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 *10^th^ 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.

<u>Soil erosion control</u>: 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)

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.

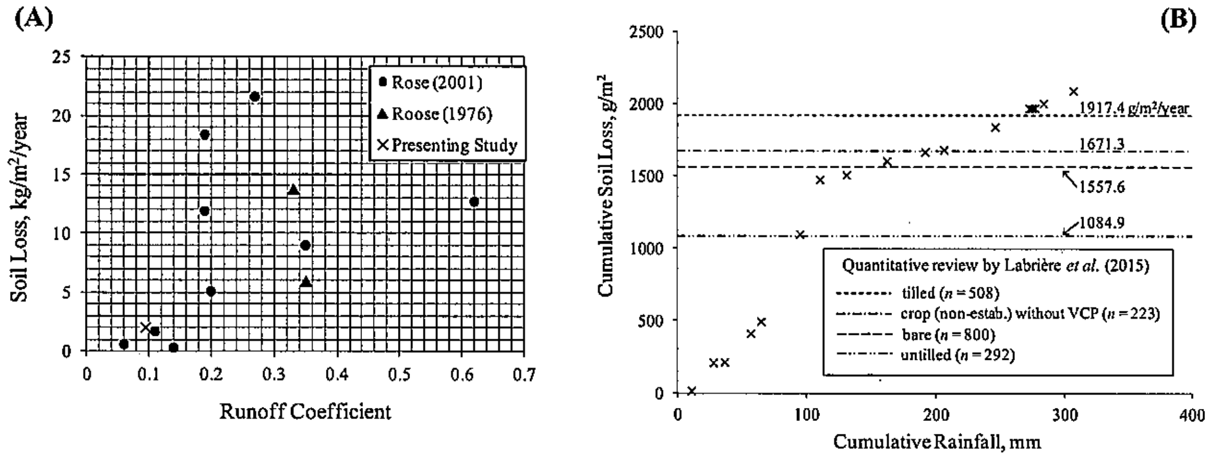

Figure: **(A)** Relationship between average annual runoff coefficient and soil loss (kg/m^2/year). Data set obtained from the presenting study were projected against that from the past literature including field runoff-plot study under natural rainfall across tropical climate countries of West Africa (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.

$$100K' = 2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)$$

$$M = (si + vfs)(100 - cl)$$

$$K = 0.1317 \cdot K'$$

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.

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.

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*

$$LS = (L'/22.1)^m (65.41\sin^2\theta + 4.56\sin\theta + 0.065)$$

$$m = 0.5\ (\text{ps} \geq 5.0\quad \text{ps: slope steepness \%})$$
$$= 0.4\ (3.5 \leq \text{ps} \leq 4.5)$$
$$= 0.3\ (1.0 \leq \text{ps} \leq 3.0)$$
$$= 0.2\ (\text{ps} < 1.0)$$

where θ is slope gradient in degree.

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.

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)

$0 \leqq C \leqq 1$

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)

$0 \leqq C \leqq 1$

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.

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

	Landuse	*C*	*P*
C Factor:	Rice paddy (lowland)	0.28	0.1
P Factor:	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 *In* the Manual for USLE	If rows and tillage are in the direction of slope/ when terrace is not maintained and overtopping is frequent		1
	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 "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

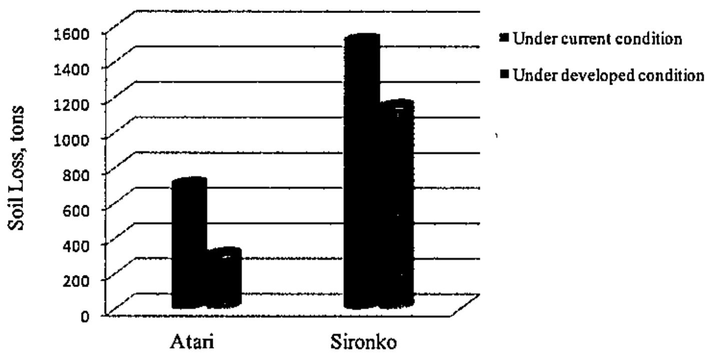

Figure: Estimated volume of soil loss from the planning area (over 1-year period).

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 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

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