shows relatively low due to lack of observation period (less than 1 year) and also to a gentle slope gradient studied. It is; however, implying that corresponding soil loss amount falls within realistic range of soil loss from bare plots under natural rainfall of tropical climate countries as reported by Roose (1976) and Rose (2001) (**Figure-A**). This may be explained more clearly from **Figure-B** showing relationship between cumulative rainfall and corresponding soil loss. Labrière *et al.* (2015) reported that annual mean soil loss ranged from 1,495.5 to 2,458.3 g/$m^2$/year from runoff plots with tilled bare soil under natural/simulated rainfall; $n$=800 events, across 21 humid-tropical countries of West/Central/East Africa, South-east Asia, North East Australia, America and North Pacific Ocean, covering tropical rainforest and tropical monsoon regions, with the median values for annual rainfall (only for measured-cases), slope length and steepness were 2,444 mm, 16.4 m and 16.5 %, respectively. Under the presenting study the unit area soil loss of 2,009 g/$m^2$ was observed for the 7-month monitoring period.

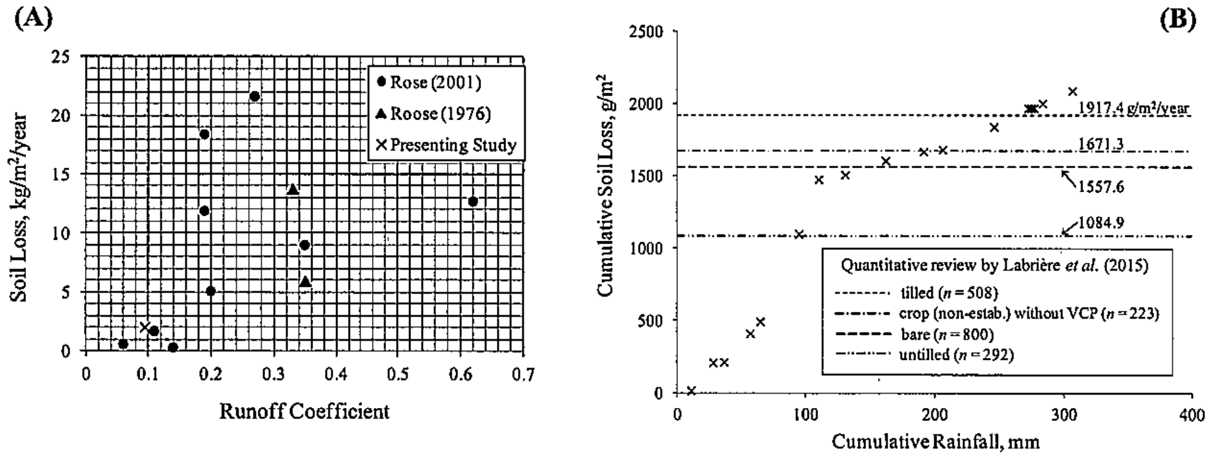



**Figure:** **(A)** Relationship between average annual runoff coefficient and soil loss (kg/$m^2$/year). Data set obtained from the presenting study were projected against that from the past literature including field runoff-plot study under natural rainfall across tropical climate countries of West Africa (Roose, 1976) and Southeast Asia/ Oceania (Rose, 2001). Field monitoring period of the presenting study was limited

2 The single hydrologically isolated runoff plot was installed on a typical upland maize cultivation field in Mbale (nearby the district production office), and was maintained on bare surface during the observation period from 26th September 2015 to 27th April 2016 under natural rainfall. At the bottom (lower) of plot is a settling basin for collecting runoff/sediment, by referring to practical and low cost setup proposed by Kobayashi (2008). The rainfall amount was measured recorded for each event using a rain gauge, manually.

to 7 months while others present 1-year annual mean values for the minimum 20 $m^2$ to the largest 5,000 $m^2$ plot with slope gradient 1.25 to 50%. **(B)** Cumulative soil loss observed during a 7-month observation period in relation with cumulative rainfall and mean soil loss ($g/m^2$/year) reviewed by Labrière *et al.* (2015) using event data from the field runoff studies across 21 humid-tropical countries. VCP in the legend denotes vegetation-related conservation practice(s).

### *4. Method of soil loss estimation from the project site using USLE*

#### (1) Quantification of average soil loss

The average soil loss ($A$) due to water erosion per unit area per year (t/ha) was estimated using an empirically based model, Universal Soil Loss Equation (USLE) developed by USDA-ARS (Wischmeier and Smith, 1978). The amount of potential soil erosion is calculated as

$$A = R \text{ x } K \text{ x } L \text{ x } S \text{ x } C \text{ x } P$$

where $A$ is the average soil loss due to water erosion (ton $ha^{-1}$ per year), $R$ the rainfall and runoff erosivity factor (MJ mm $ha^{-1}$ $h^{-1}$ per year), $K$ the soil erodibility factor (ton h $MJ^{-1}$ $mm^{-1}$), $L$ the slope length (m), $S$ the slope steepness (%), $C$ the cover and management practice factor, and $P$ the support practice. The USLE, which was developed for field use in the USA, uses inputs and produces output in US customary units, thus factor values were converted to SI units (Système International d'Unités) for presentation purpose. The calculation can basically be applicable and useful to estimate annual soil loss but not for event-to-event erosion. The application of this estimate is to enable farmers and soil conservation advisers <"planners"> to select combinations of land-use, cropping practice, and conservation practices, which will keep the soil loss down to an acceptable level (Hudson, 1993). Details of the variables for individual factor of the equation are shown below.

**Table:** Variable for individual factor of the USLE.

| Component for Factor | Variable and description |
|---|---|
| Rainfall Erosivity Factor: $R$ (MJ mm $ha^{-1}$ $h^{-1}$) | |
| $R = \sum E \text{ x } I_{30}$<br>$E = E_k \text{ x } r$<br>$E_k = 0.119 + 0.0873 \log_{10} I \quad (I \leq 76.2 \text{ mm/h})$<br>$E_k = 0.283 \quad (I > 76.2 \text{ mm/h})$ | where $E$ is individual total storm kinetic energy in MJ $ha^{-1}$ and $I_{30}$ the maximum 30-min intensity in mm $h^{-1}$,<br>$E_k$ is the rainfall energy per unit depth of rainfall (MJ $ha^{-1}$ $mm^{-1}$ $h^{-1}$)<br>$r$ rainfall amount (mm), and I rainfall intensity for particular increment in a rainfall event (mm $h^{-1}$).<br>The factor product $EI$ quantifies the effects of raindrop impact and reflects the amount and rate of runoff likely to be associated with the rain (Wischmeier and Smith, 1978). |
| **data/ measurement/ relevant information:** | |
| Measured rainfall during March/2015 to February/2016 of Atari and Sironko were 924 mm and 1,183 mm, respectively, and these amount meet with or fall within the range of rainfall distribution; 901-1,100 mm, covering lower-belt of Mt. Elgon region while overall farmlands range 900 – over 2,100 mm (NEMA, 2009) if extended to mountainous areas. Meteorological stations (with a data-loggers) were installed nearby the site of Atari and Sironko, presenting flood plain area. The rainfall data with 10-min interval were used to calculate the individual total storm kinetic energy. | |
| Soil Erodibility Factor: $K$ (t h $MJ^{-1}$ $mm^{-1}$) | |

| | |
|---|---|
| $100K' = 2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)$<br>$M = (si + vfs)(100 - cl)$<br>$K = 0.1317 \cdot K'$ | where $a$ is organic matter content, O.M. (%), $b$ soil structure code under USDA, $c$ soil permeability as permeability coefficient in cm/sec, $Si$ content of silt (%), $vfs$ content of very fine sand (%) and $Cl$ (< 0.002 mm) clay content (%). $K'$ is US customary unit therefore needs to be converted to SI units by factoring 0.1317. $K$ value specifies the tendency of the soil to erode.<br>The formula is applicable if the combined content (%) of soil and very fine sand (0.1-0.05mm) below 70% for estimation of $K'$ value.<br>The factor reflects the ease with which the soil is detached by splash during rainfall and/or surface flow; related to the integrated effect of rainfall, runoff and infiltration and accounts for the influence of soil properties on soil loss during storm runoff events (Angima *et al.*, 2003). |

**data/ measurement/ relevant information:**

Parameters were determined based on the basic soil physical characteristics investigated by the Environmental Impact Survey conducted by the PISD Project during 2015 September/October (wet season) and 2016 February (dry season). The soil samples were collected from top layer (A1) and air dried at about 25°C for 5 days to eliminate the moisture followed by sieving through a 2 mm mesh to remove debris and other non-soil materials including stones and plant roots. The sieved soil sample were then analysed from the Soil, Plant and Water analytical Laboratory at the Department of Agricultural and Environmental Science, Makerere University. Soil particle size distribution was determined using the hydrometer method to separate particles using the British Standard mesh-size (civil engineering). Soil samples were collected from 3 plots of each of two rice fields and one upland field within the project planning site to composite for representativeness over the site (in the wet and the dry seasons). Soil permeability (rate) was measured *in situ* by a simple filed percolation test using a dug hole. Soils of rangeland (bush/grassland) were categorized as upland soils due to their topographic location and therefore the same $K$ value were applied across these fields.

Slope Length Factor: $LS$

| | |
|---|---|
| $LS = (L'/22.1)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$<br>$m = 0.5$ (ps $\geq 5.0$ ps : slope steepness %)<br>$= 0.4$ ($3.5 \leq$ ps $\leq 4.5$)<br>$= 0.3$ ($1.0 \leq$ ps $\leq 3.0$)<br>$= 0.2$ (ps $< 1.0$) | where $\theta$ is slope gradient in degree.<br>Measurements for $LS$ were taken from the top of each field plot to its position down-slope (edge) where deposition was more than detachment and the length was less than 200 m.<br>The factor accounts for the effect for the effect of slope length and slope gradient on erosion (Angima *et al.*, 2003). |

**data/ measurement/ relevant information:**

Field slope length and gradient were determined using the 1:50,000 topographic map (1-m contour interval) developed for Atari and Sironko by the Aerial Photo Survey conducted for the PISD Project during the dry season February 2016. Maximum slope length was identified by taking consideration of erosion or deposit dominant area and related boundaries of landuse of each site. Aerial photos were also referred to overview ground conditions of the site. Field plots under different landuse were categorized into groups by range of maximum slope length to determined $LS$ factor, individually.

Cover management factor: $C$

| | |
|---|---|
| $C$ (dimensionless ratio)<br>$0 \leq C \leq 1$ | $C$-factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from a clean-tilled, continuous fallow. This factor represents the reducing effects of plant canopy and plant residue on soil erosion. |

**data/ measurement/ relevant information:**

$C$-factor was determined by reviewing and referring to previous field studies (literature) in which the USLE was directly applied for their individual evaluation purposes. The literature discussed mostly on erosion impacts under landuse difference or conversion from scale of rice-paddy plots to watershed comprising lowland paddies and others. Similarity in climate, annual precipitation, topographic location, feature of rice paddy practices were considered to select and adopt a value for the factor.

Support practice factor: $P$

| | |
|---|---|
| $P$ (dimensionless ratio)<br>$0 \leq C \leq 1$ | $P$-factor is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with up and down the slope culture, including terracing, contour tillage, and permanent barriers or strips. The value varies depending on the slope length and steepness. |

**data/ measurement/ relevant information:**

$P$-factor was determined also by reviewing and referring to the literature in which the USLE was directly applied. The literature discussed mostly on erosion impacts under landuse difference or conversion from scale of rice-paddy plots to watershed comprising lowland paddies and others. Similar consideration was taken into account for practical purpose. Note that $P$-factor value was changed from 1.0 (= no conservation measure, ploughing up and down slope directions) to 0.6 for the developed scenario where enhanced farm practices (plot arrangement, tillage and land husbandry) are to be expected. Range of slope gradient falls within 1–2 % or less than that.

---

**Table:** Current landuse (area, ha) for Atari and Sironko project areas calculated by the Arc-GIS database.

Scenarios

*Present*

Atari:

| Landuse | Area, ha |
|---|---|
| Bush (rangeland) | 28 |
| Grass field (rangeland/grazing) | 196 |
| Cultivated field | 219 |
| Paddy field | 211 |
| Total | 654 |

Sironko:

| Landuse | Area, ha |
|---|---|
| Bush (rangeland) | 380 |
| Grass field (rangeland/grazing) | 594 |
| Cultivated field | 341 |
| Paddy field | 144 |
| Total | 1,459 |

*Developed* (land converted)

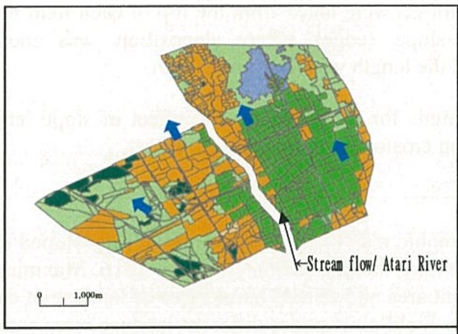
Atari:

| Landuse | Area, ha |
|---|---|
| Paddy field | 570 |
| Other cultivated land | 84 |
| Total | 654 |

Sironko:

| Landuse | Area, ha |
|---|---|
| Paddy field | 1,000 |
| Other cultivated land | 459 |
| Total | 1,459 |

Note: Broadleaf area, river (0-2ha), swamp, road and other spaces excluded for analytical purpose. Area of unit farm plots (rice/other crop) under the developed condition assumed as 50 x 150 ($m^2$) and 50 x 200 ($m^2$) for Atari and Sironko, respectively.



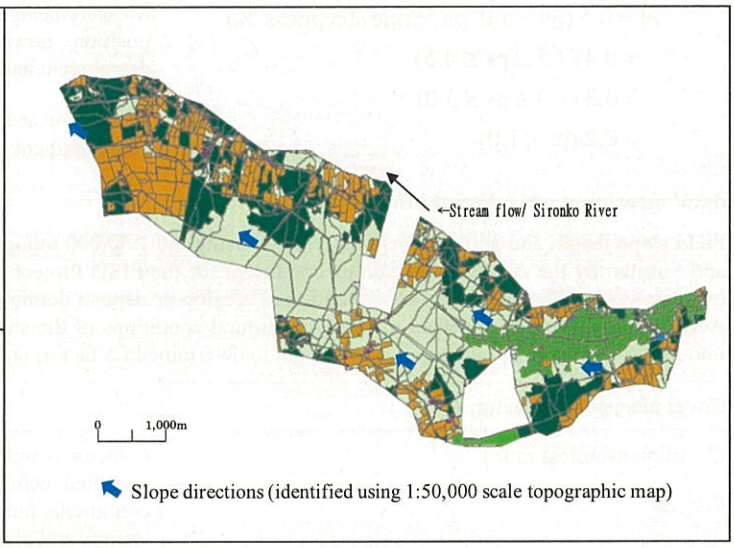




**Figure:** Landuse map for the project planning area of Atari (left) and Sironko (right) under present condition.

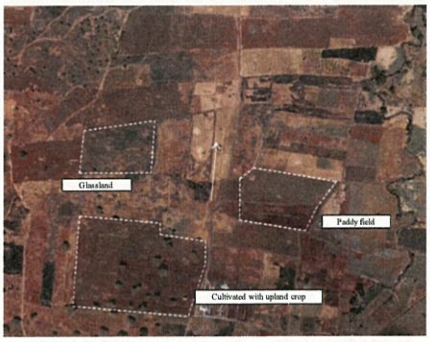



**Figure:** Aerial view of the left bank Atari commanding typical landuse condition. Arrows indicate direction of slope (maximum slope length) with very gentle steepness. The aerial photograph obtained during the aerial photo survey conducted for the PISD Project in February 2015.

### 5. Result

Individual parameters for USLE equation are summarized below for both Atari and Sironko. Data presented here are meant to show process of soil loss estimation using the empirical model that hinder some key process of soil erosion by water.

**Table:** Summary of *R* value (rainfall erosivity) for Atari and Srironko (present/developed).

Site: Atari

| Month, 2015/16 | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Total | Total Rainfall, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *R*, MJ・mm/ha・h | 183 | 729 | 406 | 1,083 | 26 | 167 | 79 | 277 | 152 | 761 | 1,381 | 0 | 5,244 | 924 |
| % | 3.5 | 13.9 | 7.7 | 20.6 | 0.5 | 3.2 | 1.5 | 5.3 | 2.9 | 14.5 | 26.3 | 0.0 | 100.0 | - |

Site: Sironko

| Month, 2015/16 | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Total | Total Rainfall, mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *R*, MJ・mm/ha・h | 233 | 1,073 | 1,057 | 439 | 53 | 713 | 511 | 116 | 1,192 | 180 | 20 | 0 | 5,585 | 1,183 |
| % | 4.2 | 19.2 | 18.9 | 7.9 | 1.0 | 12.8 | 9.2 | 2.1 | 21.3 | 3.2 | 0.4 | 0.0 | 100.0 | - |

**Table:** Summary of *K* value (soil erodibility) for Atari and Srironko (present/developed).

Site: Atari

| Site | Soil type | Percentage, % | | | | *M*** | *a* | *b* | Coefficient of permeability | *c* | *K'* | *K* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Clay (Cl) | Silt (Si) | VFS* | | O.M, % | Structure | | Permeability | | t・h/MJ・mm |
| Lowland Rice | Sandy Clay Loam | 50.0 | 36.0 | 14.0 | 16.5 | 1952 | 4.86 | 3 | $10^{-5}$ | 3 | 0.1170 | 0.0154 |
| Upland | Sandy Clay Loam | 52.0 | 36.0 | 12.0 | 13.0 | 1600 | 5.25 | 3 | $10^{-5}$ | 3 | 0.0962 | 0.0127 |

Site: Sironko

| Site | Soil type | Percentage, % | | | | *M*** | *a* | *b* | Coefficient of permeability | *c* | *K'* | *K* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Clay (Cl) | Silt (Si) | VFS* | | O.M, % | Structure | | Permeability | | t・h/MJ・mm |
| Lowland Rice | Sandy Loam | 60.0 | 26.0 | 14.0 | 18.0 | 2368 | 3.94 | 2 | $10^{-4}$ | 3 | 0.1189 | 0.0157 |
| Upland | Sany Loam | 58.0 | 36.0 | 10.0 | 20.5 | 1952 | 3.88 | 2 | $10^{-5}$ | 3 | 0.0961 | 0.0127 |

*VFS: Very Fine Sand, 0.18-0.063mm instead of 0.1-0.05mm (USDA)

***M* = (Si+VFS) (100-Cl)

| *b*: Soil Structure | | |
|---|---|---|
| | 1 | very fine granular |
| | 2 | fine granular |
| | 3 | med. or coarse granular |
| | 4 | blocky, platy or massive |

| *c*: Permeability | | |
|---|---|---|
| | 6 | very slow |
| | 5 | slow |
| | 4 | slow to med. |
| | 3 | moderate |
| | 2 | mod. to rapid |
| | 1 | rapid |

Site: Atari

| Site | Soil type | *K*, t・h/MJ・mm |
|---|---|---|
| developed farm area | Sandy Clay Loam | 0.0140 |

**K* value as an average value of lowland and upland areas, Atari (assumption: soil material of top layer removed and spread over the development area during construction period under the project implementation)

Site: Sironko

| Site | Soil type | *K*, t・h/MJ・mm |
|---|---|---|
| developed farm area | Sandy Clay Loam | 0.0142 |

**ditto* (for Sironko)

**Table:** Summary of *LS* value (topographic factor) for Atari and Sironko (present/developed).

Site: Atari

| Slope category | Landuse of Segment | No of plot | $L'$, m | $\theta$, ° | $ps$, % | $m$ | $LS$ |
|---|---|---|---|---|---|---|---|
| Atari, Right bank upper | Paddy field small | 35 | 30 | 0.23 | 0.40 | 0.2 | 0.090 |
| | Paddy field med | 60 | 50 | 0.23 | 0.40 | 0.2 | 0.099 |
| | Paddy field large | 64 | 80 | 0.23 | 0.40 | 0.2 | 0.109 |
| | Cultiv. land small | 9 | 20 | 0.23 | 0.40 | 0.2 | 0.083 |
| | Cultiv. land med | 15 | 40 | 0.23 | 0.40 | 0.2 | 0.095 |
| | Cultiv. land large | 10 | 80 | 0.23 | 0.40 | 0.2 | 0.109 |
| | Grass land med | 4 | 60 | 0.23 | 0.40 | 0.2 | 0.103 |
| Atari, Right bank lower | Paddy field small | 20 | 30 | 0.12 | 0.21 | 0.2 | 0.080 |
| | Paddy field med | 40 | 80 | 0.12 | 0.21 | 0.2 | 0.097 |
| | Cultiv. land small | 120 | 20 | 0.12 | 0.21 | 0.2 | 0.073 |
| | Cultiv. land med | 15 | 50 | 0.12 | 0.21 | 0.2 | 0.088 |
| | Cultiv. land large | 11 | 100 | 0.12 | 0.21 | 0.2 | 0.101 |
| | Grass land med | 6 | 100 | 0.12 | 0.21 | 0.2 | 0.101 |
| | Bush med | 0 | | | | | |
| Atari, Left bank | Paddy field small | 10 | 20 | 0.33 | 0.58 | 0.2 | 0.092 |
| | Paddy field med | 19 | 50 | 0.33 | 0.58 | 0.2 | 0.110 |
| | Paddy field large | 13 | 80 | 0.33 | 0.58 | 0.2 | 0.121 |
| | Cultiv. land small | 35 | 20 | 0.33 | 0.58 | 0.2 | 0.092 |
| | Cultiv. land med | 58 | 60 | 0.33 | 0.58 | 0.2 | 0.114 |
| | Cultiv. land large | 4 | 100 | 0.33 | 0.58 | 0.2 | 0.126 |
| | Grass land small | 30 | 30 | 0.33 | 0.58 | 0.2 | 0.099 |
| | Grass land med | 35 | 60 | 0.33 | 0.58 | 0.2 | 0.114 |
| | Grass land large | 10 | 200 | 0.33 | 0.58 | 0.2 | 0.145 |
| | Bush med | 13 | 100 | 0.33 | 0.58 | 0.2 | 0.126 |

Site: Sironko

| Slope category | Landuse/Size | No of plot | $L'$, m | $\theta$, ° | $ps$, % | $m$ | $LS$ |
|---|---|---|---|---|---|---|---|
| Sironko, upper | Paddy field med | 170 | 80 | 0.13 | 0.23 | 0.2 | 0.098 |
| | Cultiv. land med | 40 | 60 | 0.13 | 0.23 | 0.2 | 0.092 |
| | Grass land med | 30 | 80 | 0.13 | 0.23 | 0.2 | 0.098 |
| | Bush med | 25 | 120 | 0.13 | 0.23 | 0.2 | 0.106 |
| Sironko, middle | Paddy field med | 15 | 80 | 0.14 | 0.24 | 0.2 | 0.099 |
| | Paddy field large | 2 | 200 | 0.14 | 0.24 | 0.2 | 0.119 |
| | Cultiv. land med | 110 | 80 | 0.14 | 0.24 | 0.2 | 0.099 |
| | Grass land med | 111 | 80 | 0.14 | 0.24 | 0.2 | 0.099 |
| | Bush med | 40 | 120 | 0.14 | 0.24 | 0.2 | 0.107 |
| Sironko lower | Paddy field small | 0 | | | | | |
| | Cultiv. land small | 90 | 40 | 0.08 | 0.14 | 0.2 | 0.081 |
| | Cultiv. land med | 30 | 80 | 0.08 | 0.14 | 0.2 | 0.092 |
| | Cultiv. land large | 12 | 200 | 0.08 | 0.14 | 0.2 | 0.111 |
| | Grass land med | 50 | 80 | 0.08 | 0.14 | 0.2 | 0.092 |
| | Bush med | 53 | 120 | 0.08 | 0.14 | 0.2 | 0.100 |

Site: Atari

| Location | Landuse/Size | No of plot | $L'$, m | $\theta$, ° | $ps$, % | $m$ | $LS$ |
|---|---|---|---|---|---|---|---|
| over developed area | Paddy rice | 760 | 150 | 0.23 | 0.401 | 0.2 | 0.124 |
| | Upland crop | 112 | 150 | 0.23 | 0.401 | 0.2 | 0.124 |

*reclaimed unit field plot sized as 150m(L) by 50m

Site: Sironko

| Location | Landuse/Size | No of plot | $L'$, m | $\theta$, ° | $ps$, % | $m$ | $LS$ |
|---|---|---|---|---|---|---|---|
| over developed area | Paddy rice | 1,000 | 200 | 0.12 | 0.209 | 0.2 | 0.116 |
| | Upland crop | 459 | 200 | 0.12 | 0.209 | 0.2 | 0.116 |

*reclaimed unit field-plot sized as 200m(L) by 50m

**Table:** Summary of *C* (crop management factor) and *P* (conservation practice factor) value for Atari and Sironko (present/developed).

*C* Factor:
*P* Factor:

| Landuse | *C* | *P* |
|---|---|---|
| Rice paddy (lowland) | 0.28 | 0.1 |
| upland crop, cultivated | 0.35 | 1 |
| bush (rangeland) | 0.10 | 1 |
| grassland (rangeland/grazing-yard/prairie) | 0.10 | 1 |

*Under developed conditions*

| Landuse | *C* | *P* |
|---|---|---|
| Rice paddy | 0.28 | 0.1 |
| Cultivated with upland crop | 0.35 | 0.6 |

Factors in litelature:

| Literature | Landuse | *C* Factor | *P* Factor |
|---|---|---|---|
| **Roose (1976)** | Rice paddy (lowland), intensive fertilization | 0.1-0.2 | |
| West Africa (coastal countries) | Cultural techniques: corn, sorghum, millet | 0.4-0.9 | |
| annual rainfall 500-2100 mm | Crop cover of slow development | 0.3-0.8 | |
| | Over-grazed savannah or prairie | 0.1 | |
| | Bare soil continuously fallowed | 1 | |
| **Wischmeier and Smith (1978)** | No mulch (0% grand cover) | 1 | |
| USDA-ARS | If rows and tillage are in the direction of slope/ when terrace is not maintained and overtopping is frequent | | 1 |
| *In* the Manual for USLE | | | |
| | Contouring (slope 1-2%) | | 0.6 |
| | Farm planning area (slope 1-2%) | | |
| | -contour factor | | 0.6 |
| | -stripcrop factor | | 0.3 |
| **JICA (1999)** | Paddy (terrace) | 0.01 | 0.04 |
| Indonesia, West Java (ann. rainfall 2,000 mm) | Uplands (contour bund) | 0.4 | 0.5 |
| **Komamura et al. (2000)** | Forest | 0.001 | |
| Thailand, South | Paddy | 0.028 | |
| SCL - CL soil | Perrenial crop | 0.2 | |
| | Urban | 0.45 | |
| | Orchard | 0.15 | |
| | Bare land | 0.8 | |
| | Others | 0.225 | |
| **Ohbayashi et al. (2002)** | Paddy land | 0.1 | |
| China, Sichuan | Paddy-wheat | 0.111 | |
| Calcareous soil | Wheat(rape)-s.poteto+corn | 0.227 | |
| | Wheat(rape)-corn | 0.339 | |
| **Yoshikawa et al. (2004)** | Paddy land, flat plane | 0.38 | 0.6 |
| Japan | Paddy land, slope side | 0.02 | 0.5 |
| | Paddy land, abandoned, slope side | 0.04 | 0.5 |
| | Upland field: corn | 0.4 | |
| | Mowing grass | 0.02 | 1 |
| | - longitudinal ridge/flat ridge | | 1 |
| **Paiboonsak et al. (2005)** | Paddy field | 0.28 | 0.1 |
| Thailand, Northest (rainfall 950-1300 mm) | Crop field | 0.6 | 1 |
| lowland restricted to paddy | | | |
| **Vezina et al. (2006)** | Paddy field | 0.55 | 0.1 |
| Vietnam, northern highland (mean rainfall 1500mm/yr) | | | |
| paddy rice (2 cycles) alluvial plains (0-10° slope) | | | |
| **Unoki et al. (2009)** | Forest | 0.005 | |
| Japan, Hokkaido | Wheat | 0.2 | if no conserv. meas., *P*=1 |
| volcanic ash soil | Other than wheat | 0.4 | |
| | Grassland | 0.02 | |
| | Bare land | 1 | |
| | Water body | 0 | |
| **Shinde et al. (2009)** | Paddy | 0.28 | |
| India | Corn | 0.35 | |
| annual rainfall 1300 mm (monsoon) | Forest | 0.004 | |
| | Range | 0.1 | |
| | Wetland | 0.4 | |
| | Water body | 1 | |
| | - land with 0-2 % slope | | 0.6 |
| **Chen et al. (2012)** | Rice cultivation | 0.1 | 0.01 |
| Northern Taiwan | - abandaned | 0.05 | 0.01 |
| terraced paddy system | - green manure amendment | 0.25 | 0.01 |
| **Lai et al. (2015)** | Paddy field/ non-irrigated farmland | 0.06 | 0.11 |
| China, south | 0-5% slope | | |
| typical hilly area, 1500-2400 mm rain | | | |
| **OMAF*** | grain corn | 0.4 | |
| Ontario, Canada | silage corn | 0.5 | |
| | cereals (spring & winter) | 0.4 | |
| | seasonal horticultural crops | 0.5 | |
| | fruit trees | 0.1 | |
| | hay and pasture | 0.02 | |
| | up&down slope | | 1 |
| | cross slope | | 0.75 |
| | contour farming | | 0.5 |
| | strip cropping, cross slope | | 0.37 |
| | strip cropping, contour | | 0.25 |

*OMAFRA: Ontario Ministry of Agriculture, Food and Rural Affairs

**Table:** Summary of computed soil loss *A* (t) as 1-year basis under present condition of Atari and Sironko.

Site: Atari River Basin

| Location | Landuse/Size | No of plot | *R* (MJ·mm/ha·h) | *K* (t·h/MJ·mm) | *L*·*S* | *C* (0≦*C*≦1) | *P* (0≦*P*≦1) | *A* (t/ha per year) | Area within the Project Site (ha) | Soil Loss (t per year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Right bank, upper | Paddy field small | 35 | 5,244 | 0.0154 | 0.090 | 0.28 | 0.1 | 0.2030 | | |
| | Paddy field med | 60 | 5,244 | 0.0154 | 0.099 | 0.28 | 0.1 | 0.2248 | | |
| | Paddy field large | 64 | 5,244 | 0.0154 | 0.109 | 0.28 | 0.1 | 0.2469 | | |
| Right bank, lower | Paddy field small | 20 | 5,244 | 0.0154 | 0.109 | 0.28 | 0.1 | 0.2469 | | |
| | Paddy field med | 40 | 5,244 | 0.0154 | 0.097 | 0.28 | 0.1 | 0.2191 | | |
| Left bank | Paddy field small | 10 | 5,244 | 0.0154 | 0.092 | 0.28 | 0.1 | 0.2073 | | |
| | Paddy field med | 19 | 5,244 | 0.0154 | 0.110 | 0.28 | 0.1 | 0.2490 | | |
| | Paddy field large | 13 | 5,244 | 0.0154 | 0.121 | 0.28 | 0.1 | 0.2735 | | |
| | | | | | | ---- average ---- | | 0.2338 | 211 | 49.3 |
| Right bank, upper | Cultiv. land small | 9 | 5,244 | 0.0127 | 0.083 | 0.35 | 1.0 | 1.923 | | |
| | Cultiv. land med | 15 | 5,244 | 0.0127 | 0.095 | 0.35 | 1.0 | 2.209 | | |
| | Cultiv. land large | 10 | 5,244 | 0.0127 | 0.109 | 0.35 | 1.0 | 2.537 | | |
| Right bank, lower | Cultiv. land small | 120 | 5,244 | 0.0127 | 0.073 | 0.35 | 1.0 | 1.706 | | |
| | Cultiv. land med | 15 | 5,244 | 0.0127 | 0.088 | 0.35 | 1.0 | 2.049 | | |
| | Cultiv. land large | 11 | 5,244 | 0.0127 | 0.101 | 0.35 | 1.0 | 2.354 | | |
| Left bank | Cultiv. land small | 35 | 5,244 | 0.0127 | 0.092 | 0.35 | 1.0 | 2.130 | | |
| | Cultiv. land med | 58 | 5,244 | 0.0127 | 0.114 | 0.35 | 1.0 | 2.653 | | |
| | Cultiv. land large | 4 | 5,244 | 0.0127 | 0.126 | 0.35 | 1.0 | 2.939 | | |
| | | | | | | ---- average ---- | | 2.278 | 219 | 499 |
| Right bank, upper | Grass land med | 4 | 5,244 | 0.0127 | 0.103 | 0.10 | 1.0 | 0.684 | | |
| Right bank, lower | Grass land med | 6 | 5,244 | 0.0127 | 0.101 | 0.10 | 1.0 | 0.673 | | |
| Left bank | Grass land small | 30 | 5,244 | 0.0127 | 0.099 | 0.10 | 1.0 | 0.660 | | |
| | Grass land med | 35 | 5,244 | 0.0127 | 0.114 | 0.10 | 1.0. | 0.758 | | |
| | Grass land large | 10 | 5,244 | 0.0127 | 0.145 | 0.10 | 1.0 | 0.964 | | |
| | | | | | | ---- average ---- | | 0.748 | 196 | 147 |
| Right bank, upper | Bush med | 0 | 5,244 | 0.0127 | 0.000 | 0.10 | 1.0 | 0.000 | | |
| Right bank, lower | Bush med | 0 | 5,244 | 0.0127 | 0.000 | 0.10 | 1.0 | 0.000 | | |
| Left bank | Bush med | 13 | 5,244 | 0.0127 | 0.126 | 0.10 | 1.0 | 0.840 | | |
| | | | | | | ---- average ---- | | 0.280 | 28 | 7.84 |
| | | Total Soil Loss from the Project Area, ton/year | | | | | | | | **703** |

Site: Sironko Wetland

| Location | Landuse/Size | No of plot | *R* (MJ·mm/ha·h) | *K* (t·h/MJ·mm) | *L*·*S* | *C* (0≦*C*≦1) | *P* (0≦*P*≦1) | *A* (t/ha per year) | Area within the Project Site (ha) | Soil Loss (t per year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper | Paddy field med | 170 | 5,585 | 0.0157 | 0.098 | 0.28 | 0.1 | 0.240 | | |
| Middle | Paddy field med | 15 | 5,585 | 0.0157 | 0.099 | 0.28 | 0.1 | 0.243 | | |
| | Paddy field large | 2 | 5,585 | 0.0157 | 0.119 | 0.28 | 0.1 | 0.291 | | |
| Lower | Paddy field med | 0 | 5,585 | 0.0157 | 0.000 | 0.28 | 0.1 | 0.000 | | |
| | | | | | | ---- average ---- | | 0.193 | 144 | 28 |
| Upper | Cultiv. land med | 40 | 5,585 | 0.0127 | 0.092 | 0.35 | 1.0 | 2.287 | | |
| Middle | Cultiv. land med | 110 | 5,585 | 0.0127 | 0.099 | 0.35 | 1.0 | 2.450 | | |
| Lower | Cultiv. land small | 90 | 5,585 | 0.0127 | 0.081 | 0.35 | 1.0 | 1.993 | | |
| | Cultiv. land med | 30 | 5,585 | 0.0127 | 0.092 | 0.35 | 1.0 | 2.289 | | |
| | Cultiv. land large | 12 | 5,585 | 0.0127 | 0.111 | 0.35 | 1.0 | 2.749 | | |
| | | | | | | ---- average ---- | | 2.354 | 341 | 803 |
| Upper | Grass land med | 30 | 5,585 | 0.0127 | 0.098 | 0.10 | 1.0 | 0.692 | | |
| Middle | Grass land med | 111 | 5,585 | 0.0127 | 0.099 | 0.10 | 1.0 | 0.700 | | |
| Lower | Grass land med | 50 | 5,585 | 0.0127 | 0.092 | 0.10 | 1.0 | 0.654 | | |
| | | | | | | ---- average ---- | | 0.682 | 594 | 405 |
| Upper | Bush med | 25 | 5,585 | 0.0127 | 0.106 | 0.10 | 1.0 | 0.751 | | |
| Middle | Bush med | 40 | 5,585 | 0.0127 | 0.107 | 0.10 | 1.0 | 0.759 | | |
| Lower | Bush med | 53 | 5,585 | 0.0127 | 0.100 | 0.10 | 1.0 | 0.709 | | |
| | | | | | | ---- average ---- | | 0.740 | 380 | 281.1 |
| | | Total Soil Loss from the Project Area, ton/year | | | | | | | | **1,517** |

**Table:** Summary of computed soil loss $A$ (t) as 1-year basis under "developed" condition of Atari and Sironko.

Site: Atari River Basin

| Location | Landuse/Size | No of plot | $R$ (MJ·mm/ha·h) | $K$ (t·h/MJ·mm) | $L \cdot S$ | $C$ ($0 \leq C \leq 1$) | $P$ ($0 \leq P \leq 1$) | $A$ (t/ha per year) | Area within the Project Site (ha) | Soil Loss (t per year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Atari | Paddy rice | 760 | 5,244 | 0.0140 | 0.124 | 0.28 | 0.10 | 0.2551 | 570 | 145.4 |
| under development | Upland crop | 112 | 5,244 | 0.0140 | 0.124 | 0.35 | 0.60 | 1.9133 | 84 | 161 |
| | | | Total Soil Loss from the Project Area | | | | | | | 306 |

Site: Sironko Wetland

| Location | Landuse/Size | No of plot | $R$ (MJ·mm/ha·h) | $K$ (t·h/MJ·mm) | $L \cdot S$ | $C$ ($0 \leq C \leq 1$) | $P$ ($0 \leq P \leq 1$) | $A$ (t/ha per year) | Area within the Project Site (ha) | Soil Loss (t per year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sironko | Paddy rice | 1,000 | 5,585 | 0.0142 | 0.116 | 0.28 | 0.10 | 0.2575 | 1,000 | 257.5 |
| under development | Upland crop | 459 | 5,585 | 0.0142 | 0.116 | 0.35 | 0.60 | 1.9314 | 459 | 887 |
| | | | Total Soil Loss from the Project Area | | | | | | | 1,144 |

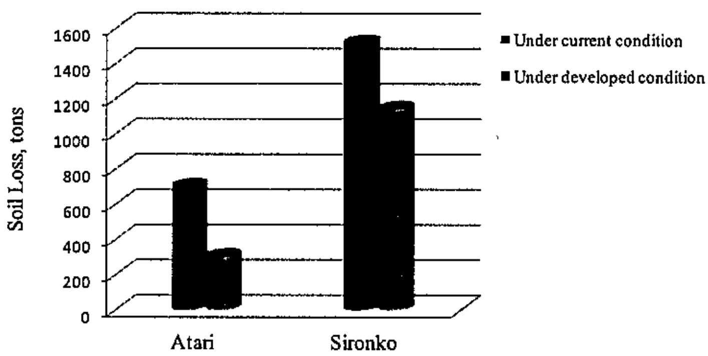



**Figure:** Estimated volume of soil loss from the planning area (over 1-year period).

## *6. Discussion*

In the study, we evaluated potential soil loss from cultivated land of two development planning areas of Atari and Sironko under the scenarios including present landuse and the developed condition with paddy system for a single year using the data set of 1-year rainfall, basic soil and landuse information. Soil loss amount (t/year) and unit area of soil loss amount (t/ha/year) estimated by applying the USLE were summarized in the table below. Both year-based and unit area soil loss amount from Atari and Sironko shows significant differences reflecting scale difference being associated with inherit landuse difference over the two sites under landuse-conversion. Magnitude of soil loss is greater for Sironko than that of Atari implying severer potential of soil erosion due mainly to special landuse patterns within the planning area which comprise of lowland paddies, cultivated land and rangelands. This may be reasonable result regarding closed value ranges of slope gradient, soil properties and the total storm kinetic energy of rainfall (5,244 and 5,585 MJ mm/ha h for Ataria and Sironko, respectively) across two sites and these are reflected by the factors of *LS*, *K* and *R*. Higher amount of soil loss for Sironko is attributed to increased cultivated land (with upland crop) for sediment source under the scenario of "developed condition" where vast area of rangelands having relatively higher ability of buffering are converted to the cultivated land. Consequently it is estimated greater mitigation of soil loss for Atari than for Sironko, as indicated by the percent mitigation.

**Table:** Estimated volume of soil loss (t/ha) from the planning area for 1-year observation period.

| Condition | Atari | Sironko |
|---|---|---|
| Under current condition | 703 t<br>(1.07 t/ha/year) | 1,517 t<br>(1.04 t/ha/year) |
| Under developed condition<br>(paddy and cultivated fields) | 306 t<br>(0.47 t/ha/year) | 1,144 t<br>(0.78 t/ha/year) |
| Total cultivated area* yielding soil loss | 654 ha | 1,459 ha |
| **Percent mitigation** | **56 %** | **25 %** |

*landuse data calculated for areal distribution of individual landuse based on Arc-GIS analysis. The total area includes Bush, Cultivated field, Grassland and Paddy field as current landuse basis; while, residential area, road, swamps, and other spaces were excluded.

Percent mitigation, degree of soil loss mitigation under different landuse setup, is defined as

$$\text{Percent Mitigation (\%)} = \frac{(S_0 - S_{conserv})}{S_0} \text{x}100$$

where $S_0$ is soil loss estimated for current condition (t/year), and $S_{conserv}$ is soil loss estimated for developed condition (t/year).

Ranges of soil loss (t/ha/year) estimated by the presenting study are compare with the previous field studies conducted for various landscape and landuse conditions within Uganda (see the table below). Soil loss amount of the two sites under the present or the developed condition falls within the range of low gentle slope gradient that can be found on hillslope position of cultivated field with slope gradient of a few percentages (1-6%), as is estimated by Brunner *et al.* (2008).

**Table:** Example of measured mean annual soil loss from dominant landuse system in Uganda.

| Range of soil loss (t/ha/year) | Landscape | Landuse | Author |
|---|---|---|---|
| 34 - 207 | Plateau | Footpaths and agricultural fields | De Meyer *et al.* (2011)* |
| 40 - 45 | Plateau | Maize, maize-bean intercrop | Majaliwa (1998)* |
| 35.99 | Mountainous hill slopes (10-25%), Mt. Elgon region | Annual crops (maize) | Semalulu *et al.* (2014) |
| 20 | Plateau | Annual cropping | Nakileza (2005)* |
| 3.3 | Hillslope position as summit, 1-2% slope | Maize cropping on soil of Sandy Clay to Sandy Clay Loam | |
| 2.5 | Hillslope position as upper-shoulder, 2% slope | *Ditto* | Brunner *et al.* (2008)** |
| 2.0 (average) | Entire hillslope from summit to valley, 1-6% slope | Maize cropping on soil of Sandy Clay/ Sandy Loam to Sandy Clay Loam | |
| 0.01 - 0.32 | Plateau | Forest | Kizza *et al.* (2013)* |

* after Bamutaze (2015)

**estimated by a process-based physical prediction model, Water Erosion Prediction Project (WEPP, developed by USDA-Agricultural Research Service) using input parameters including soil texture, rock fragments, organic matter and Cation Exchangeable Capacity (CEC), land management, tillage option, meteorological data and delineation of overland flow elements for individual hillslope unit.

**Table:** Categorization of soil erosion risk for Mt. Elgon region by Jiang *et al.* (2014).

| Erosion risk | Threshold (t/ha/year) |
|---|---|
| Very low | Soil Loss ≤ 2 |
| Low | 2 ≤ Soil Loss ≤ 10 |
| Moderate | 10 ≤ Soil Loss ≤ 50 |
| High | 50 ≤ Soil Loss ≤ 100 |
| Very high | Soil Loss ≥ 100 |

### *7. Summary, Limitation of Data Interpretation and Implication for Necessity of Conservation*

The study assessed the effects of landuse conversion from upland-crop dominant system to rice paddy system on potential soil loss using the empirical model USLE with available meteorological and soil data. The result of this study show that development of paddy system conserve soil of cultivated land more effectively than present condition. This is clearly shown by the mitigation percentage estimated for soil loss were 56 % and 25 % for Atari and Sironko, respectively, under the scenario of landuse conversion of the presenting study although the amount of potential soil loss as yearly basis (t/ha/year); some 0.5-1.0 t/ha/year, show very-low risk level for Atari and Sironko under two scenarios (see the table above). The ranges of erosion risk well agree with that of the lowland area analyzed and reported by Jiang *et al.* (2014) for Manafwa catchment close to Mbale. It is, however, limitation exists when interpreting these results due to the following reasons.

- USLE is not a precise research tool to study the process of erosion (Hudson, 1993).
- Validity of output data may only be verifiable if data from field measurements and simulated soil loss are compared though it is not our intension in this study.
- USLE may evaluate annual soil loss from paddy system where water-tapping/ drained off condition exist season to season despite the fact that several studies attempted to apply USLE directly for paddy system with deliberations on determining the factors of Crop and Management to approximate potential ability of the paddies to reduce outflow of sediments downward (Roose, 1976; Paiboonsak *et al.*, 2005; Chen *et al.*, 2012, for instance).

For example, the USLE may present soil loss output by rill, inter-rill or sheet erosion but not channel erosion over developed gully network and associated sediment transport toward in and out of the farm plots are not taken into account (Nishimura, 1998) while the process-based physical models will present this. Consequently, the results may not provide information on sediment outflow into river system and hence impact on sedimentation and relevant water quality for environment aspect. Nevertheless it is still valuable to estimate loss or replacement of top soil from farmers' field to out of or within the plot indicating loss of farm input and other labour and financial input by the farmers on their properties as a foundation for crop production.

For more précised analysis, Soil Water Assessment Tool (SWAT) model, developed by USDA ARS, coupling with the USLE (Sakaguchi *et al.*, 2014) applicable for soil loss from paddy area, would be practical to evaluate event-to-event sedimentary discharge based on individual parameters representing regional topography, soils, landuse, farm practice, precipitation and hydrologic aspects at watershed scale. It is clear that paddy system involve complicated sedimentary and hydrological behaviour such as overflows from paddy fields during water management, paddling and drying of paddy soil where in the process transportation of sediments involve dynamics through annual farm practices.

Overall the presented result of evaluation suggests a necessity of soil conservation practices for the project site through the proposed project plan (irrigation scheme development). Nutrient losses, as NPK basis, from the top soil due to cultivation without any conservation practices can lead "Financial Loss" about US$ 172 ha/year in mountainous area of Mt. Elgon region (almost twice of that for fields with conservation) as estimated by Semalulu *et al.* (2014) for example. This holds true that prolonged soil loss process may result in serious depletion of soil fertility and hence loss of financial investment which the small-scale farmers catered for within their limited affordability despite different severity according to topographical location. Slight or very gentle slope-gradient over the project sites of Atari or Sironko involve potential erosion risk which is critically related to land preparation for upland and lowland crops (paddy rice etc) associated with surface water management. This was observed and revealed by the sedimentary outflow occurred over the lowland of Tabagonyi area in Bulambuli District near Atari (see the Figure below).

**Figure:** sedimentary outflow from paddy area due to inappropriate field-arrangement (land levelling, levee making, puddling and re-levelling) and related land husbandry. Photo was taken by the PISD Study Team during the survey in Atari area (Tabagonyi, Bulambuli District).

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