SEDIMENTATION inside a RESERVOIR: Comparison between a MATHEMATICAL Model (RUSLE) and MEASURED DATA

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Introduction

The purpose of this study is to illustrate the validity of the RUSLE (Revised Universal Soil Loss Equation) mathematical model to determine erosion and, consequently, reservoir siltation. Four case studies will be presented in this paper: three concerning existing dams (Bagré, Luphohlo and Ruzizi II) and the fourth of a designed project for future construction (Lufubu 3, part of the cascade of three plants along the Lufubu river). In the first group of existing dams, the sedimentation will be determined comparing the *ante-operam* volume-area curves of the reservoirs, with the sedimented volume assessed through a bathymetric survey carried out after 30 to 40 years of reservoir operation. The results evaluated in this way will then be compared with the those determined using the mathematical RUSLE model. With regard to the Lufubu 3 reservoir, which is not yet constructed, the sedimentation behaviour of the Lufubu river is analysed comparing the mathematical RUSLE model with the sediment rate, measured along the river for over a year by the "Zambia Special Sediment Study Group for the Lake Tanganyika Biodiversity Project", whose data were elaborated and published by Dr. Sichingabula [1].

As will be pointed out, the sedimentation analysis carried out adopting the RUSLE model is extremely expeditious and does not require the development of time-consuming and costly field analyses. This analysis provides the designer with a good reference for assessing the useful life of such important and strategic structures.

1. Overview of the Investigated Reservoirs

All the projects taken into consideration for the present analysis are in sub-Saharan Africa. The table below shows some main features of the projects examined: (Tab. 1).

Tab. 1. Main Features of the Investigated Reservoirs

Project Name		**Bagré MPP**	**Luphohlo MPP**	**Ruzizi II HPP**	**Lufubu 3 HPP**
Country	-	Burkina Faso	Eswatini	DRC / Rwanda	Zambia
Catchment Area	Km^2	35,328	594	89	9,020
Res. Capacity @ FSL	Mm^3	1,690	23.6	2.6	400
Dam High	m	30	40	13	45
Commissioned	yr	1994	1984	1989	planned

2. Overview of Erosion and Sedimentation Phenomena

Erosion refers to the detachment of soil particles caused mainly by natural forces of wind, water, ice, etc.. When these detached particles mix with various different organic and inorganic materials during the process of erosion, sediments are formed. Basically, sediments refer to complex mixtures of organic and inorganic particles in the water [2], [3].

Sediment yield is the end product of erosion or wearing away of the land. Not all this eroded material enters the stream system. Some of the material is deposited as alluvial fans, along river channels, and across flood plains. The portion of eroded material that is transported through the stream network to some point of interest is referred to as the sediment yield. Therefore, the amount of sediment inflow to a reservoir depends on the sediment yield produced by the upstream watershed. The factors that determine a watershed's sediment yield can be summarized as follows [4]: rainfall amount and intensity; soil type and geologic formation; ground cover; land use; topography; upland erosion rate; drainage network density; slope, shape, size and alignment of channels.

All reservoirs formed by dams on natural water courses are subject to some degree of sediment inflow and deposition.

The deposition within the reservoir develops from upstream to downstream, depositing the coarser material in the upper part and the finer component in the downstream part of the reservoir.

The sedimentation process is progressive and tends to settle on a final horizontal surface. (Fig. 1).

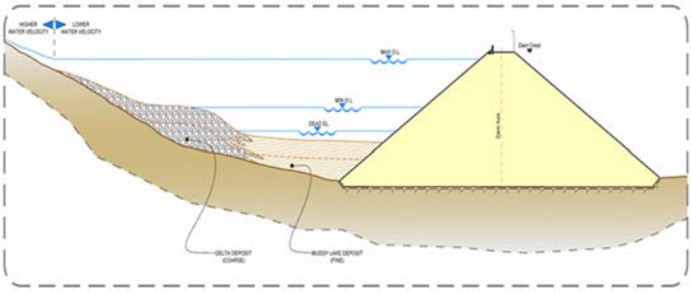


Fig. 1. Typical reservoir sediment profile

3. RUSLE Erosion Model

The Revised Universal Soil Loss Equation (RUSLE) is a mathematical model used to estimate soil loss. The RUSLE method combines the effects of the environmental factors mainly governing soil erosion on a single parametric equation. According to RUSLE, annual soil loss is expressed by means of the following formula (1):

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

where the factors, synthetically, represent: A = specific mean annual soil loss, R = index expressing the erosivity power of the rain, K = pedologic factor expressing soil erodibility, L = topographic factor related to slopes length, S = topographic factor related to slope steepness, C = correction coefficient accounting for land cover, P= correction coefficient accounting for control practices.

A Factor

A is expressed in terms of mass per unit area of soil loss in the unit time (*tons/km²/year* or *tons/hectare/year*). The factors R, K, L, S, C and P are estimated on an empirical basis as illustrated hereafter.

R Factor

Rain is one of the major factors that govern soil loss, both in terms of impact energy of the water drops (that detach the soil particles) and because excess water that does not permeate the soil flows on the surface causing sheet and rill erosion. This aspect is nevertheless more related to the local morphology of the terrain such as slope steepness and length. On a yearly basis, the kinetic energy of the rain can be considered by means of the Modified Fournier Index (MFI) that is expressed as follows (2):

$$MFI = \sum_{i=1}^{12} \frac{{p_i}^2}{P} \tag{2}$$

where p_i is the average monthly precipitation of the i^{th} month and P represents the average annual total rainfall.

Then, the R factor is calculated as (3):

$$R = 4.17 \cdot MFI - 152 \tag{3}$$

Expressing p and P in mm, the R factor assumes dimensions of $\frac{MJ \cdot mm}{ha \cdot yr \cdot h}$.

K Factor

Soil texture and composition mark the way and the amount of loss processes. K factor is expressed as a function of sand, silt, clay and organic carbon concentration. The K factor is expressed as the rate of soil loss per rainfall erosion index unit, typically $\frac{ton \cdot ha \cdot h}{MJ \cdot ha \cdot mm}$, and is given by (4):

$$K = 7.592 \left[0.2 + 0.3 \cdot e^{\left[-0.0256 \cdot SAN \cdot \left(1 - \frac{SIL}{100}\right)\right]}\right] \cdot \left(\frac{SIL}{CLA + SIL}\right)^{0.3} \cdot \left[1 - \frac{0.25 \cdot OrgC}{OrgC + e^{(3.72 - 2.95 \cdot OrgC)}}\right] \cdot \left[1 - \frac{0.7 \cdot SN1}{SN1 + e^{(-5.51 + 22.9 \cdot SN1)}}\right] \tag{4}$$

where SAN, SIL, CLA and $OrgC$ are sand, silt, clay and organic carbon contents of the soil (%), and $SN1 = 1 - SAN/100$, respectively.

L & S Factors

Within the RUSLE, the L and S factors reflect the effect of topography on erosion; the slope length factor (L) represents the effect of slope length, and the slope steepness factor (S) reflects the influence of the slope gradient on erosion phenomena. The L and S factors are commonly evaluated as a unique parameter and referred to as the relief factor LS. The LS parameter is evaluated as follows (5):

$$LS = 1.4 \cdot \left(\frac{A_s}{a_0}\right)^{0.4} \cdot \frac{sin(\theta)}{b_0} \tag{5}$$

where: A_s = upslope drainage specific area of the considered cell, a_0 = 22.1 m, reference slope length, θ = slope of the cell, and b_0 = 0.0896, *sine* of a reference slope equal to 9%. The LS is a non-dimensional factor whose values range, for the catchment area of interest.

C & P Factors

The Land Cover Management Factor (C) is used to express the effect of plants and soil cover [11]. Plants can reduce the runoff velocity and protect surface pores. The C factor measures the combined effect of all interrelated cover and management variables, and it is the factor that is most readily changed by human activities [11]. By definition, C equals 1 under standard fallow conditions. As surface cover is added to the soil, the C factor value approaches zero. Since the satellite image data provide up to date information on land cover, the use of satellite images in the preparation of land cover maps is widely applied in natural resource surveys [11]. Therefore, since the C factor is strictly related to the land cover and land use, its evaluation can be performed by means of the digitized land cover dataset and by joining the land cover attributes to C values assessed by an average of the literature values, according to the following assessing table (Tab. 2):

Tab. 2 C corrective coefficient associated to land cover

Land Cover Classes	C
Forest	0.0019
Mosaic Forest/Shrubland/Grassland	0.0035
Savannah	0.1815
Cropland	0.35
Bare Ground	0.18
Urban and Built	0.0565
Water Bodies	0

It is noteworthy that water bodies do not contribute to soil loss and therefore the related C value is null. According to Gitas [12] the P values are calculated as the ratio of the rate and amount of soil loss due to a specific support practice to the soil loss due to row farming upward and downward of the slope condition. The values of P factor range from 0 to 1. Among these values, the highest value is assigned to the areas where there is absence of any conservation practices (i.e., grasslands and open areas), and the minimum values given to plantation areas with contour cropping and built-up land.

4. Case Study No. 1: BAGRÈ Reservoir

4.1 Introduction

Bagrè dam is located in Burkina Faso along the Nakanbé river, at about 30 km from the Ghanaian border. It was built in 1993 and came into operation in 1994. The catchment area is approximately 35,000 km^2 and the mean annual runoff is approx. 48 m^3/s. The initial available reservoir capacity was about 1,690 Mm^3 with the F.S.L. at 235 m a.s.l.

4.2 RUSLE model

The RUSLE model was applied using the following input data:

- *R* factor
  The annual variability of precipitation was assessed by the values of the global database CRU TS (Climatic Research Unit Time-Series) [10]. This database is presented in raster form with a cell size of 0.5°/pixel and contains rainfall data from 1901 to 2014. The data are expressed as monthly averages and are obtained by interpolating data from thousands of rainfall stations. In this case, the Bagré catchment area falls within approximately 20 cells of the database and, in order to make the rainfall more representative, we only considered averages for the most recent years (2011 to 2014) in the analysis period. Taking this rainfall data

into account, the MFI values and consequently the *R* factor were calculated, applying the formulas set out in Chapter 3.

- *K* factor
  The determination of soil erodibility was deduced from the global Harmonized World Soil Database (HWSD) map from the FAO [10]. The dataset is characterized by a cell dimension of 1x1 km and contains relevant information organized on homogeneous soil map units (each characterized by the same soil properties). The dataset itself also contains key information on soil composition, chemical/physical characteristics, in relation to particle size distribution and organic carbon content. This information is thus used to determine the *K* factor at the catchment scale. For the Bagré catchment, 24 homogeneous soil map units can be identified from the FAO Harmonized World Soil Database; for each of them, the *K* value was calculated using the two equations shown, taking the average between them to obtain a more reliable assessment.
- *L* & *S* factors
  To assess the slope length factor (*L*) and the slope steepness factor (*S*), the SRTM (Shuttle Radar Topography Mission) 30 m cell size digital global elevation model was adopted.
- *C* factor
  The *C* values was based on recent satellite images from the Landsat 8 satellite (pixel size 30 m), as it has the capacity to acquire images over a large portion of the spectrum, which goes far beyond the radiation visible to the human eye and includes the infra-red, using a relationship based on the NDVI.
- *P* factor
  At the level of the basin, the distribution of anti-erosion practices is difficult to evaluate and, in any case, too variable to be defined properly. It must also be considered that the *P* factor can vary significantly over time. For these reasons, its evaluation has been neglected and, as a precaution, the maximum value, 1, has been adopted.

The *A* factor was calculated on a cell-by-cell basis, using GIS software.

The cell size used is equal to the SRTM database, i.e., 30x30 m. Figures 2 and 3 show the spatial variation of soil loss and the frequency distribution of soil erosion rates respectively.

From the analysis of the histogram (Figure 3), is clear that the distributions of the erosion rates are very skewed. In these cases, the median is a more reliable estimator of the true mean value than the mathematical mean of the values.

Consequently, the expected value of the soil erosion rate for the basin can be assumed to be equal to: $\text{RUSLE}_{\text{BAGRÉ}}$ = 2.18 t/ha/y

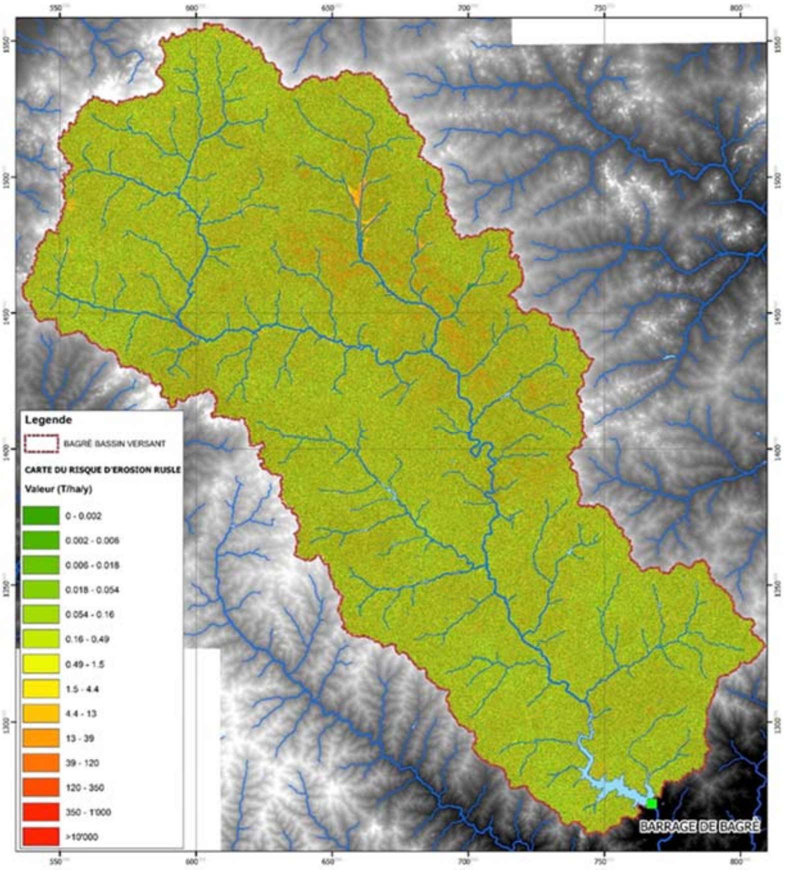


Fig. 2. Bagre, RUSLE erosion model Result

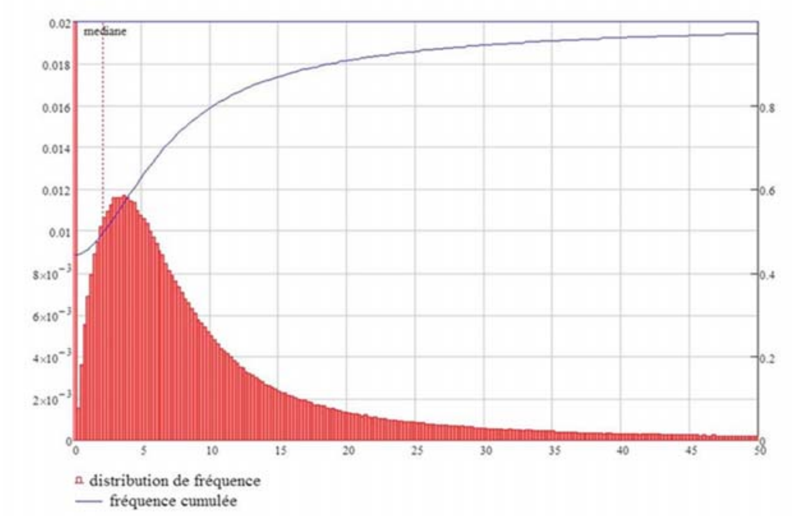


Fig. 3. Bagre, Frequency distribution of the RUSLE erosion rate

4.3 Bathymetric Survey

In 2016, after about 24 years of operation of the plant, a bathymetry of the reservoir was performed. The bathymetric investigation was carried out by means of the "SonarMite Echo Sounder1", a single-beam sonar system. The useful reservoir volume at the date of measurement was determined by comparing the historical volume-area curve of the reservoir with the newly surveyed one.

The difference between the modern and historical useful volume is the volume of sediment deposited over the years in the Bagré reservoir which results to be about 164 Mm^3, i.e. 6.8 Mm^3/yr.

4.4 Comparison of Results

The following table (Tab. 3) shows both the results of RUSLE model application and the bathymetrical survey related to average erosion rate per year and the sedimented volume during the entire existence of the reservoir up to the survey.

Tab. 3 Bagre, RUSLE vs Bathymetrical Survey

Method	t/ha/yr	10^3 m^3/yr	mm/yr
RUSLE	2.2	7,000	0.20
Bathymetrical Survey	1.8	6,800	0.19

5. Case Study No. 2: LUPHOHLO Reservoir

5.1 Introduction

Luphohlo Dam is located in Eswatini, in the north-west of the country, along the Lusushwana river and came into operation in 1994. The catchment area is approximately 594 km^2 and the mean annual runoff is approx. 3.2 m^3/s. The initial available reservoir capacity was about 23.6 Mm^3 with the F.S.L. at 1,015.6 m a.s.l.

5.2 RUSLE Model

The RUSLE model was applied using the following input data:

- *R* factor
  The assessment of the *R* factor was based on a 34 year-long historical series of precipitation data taken from the CHIRP database, which provides monthly precipitation values spatially distributed over a 0.05° x 0.05° points grid, corresponding to approximately 4990 x 5540 meters at the project location.
- *K* factor
  The determination of soil erodibility was deduced from the global Harmonized World Soil Database (HWSD) map from the FAO [10].
- *L* & *S* factors

The SRTM (Shuttle Radar Topography Mission) DEM was adopted as the main basis for the topography of the area and for the assessment of the *LS* factor at catchment scale. The database is characterized by a cell size equal to 30 m.

- *C* factor
  The land cover classification process was based on high-resolution (50 cm/pixel) satellite images from Digital Globe. As the catchment area is not too large, it was possible to delimit the classes (Forest, Savannah, etc.) manually directly on the high-definition satellite images.
- *P* factor
  The P factor has been assumed equal to 1.

The *A* factor was calculated on a cell-by-cell basis, using GIS software. The cell size used is equal to the SRTM database, i.e., 30x30 m. Figures 4 and 5 respectively show the spatial variation of soil loss and the frequency distribution of soil erosion rates. From the analysis of the histogram (Figure 5), it is clear that the distribution of the erosion rates is highly asymmetric, with most of the values located around the lowest region of the graph and few, scattered points characterized by the largest rates. In such cases, the median value allows us to make a more representative estimation of the real erosion value with respect to the simple mathematical average.

Therefore, the result of the erosion rate at the Luphohlo Dam was assumed to be: $RUSLE_{LUPHOHLO}$= 0.32 t/ha/yr.

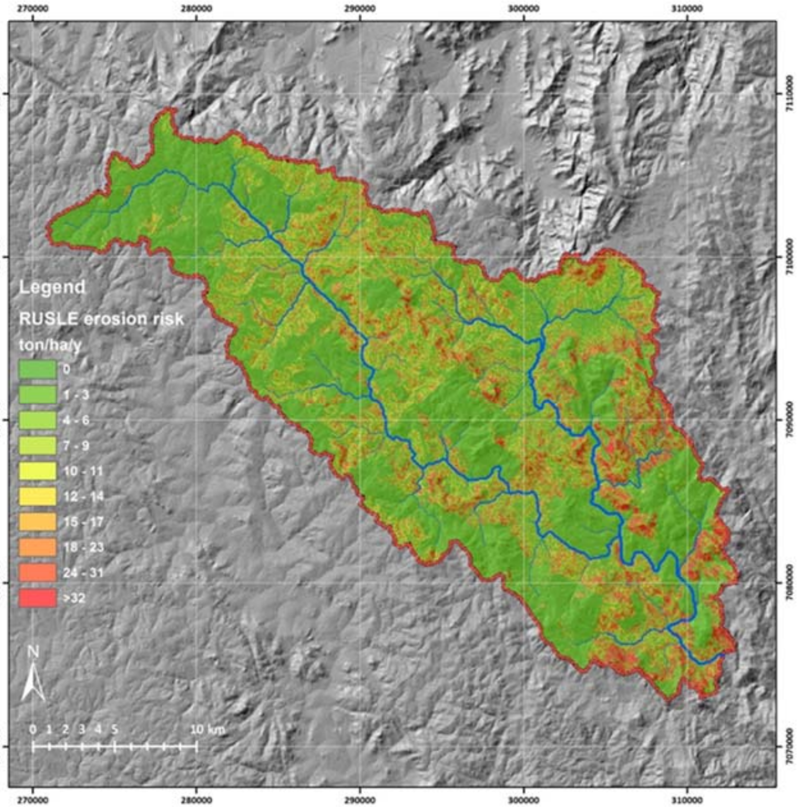


Fig. 4. Luphohlo, RUSLE erosion model Result

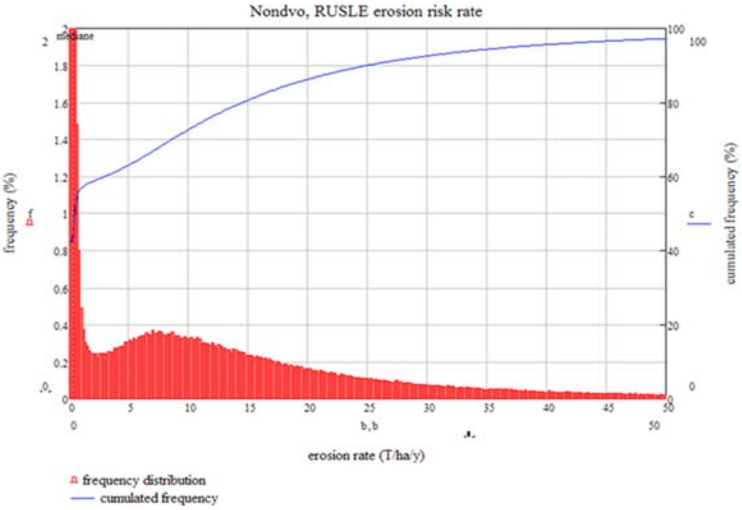


Fig. 5. Frequency distribution of the RUSLE erosion rate

5.3 Bathymetric Survey

In 2018, after about 35 years of operation of the plant, a bathymetric survey of the reservoir was performed. The investigation was carried out by means of the "SonarMite Echo Sounder1", a single-beam sonar system. The useful reservoir volume at the date of measurement was determined by comparing the historical volume-area curve of the reservoir with the newly surveyed one.

The difference between the modern and historical useful volume is the volume of sediment deposited over the years in the Luphohlo reservoir which results to be about 1.0 Mm^3, i.e., 28,600 m3/yr.

5.4 Comparison of Results

The following table (Tab. 4) shows both the results of RUSLE model application and the bathymetrical survey related to average erosion rate per year and the sedimented volume during the entire existence of the reservoir up to the survey.

Tab. 4, Luphohlo, RUSLE vs Bathymetrical Survey

Method	t/ha/yr	10^3 m^3/yr	mm/yr
RUSLE	0.3	17	0.03
Bathymetrical Survey	0.4	28	0.05

6. Case Study No. 3: RUZIZI II reservoir

6.1 Introduction

Ruzizi II Dam is located between Democratic Republic of Congo and Rwanda along the Ruzizi river about 20 km downstream of the Lake Kivu. It came into operation in 1989. The catchment area is approximately 90 km^2. The initial available reservoir capacity was about 2.57 Mm^3 with the F.S.L. at 1,394.0 m a.s.l.

6.2 RUSLE model

The RUSLE model was applied using the following input data:

- *R* factor
  The assessment of the *R* factor was carried out on the basis of recorded historical rainfall series. The data consists of a 57-year historical series, from 1950 to 2006, containing monthly cumulative values of rainfall in the Lake Kivu area obtained from radar measurements. Considering that Lake Kivu is less than 10 km upstream of the Ruzizi II reservoir, the rainfall data can be considered already spatialised and scaled to the area and can be used as a constant multiplication factor (which does not vary in space). The values MFI and *R* have been calculated as explained in Chapter 3.
- *K* factor
  The determination of soil erodibility was deduced from the global Harmonized World Soil Database (HWSD) map from the FAO [10].
- *L* & *S* factors
  For the assessment of the *LS* factors the average values of the two database models SRTM (Shuttle Radar Topography Mission) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) were adopted.
- *C* factor
  The *C* value was based on recent satellite images from the Landsat 8 satellite (pixel size 30 m), using a relationship based on the NDVI.
- *P* factor
  At the level of the basin, the distribution of anti-erosion practices is difficult to evaluate so as a precaution, the maximum value, 1, was also adopted in this case study.

The *A* factor was calculated on a cell-by-cell basis, using GIS software. The cell size used is equal to the ASTER/ASRTM database, i.e., 30x30 m. Figures 6 and 7 respectively show the spatial variation of soil loss and the frequency distribution of soil erosion rates.

From the analysis of the histogram (Figure 7), it is clear that frequency distribution of the erosion rates is highly asymmetric with most of the values located around the lowest region of the graph and few, scattered points characterized by the largest rates. Also in this case, the median is a more reliable estimator of the true mean value than the mathematical mean of the values.

Consequently, the expected value of the soil erosion rate for the basin can be assumed to be: $RUSLE_{RUZIZI}$= 17 t/ha/yr

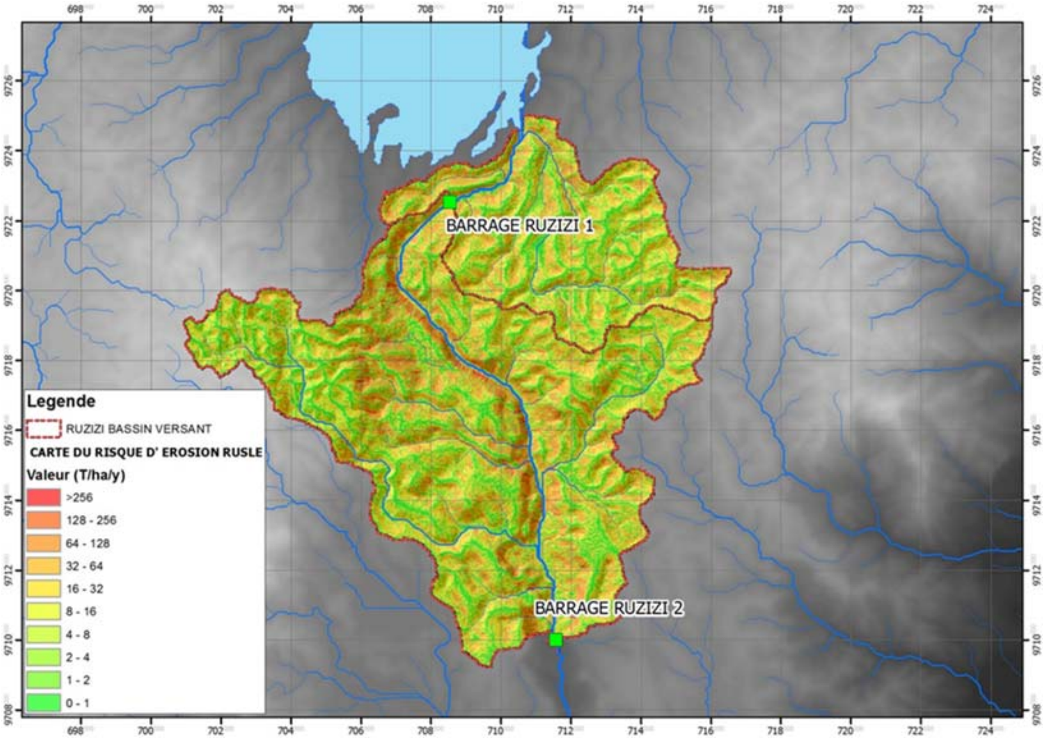


Fig. 6. RUSLE erosion model Result

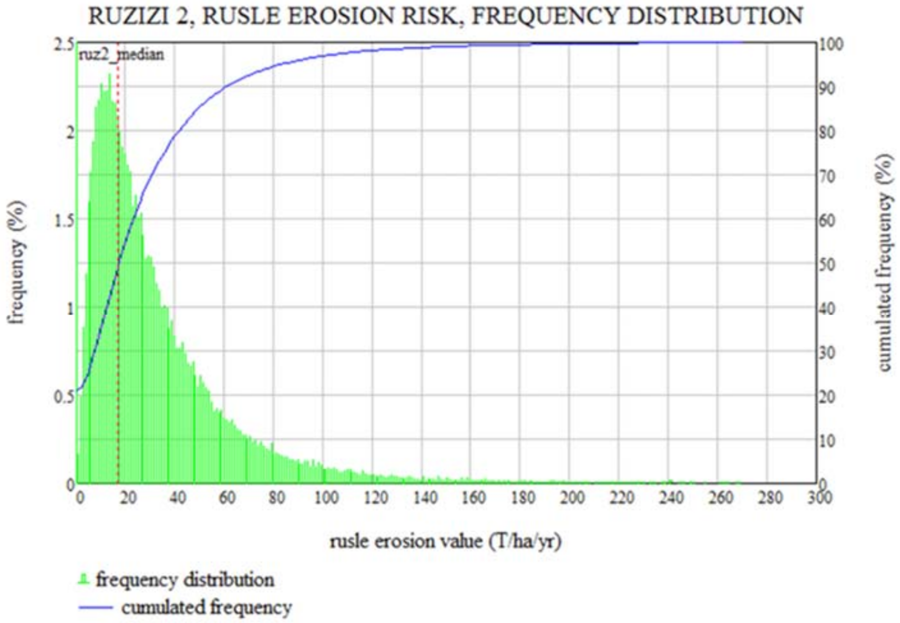


Fig. 7. Frequency distribution of the RUSLE erosion rate

6.3 Bathymetrical Survey

In 2013, after about 24 years of operation of the plant, a bathymetrical survey of the reservoir was performed. The bathymetric investigation was carried out by means of the "SonarMite Echo Sounder1", a single-beam sonar system. The useful reservoir volume at the date of measurement was determined by comparing the historical volume-area curve of the reservoir with the newly surveyed one.

The difference between the modern and historical useful volume is the volume of sediment deposited over the years in the Ruzizi II reservoir which results to be about 1.9 Mm^3, i.e., 80,000 m^3/yr.

6.4 Comparison of Results

The following table (Tab. 5) shows both the results of RUSLE model application and the bathymetrical survey related to average erosion rate per year and the sedimented volume during the entire existence of the reservoir up to the survey.

Tab. 5 Ruzizi II, RUSLE vs Bathymetrical Survey

Method	t/ha/yr	10^3 m^3/yr	mm/yr
RUSLE	17.0	137	1.55
Bathymetrical Survey	10.7	86	0.97

7. Case Study No. 4: LUFUBU 3 HPP

7.1 Introduction

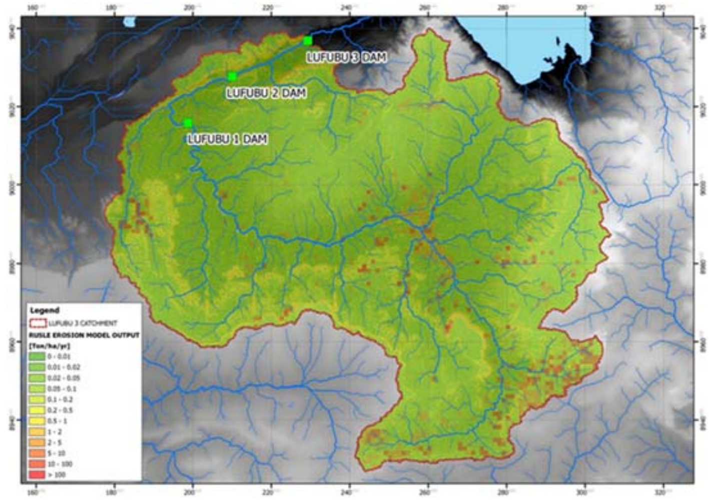
The planned Lufubu 3 dam is located in the north-east of Zambia, approximately 60 km N-NE from Mporokoso, along the Lufubu river, approximately 20 km upstream from Lake Tanganyika.
The catchment area is approximately 9,000 km^2 and the mean annual runoff is approx. 62 m^3/s.

7.2 RUSLE model

The RUSLE model was applied using the following input data:

- *R* factor
  The *R* factor was estimated on a 31-year historical rainfall series, from 1981 to 2013, containing monthly cumulative values of rainfall at Kasama station. With this series, the values of MFI and *R* were assessed applying the formulas illustrated in Chapter 3.
- *K* factor
  The determination of soil erodibility was deduced from the global Harmonized World Soil Database (HWSD) map from the FAO [10].
- *L* & *S* factors
  For the assessment of the *LS* factors the average values of the two database models SRTM (Shuttle Radar Topography Mission) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) were adopted.
- *C* factor
  The *C* values was evaluated adopting the Advanced Very High-Resolution Radiometer (AVHRR) global land cover dataset and by joining the land cover attributes illustrated in Chapter 3.
- *P* factor
  At the level of the basin, the distribution of anti-erosion practices is difficult to evaluate so as a precaution, the maximum value, 1, was also adopted in this case study.

The *A* factor was calculated on a cell-by-cell basis, using GIS software. The cell size used is equal to the SRTM database, i.e., 20x20 m. Figure 8 shows the spatial variation of soil loss, whereas the table on the right numerically summarises the classification (frequency analysis) of the erosion values.



Erosion Class from-to [t/ha/yr]	Occurrence [%]
0-0.01	*38.4*
0.01-0.02	*0.5*
0.02-0.05	*3.7*
0.05-0.1	*11.7*
0.1-0.2	*18.9*
0.2-0.5	*14.4*
0.5-1.0	*5.3*
1-2	*3.0*
2-5	*1.9*
5-10	*0.8*
10-100	*1.3*
>100	*0.1*

Fig. 8. RUSLE erosion model Result

From the above table, the erosion classes are highly dispersive and therefore the average value cannot be taken as being characteristic. The evaluation of the erosion rate taken to be more representative is defined in statistics as the average 95% fractile. Consequently, the expected value of the soil erosion rate for the basin can be assumed to be: $\text{RUSLE}_{\text{LUFUBU 3}} = 0.14$ t/ha/yr

7.3 Measured Data

A bathymetrical survey could not be carried out in the case of the Lufubu 3 reservoir because the project is still ongoing, and the reservoir does not yet exist. However, a sedimentation study was carried out based on an investigation campaign [1] concerning the measurement of sedimentation in the Lufubu river.

The study was funded by the United Nations Development Programme/Global Environment Facility (UNDP/GEF) and executed by the United Nations Office for Project Services (UNOPS). This study analysed the results of discharge and sedimentation monitored in the southern Lake Tanganyika basin. The direct measurement campaign [1] consisted of 472 measurements taken between 16/09/98 and 31/12/99 at the hydrometric station of Keso falls, very close to Lufubu 3 dam.
The following table (Tab. 6) reports the main features of Lufubu river station, where the data were collected.

Tab. 6 Lufubu River, Station at, at Kabyolwe Village.features

Station	Period of Study	No. Of days	Drainage Area	Total Discharge	Total sed. Load	Sed.Load
No.	dd/mm/yy	dd	km^2	billion m^3	t	t/km^2
7.775	16/09/98-31/12/99	472	7'047	2.6	57'412	8.1

An analysis of discharge and suspended sediment load revealed that in the period of study the total discharge deposited into Lake Tanganyika was 2.6 billion m^3 while the deposited suspended sediment load was 57,412 tonnes. In terms of sedimentation load, the Lufubu river transported 8.1 t/km^2 into Lake Tanganyika, with an erosion rate of 0.06 t/ha/yr.

7.4 Comparison of Results

The following table (Tab. 7) shows both the results of RUSLE model application and the direct sampling measurements carried out during Dr. Sichingabula's campaign.

Tab. 7 Lufubu, RUSLE vs Measured data

Method	t/ha/yr	10^3 m^3/yr	mm/yr
RUSLE	0.14	115	0.013
Measured data	0.06	66	0.007

8. Conclusions

The following table (Tab. 8) shows the comparison of results obtained with the RUSLE mathematical model and data measured either by means of bathymetrical survey or by sampling sediments along the river.

Tab. 8. Comparison between a MATHEMATICAL Model (RUSLE) and MEASURED DATA

	Sedimentation VOLUME		EROSION rate		
	RUSLE 10^3 m^3/yr	Meas. data 10^3 m^3/yr	RUSLE mm/yr	Meas. data mm/yr	Type of field investigation
Bagré	7,000	6,800	0.20	0.19	bathymetric survey
Luphohlo	17	28	0.03	0.05	bathymetric survey
Ruzizi II	137	86	1.55	0.97	bathymetric survey
Lufubu Cascade	114	65	0.013	0.007	sediment sampling along the river

As can be seen from the table above, the erosion rate (mm/yr) varies considerably depending on the basin and ranges from about 0.01 mm/yr to about 1 mm/yr.

A comparison of the results obtained with the RUSLE mathematical model and the results obtained with measured data (bathymetrical survey or sediment sampling along the river) shows that the mathematical model always hits the order of magnitude of the sedimentation.

We consider the deviation of the results between the two approaches (mathematical model and measured data) to be well within the range of differences that can be expected for a complex phenomenon such as erosion and consequently sedimentation.

Therefore, the RUSLE model is to be regarded as an excellent tool for estimating sediment within a reservoir, especially in projects where measured data are scarce.

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Mr. Tatti has almost twenty years of international experience in hydrological and hydraulic studies for large hydropower and dam projects. Notably he has acquired a remarkable expertise as hydrologist and/or hydraulic expert for the design of several dams or hydropower plants including Mbabane-Manzini dam, Lower Diamphwe dam, Kikonge HPP, Plaine Hollandase dam, Grand Anse dam etc.. He has gained significant expertise in hydrologic and climate change studies for large rivers (Nile, Omo, Rioni, etc.). He has been responsible for the climate change modelling of most of the firm's recent projects. His remarkable experience in hydrology and dams engineering includes being a member of panel of experts for the technical assistance of dam development in Mauritius.

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