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Institute of Water
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**Institute of Water and Energy Sciences (Including Climate Change)**

# SOIL LOSS IN A CATCHMENT AND CHANGE OF STORAGE VOLUME IN A HYDROPOWER RESERVOIR

# CASE STUDY: LOM PANGAR HYDROELECTRIC DAM, EAST REGION CAMEROON.

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## Declaration of Academic Integrity

I Ousmanou NJOYA, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

**Abstract**

For many purposes such as water supply, irrigation flood control and hydropower production, many reservoirs are built throughout the planet. However, because of the processes of erosion and sedimentation, these infrastructures are facing a big problem of progressive reduction of their storage capacity. Consequently, a good knowledge of the change of storage for proper planning and management is very important. The well-known Universal Soil Loss Equation (USLE) was used to evaluate the gross erosion in Lom Pangar catchment and the sediment delivery ratio relation used to evaluate the quantity of sediment that effectively reach the outlet of the catchment.

To evaluate the soil loss from the watershed using USLE model, the topographic map of 30 m x30m resolution was used in ArcGIS software to generate the LS factor which average was 3.64. To determine the erodibility factor, the FAO map was used to generate different soil type, present in the catchment and come up with different mineral component. The average erodibility was evaluated to be 0.024 t. ha.h (ha MJ mm). The roose (1980) equation and the average annual rainfall were used to generate the erosivity factor which average for the watershed was 14 509.55 MJ mm $ha^{-1}$ $h^{-1}$ $yr^{-1}$. Concerning the cover factor, the MODIS table and the classified map were used to come up with an average C factor of 0.08. In order to avoid underestimating the soil loss, the practice factor was considered to be one. Following the determination of different factors, the gross erosion was developed to be 202.8 million ton of soil per year with an average of 28.392 million ton per year that effectively reach the outlet. On the quantity that reach the outlet, the Brune (1953) Sediment trap efficiency was applied and 50.7% of the storage volume is filled after 140 years.

The impact of land use change on erosion was studied too. That for the year 2015 and 2017, and main result was 101.4 t/ha/year of soil lost in 2017 instead of 28.4 t/ha/year in 2015. Based on the construction design parameter, the useful life of reservoir is generally 100 years; per consequent, it can be retained from our result that the sediment is not a major problem in Lom Pangar reservoir.

**Résumé**

Pour des nombreuses fins telles que l'approvisionnement en eau, le contrôle des inondations et la production hydroélectrique, de nombreux réservoirs sont construits de par le monde. Cependant, en raison du processus d'érosion et de sédimentation, ces infrastructures font face à un gros problème de réduction progressive de la capacité de stockage. Par conséquent, une bonne connaissance du changement de stockage pour une planification et une gestion appropriées est très importante. L'Équation universelle des pertes de sol (USLE) développée par Wischmeier & Smith, 1978 a été utilisée pour évaluer l'érosion brute dans le bassin versant de Lom Pangar et le rapport entre l'érosion brute et la quantité des sédiments arrivant à l'exutoire développée par Vanoni (1975) a été utilisée pour évaluer la quantité de sédiments atteignant effectivement la sortie du bassin versant.

Pour évaluer la perte de sol du bassin hydrographique à l'aide du modèle USLE, la carte topographique de 30 m * 30 m de résolution a été utilisée dans le logiciel ArcGIS pour générer le facteur LS dont la moyenne était de 3,64. Pour déterminer le facteur d'érodibilité, la carte de la FAO a été utilisée pour générer différents types de sols, présents dans le bassin versant et présenter leurs différentes compositions minéralogiques. L'érodibilté moyenne a été évaluée à 0,024 t. Ha.h (ha MJ mm). L'équation de roose (1980) et les données de pluviométrie annuelle moyenne ont été utilisées pour générer le facteur d'érosivité dont la moyenne pour le bassin versant était de 14 509,55 MJ mm ha-1 h-1 an-1. En ce qui concerne le facteur de couvert végétal, le tableau MODIS et la carte classifiée ont été utilisés pour obtenir un facteur C moyen de 0,08. Afin d'éviter de sous-estimer la perte de sol, le facteur de pratique a été considéré comme 1. À la suite de la détermination de différents facteurs, l'érosion brute a été estimée pour atteindre 202,8 millions de tonnes de sol par année, avec une moyenne de 28.392 millions de tonnes par an qui atteignent effectivement l’exutoire. En ce qui concerne la quantité qui atteint la sortie, l'efficacité du piège des sédiments de Brune (1953) a été appliquée et 50,7% du volume de stockage est rempli après 140 ans.

L'impact du changement d'affectation des terres sur l'érosion a également été étudié. Pour 2015 et 2017, le résultat principal a été de 101,4 t / ha / an de sol perdu en 2017 au lieu de 28,4 t / ha / an en 2015.

Se basant sur les paramètres de construction, la durée de vie d'un réservoir est considérée être 100 ans, par conséquent se basant sur nos résultat, la sédimentation n'est pas un problème majeur pour le réservoir de Lom Pangar.

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**Abbreviation**

| | |
|---|---|
| DEM | Digital Elevation Model |
| E | Storm Energy |
| EDC | Electricity Development Corporation |
| EI | Storm Erosivity |
| EI30 | 30 min Storm Erosivity |
| FAO | Food and Agriculture Organization |
| GIS | Geographical Information System |
| ha | Hectare |
| I | Precipitation Intensity (mm/h) |
| $I_{30}$ | Maximum 30 min Intensity |
| KM | Kilometer |
| $KM^2$ | Square Kilometer |
| kWh | Kilowatt Hour |
| m | Metre |
| $M^3$ | Cubic Metre |
| mg/l | Milligram per Liter |
| MJ/ha.mm/h | Mega Joule per Hectare. Millimetre per Hour |
| $Mm^3$/year | Million Cubic Meter per Year |
| MODIS | Moderate-resolution Imaging Spectroradiometer |
| MUSLE | Modified Universal Soil Loss Equation |
| oC | Degree Celsius |

| | |
|---|---|
| RUSLE | Revised Universal Soil Loss Equation |
| SWAT | Soil and Water Assessment Tool |
| t.ha.h/ha/MJ/mm | Ton Hectare Hour per Hectare per Mega Joule per Millimetre |
| TE | Trap efficiency |
| USGS | United States Geological Survey |
| USLE | Universal Soil Loss Equation |
| WEPP | Water Erosion prediction Project |
| $\lambda$ | Lambda |

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# CHAPTER 1. INTRODUCTION

## 1.1 Background

Erosion refers to the detachment of the soil particles mainly by the natural forces wind, water, ice or vegetation. When these detached particles mix organic and inorganic materials during the process of erosion, sediments are formed. Basically, sediments refer to the complex mixture of organic and inorganic particles in the water. In case of reservoir sediments, water is the major source of erosion. Water flows over land causes increase in total suspended solids concentration in the river and hence adding sediments to the reservoir (Dahal, 2013). The process of sedimentation seriously affects the reservoirs worldwide. As the river enters the impoundment, the flow velocities decrease and the sediment carrying capacity drops, causing sedimentation, which reduces the reservoir's storage capacity. According to Petkovsek and Roca (2014), sedimentation is the main cause for 1% of annual reduction of water reservoir worldwide. The majority of existing dams and other impounding structures continuously trap sediment and have no specific provisions for sustained long-term use. The life span of the storage capacity of the dam is frequently designed to be less than 100 years (Sumi and Hirose, 2009). However, sometime the dams reach their design capacity in a shorter time due to the sedimentation problem.

Sediment yield is the net result of soil erosion and processes of sediment accumulation, so it depends on variables that control water and sediment discharge to reservoirs. Typically, sediment yield reflects the influences of climate (precipitation), catchment properties (soil type, topography), land use/cover, and drainage properties (stream network form and density)(Duru, 2015). Erosion is a natural process causing soil loss and generating sediment yield from catchment areas even in the absence of human alterations of land cover ( Duru, 2015).

Sediment yields vary from low values in humid, low-relief catchments to very high values in arid, mountainous areas. Due to human modifications, erosion rates rise above natural levels, a phenomenon known as accelerated erosion. Accelerated erosion is a serious matter that reflects increased population and expansion of arable lands use (Chakrapani, 2005).

## 1.2. Problem statement

The population growth in Cameroon, precisely in East region is estimated at 2.5% (world bank, 2016) and the conversion of land to agriculture as well as timber exploitation led to the deforestation rate of 1.07% (National Conservation, 2010). Parameters, which are highly significant for the process of erosion that generate quantity of sediment, load in the water and per consequent affect the lifespan of reservoir.

For many purposes such as water supply, irrigation flood control and hydropower production, many reservoirs are built throughout the planet. However, because of the processes of erosion and sedimentation these infrastructures are facing a big problem of progressive reduction of their storage capacity. Consequently, a good knowledge of the change of storage for proper planning and management is very important.

## 1.3 Objectives of the study

The main objective of the present study is to study the dynamics of sediment in the hydropower reservoir from the Lom Pangar watershed and the establishment of the change of the reservoir capacity caused by the sediment load.

The specific objectives are:

- To calculate the USLE factors ( erodibility K, erosivity R, slope length factor LS, practice factor P, land use/cover C
- To calculate the soil losses and sediment yields in the stream
- To compute the volume of sediment in the reservoir for many years and produce the sediments and reservoir profile in order come up the lifespan of the reservoir,
- To analyse the impact of land cover/ land use change on erosion for years 2015 and 2017

## 1.4. Research Questions

- What are the USLE factors of Lom Pangar Catchment?
- What is the sediment yield in Lom Pangar Stream?
- How do accumulation of sediment in Lom Pangar reservoir affect his lifespan?
- What is the impact of Land Use Change on Erosion

## 1.5. Limitation of this study

Many limitations are introduced during the course of this study. One of the major limitations are related to the model:

- ✓ The Universal Soil Loss Equation (USLE) used in our research is used to estimate average annual soil loss. So that model can not be used to evaluate the soil loss for a particular storm;
- ✓ This model considers only sheet and rill erosion. Consequently does not consider gully erosion, stream bank erosion, mass wasting (landslides);
- ✓ The model does not consider the unpredictable human element;
- ✓ To better exploit this model, emphasis should be laid on the spatial variability associated with precipitation. There was only one rain gauge station in the Lom Pangar watershed. This can cause considerable errors in the Erosivity estimation of the entire catchment.

# CHAPTER 2. LITERATURE REVIEW

## 2.1. Concept of Erosion

As the result of runoff from rainfall or snowmelt, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in reservoir, in lakes or at the sea (Yang and Randle, 2006). Approximately 40% of the world's fertile lands are excessively degraded as a result of erosion (Duru, 2015). Excessive (or accelerated) erosion causes both "on-site" and "off-site" problems. On-site impacts include decreases in agricultural productivity and (on natural landscapes) ecological collapse, both because of loss of the nutrient-rich upper soil layers. In some cases, the eventual end result is desertification. Off-site effects include sedimentation of waterways and eutrophication of water bodies, as well as sediment related damage to roads and houses. Water and wind erosion are the two primary causes of land degradation; combined, they are responsible for about 84% of the global extent of degraded land, making excessive erosion one of the most significant environmental problems worldwide.

## 2.2. Factors controlling sediment yield.

Sediment yield is the end product of erosion or wearing away of land surface by the action of water, wind, ice and gravity. The total amount of onsite sheet, rill, and gully erosion in a watershed is known as the gross erosion. However, not all of 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 the 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. According to (Yang and Randle, 2006), the factors that determine a watershed's sediment yield can be summarized as follow:

a) Rainfall amount and intensity

Rainfall can be considered as the main driving force responsible of the soil particles detachment, and transportation. That capacity of rainfall to contribute to the sedimentation is called erosivity and depends on the intensity, duration and frequency of rainfall (Yimer, 2013). According to Wall (2011), the process of erosion by rain is materialized by the impact of raindrops on the soil surface that break down soil and disperse aggregates materials. The raindrop splash and runoff water easily remove lighter aggregates materials such as fine sand, silt, clay and organic matter rather than larger Sand and gravel particles that need greater raindrop energy or runoff amounts.

b) Soil type and geologic formation

The ability of soils to resist to erosion is his erodibility and depend on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion (Wall, 2011). Soil structure refers to the arrangement of soil particles in the aggregates. Well structured soil allows the free movement air and water through fissures between the structure unit. The soil with a poor soil stucture has a high risk of generiting runoff that will wash away soil particles.

c) Ground cover

According to Bochet (2004), soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.

The effectiveness of any crop, management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. In this respect, crops which provide a food, protective cover for a major portion of the year (for example, alfalfa or winter cover crops) can reduce erosion much more than can crops which leave the soil bare for a longer period of time (e.g. row crops) and particularly during periods of high erosive rainfall (spring and summer). However, most of the erosion on annual row crop land can be reduced by leaving a residue cover greater than 30% after harvest and over the winter months, or by inter-seeding a forage crop (e.g. red clover).

d) Topography

Naturally the steeper the slope of a field, the greater the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water, which permits a greater degree of scouring (carrying capacity for sediment).

e) Channel hydraulic characteristics

f) Runoff

Summerfield and Hilton (1994) studied the variables controlling mechanical denudation rates in drainage basins exceeding 5 x 105 $km^2$ in area and concluded that physical factors (basin area, mean annual runoff, temperature, precipitation) have no significant influence on physical denudation processes, although channel gradient and basin relief can be considered as dominant controlling variables ( Duru, 2015).

### 2.3. Grain size and Sedimentation

The knowledge or the good appreciation of whether the river can erode, transport or deposit sediment is given by the Hjulstrom diagram. That diagram highlight the relationship existing between the grains sizes of sediment, flow velocity and transport mode of sediment.

In the condition of stagnant or very low flow velocity, the deposition of sediment occurs from the important size to the small size according to the importance of the flow. Concerning the erosion process, high velocity is required to erode sediment even in the case of small size particles, this because of the cohesive forces between those particles (Dahal, 2013).

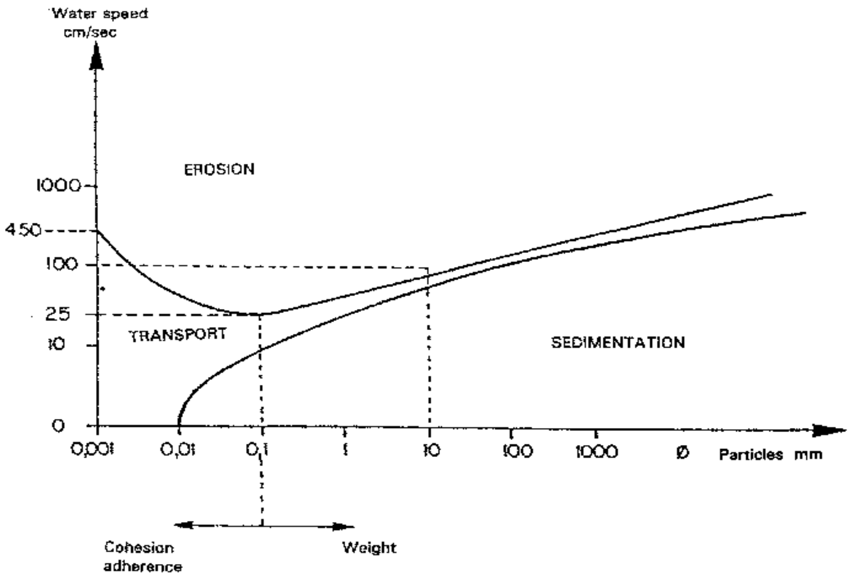



**Figure 2.1 Hjulström diagram, showing the relationship between the velocity of a water flow and the transport grains (Dahal, 2013)**

This diagram provides some very important information.

1. The material most easily dislodged by runoff has a texture close to that of fine (100 m) sand. More clayey material is stickier. The coarser material has heavy particles which can only be moved at higher fluid speed. It is interesting to note that for Wischmeier the most erodible soils are those rich in loam and fine sand.

2. As long as the flow is slow (25 cm/sec), it cannot erode. Measures will therefore have to be taken to spread and slow down the flow, in order to prevent linear erosion. This is the basis of the theory of dissipation of runoff energy.

3. Fine clay and loam particles are easily transported, even at low speeds, but in the case of anything coarser than fine sand, it is a short distance from erosion site to sedimentation site. This explains why ditches to channel runoff water either erode if they are too narrow or steep, or silt up with coarse material which cannot be moved. This is one of the reasons why diversion ditches are unpopular in developing countries, for such ditches and channel terraces have to be regularly cleared and maintained.

## 2.4. Empirical approaches for erosion estimation

Empirical equation are developed using data collected from specific geographical area.

The following empirical methods are the mainly used in the estimation of the erosion rate:

- Universal soil loss equation (USLE) or its modified versions;
- Sediment yield as a function of drainage area;
- Sediment yield as a function of drainage characteristics.

### 2.4.1. Universal Soil Loss Equation (USLE)

Conservation of soil and water requires both knowledge of the factors affecting these resources, and methods for controlling those factors to preserve those resources. Over the years, field, plot and small watershed studies have provided much valuable information regarding the complex factors and interactions involved in the environmental operations of land use and farming. These studies are the basis of the Universal Soil Loss Equation (USLE), which is a conservation planning tool that has been demonstrated to do a reasonably good job of estimating erosion for many disturbed-land uses (Renard et al., 2010).

The USLE soil loss equation is:

$$A = R\ K\ L\ S\ C\ P \qquad (1)$$

Where *A* is the computed soil loss per unit area, expressed in the units selected for *K* and for the period selected for *R* (in common practice these are usually selected such that they compute *A*, soil loss in US tons per acre per year).

*R*, the rainfall and runoff factor is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.

*K*, the soil erodibility factor, is the soil loss rate per rainfall erosion index unit for the specified soil under Unit Plot conditions.

*L* and *S* are the slope length and steepness factors in relation to the conditions on a unit plot.

*C*, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area under the tilled continuous fallow Unit Plot conditions (*C* thus ranges from a value of zero for completely non-erodible conditions, to a value of 1.0 for the worst-case Unit Plot conditions).

And *P*, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down slope.

The USLE was widely used both within the United States and internationally. As use of the USLE expended and it was applied in other situations, like disturb forestlands, limitations of the technology became apparent. At the same time, continuing soil erosion research on both natural plots and under simulated rainfall led to improve understanding of the physical processes involved in hillslope sheet and rill erosion. Recognized limitations and advancements in erosion science pointed to the need for updating the USLE.

In 1985 scientists and engineers came up with important decisions evolved including the need to develop technology to replace the USLE with physically based model called Water Erosion prediction Project (WEPP); and to computerize and update the USLE with an improved model, called revised Universal Soil Losses Equation (Renard et al. 2010).

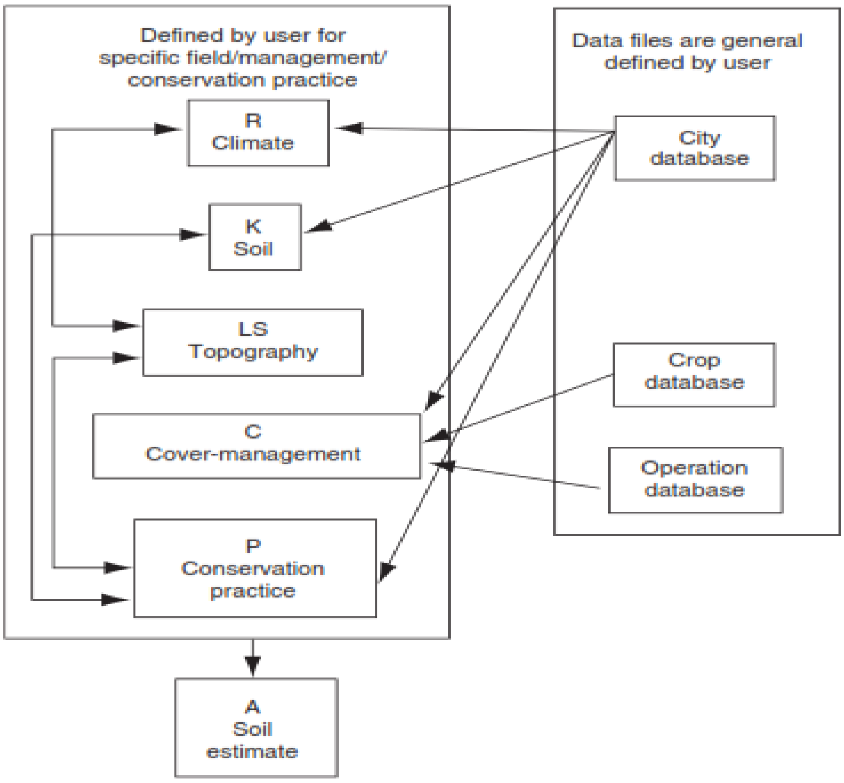



**Figure 2.2 Block diagram indicating the parameters of the Revised universal Soil Loss Equation (Renard et al., 2010)**

### 2.4.2. Sediment yield as a function of drainage area

Empirical sediment yield equation can be developed as function of drainage area based on the reservoir sediment survey data. Strand (1975) developed the following empirical equation for Arizona, New Mexico and California (Yang and Randle, 2006).

$$Q_s = 2.4A_d^{-0.229} \qquad (2)$$

Where

Qs= sediment yield in ac-ft. /mi$^2$/yr. and

Ad= drainage area in mi$^2$

### 2.4 .3. Sediment yield as a function of drainage characteristics.

Table 2.1 gives the method of attribution of weight to different catchment characteristics. Based on the some of those catchment characteristics, Table 2.2 gives the possible annual sediment yield from the concerned catchment.

**Table 2.1. List of drainage basin characteristics and possible range of numerical rations**

| Drainage basin characteristics | Sediment yield levels | | |
|---|---|---|---|
| | High rating | Moderate rating | Low rating |
| Surface geology | 10: marine shales and related mudstone and siltstone | 5: rocks of medium harness moderately weathered and fractured | 0: massive hard formations |
| soils | 10: fine textured and easily dispersed or single grain salts and fine sands | 5: medium textured, occasional rock fragments, or caliche crusted layers | 0: frequent rock fragments, aggregated clays; or high organic content |
| Climate | 10: frequent intense convective storms | 5: infrequent convective storms, moderate intensity | 0: humid climate with low intensity rainfall, arid climate with low intensity rainfall, or arid climate with rare convective storms |
| Runoff | 10: high flows or volume per unit area | 5: moderate flows or runoff volume per unit area | 0: low flows or volume per unit area or rare runoff events |

| | | | |
|---|---|---|---|
| Topography | 20: steep slope (in excess of 30%),high relief, little or no flood plain development | 10: moderate slopes (about 20%), moderate flood plain development | 0: gentle slope (less than 5%) extensive flood plain development |
| Ground cover | 10: ground cover less than 20%, no rock or organic litter in the surface soil | 0: ground cover less than 40%, noticeable organic litter in surface soil | -10: area completely covered by vegetation, rock fragments, organic litter with little opportunity for rainfall to erode soil |
| Land use | 10: more than 50% cultivated, sparse vegetation, and no rock in surface soil | 0: less than 25% cultivated, less than 50% intensively grazed | -10: no cultivation, no recent logging, and only low intensity grazing if any |
| Upland erosion | 25: rill, gully or landslide erosion over more than 50% of the area | 10: rill, gully or landslide erosion over about 25% of the area | 0: no apparent sign of erosion |
| Channel erosion | 25: continuous or frequent bank erosion or active head cuts and degradation in tributary channels | 10: occasional channel erosion of bed or banks | 0: wide shallow channels with mild gradients, channels in massive rock, large boulders or dense vegetation or articially predicted channels. |

Source: Yang and Randle, 2006

**Table 2.2 Drainage basin sediment yield classification**

| Drainage basin classification number | Total rating | Annual sediment yield (ac-ft/mi2) |
|---|---|---|
| 1 | Greater than 100 | Greater than 3 |
| 2 | 75 to 100 | 1.0 to 3.0 |
| 3 | 50 to 75 | 0.5 to 1.0 |
| 4 | 25 to 50 | 0.2 to 0.5 |
| 5 | 0 to 25 | Less than 0.2 |

Source: Yang and Randle, 2006

## 2.5. Trap efficiency and reservoir sedimentation

According to Basson et al., (2008), the storage capacity of the reservoir depends upon the mean annual runoff and a reservoir traps about 97% of the input sediment yield. The ratio of deposited sediment quantity to the total sediment inflow is called trap efficiency. The two variables that influence trap efficiency are sediment particle fall velocity and flow rate along a reservoir. Particle fall velocity is influenced by shape and size of materials, viscosity and chemical composition of the water. Based on the large reservoirs in the United States, Brune (1953) developed a relationship between trap efficiency (ß) and C/I.

The average value of trap efficiency can be determined using:

$$ß = (C/I)/ ((0.012+0.102)*C /I) \quad \textbf{(3)}$$

Where;

ß: Trap efficiency (%),

C: The reservoir capacity ($hm^3$),

I: The mean annual inflow ($m^3/s$).

The volume and mass of sediment deposited in subsequent years of sediment trap efficiency are established on the basis of the mass of sediment transport calculated according to bathymetric surveys, USLE and MUSLE methods.

According to Hotchkiss (1995), in general, trap efficiency decreases with age as the reservoir capacity is reduced by sediment accumulation. Filling half of the initial storage takes about 50 years and most reservoirs have been designed to be used 50 to 100 years.

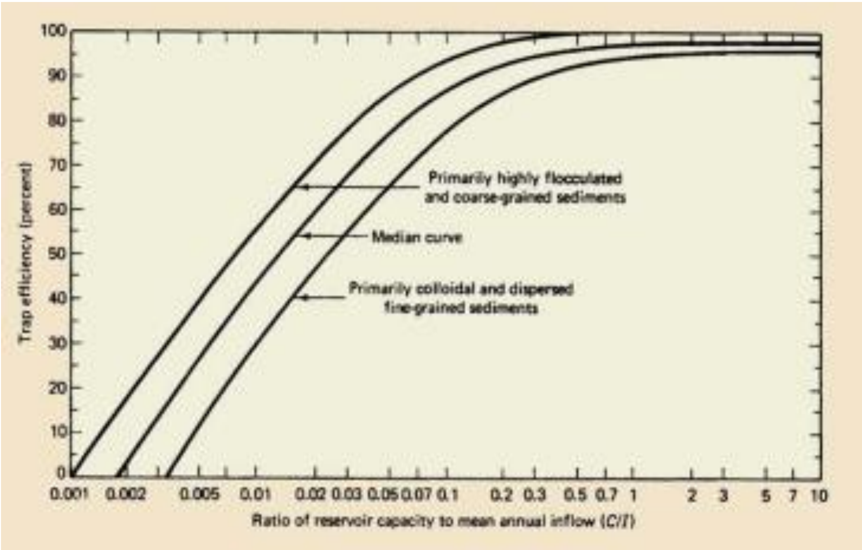



**Figure 2.3 Brune's trap efficiency curves (Duru, 2015)**

The higher the retention parameters (C/I) and the higher the trap efficiency, the faster the rate of reservoir sedimentation throughout approximately three-quarters of the reservoir’s range In other words, smaller reservoirs will trap less sediment and last longer, while the converse is true for larger reservoirs (Duru, 2015).

## 2.6 Spatial and temporal variability in sediment yields

The spatial and temporal variability of suspended sediment load have been studied at a variety of scales from all over the globe. A wide range of studies have been done on the impact of climate, topography, land use, lithology, and drainage characteristics across varying spatial and temporal scale (Duru, 2015).

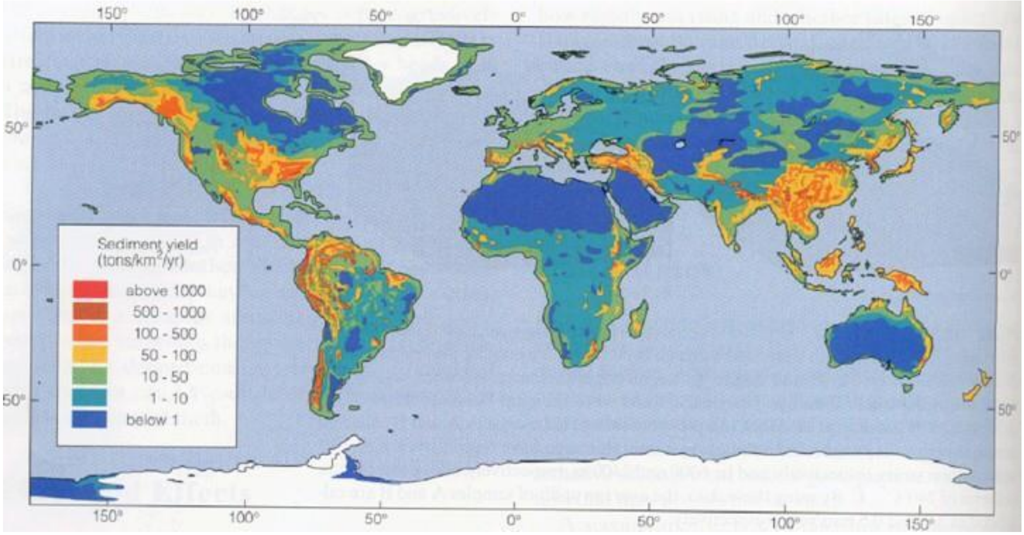



**Figure 2.4 Global pattern of suspended yields (Walling and Webb, 1996)**

Studies focusing on temporal variation of suspended sediment yields mostly emphasize anthropogenic impacts and variation in macro and micro climate. These studies suggest that soil erosion rates can be increased by the magnitude of agricultural activities, particularly given that the area of the world's surface given over to crop production and livestock grazing has increased by more than five fold over the past 200 years. For example, Milliman et al (1987), studied Holocene rates of sedimentation in the Yellow River Basin and estimated that as a result of land clearance and agricultural development, sediment yield increased beyond values existing during the early and middle Holocene. A similar range of increase was documented by Abernethy (1990) based on reservoir sedimentation in Southeast Asia that was influenced by land-use change during the last century. Abernethy also noted that developing countries could double the magnitude of sedimentation in reservoirs in approximately 20 years. Spatial variability in sediment yield may therefore reflect spatial variation in catchment properties and human activities, and temporal variation may also reflect climate change (Duru, 2015).

## 2.7. Hydrological models for sediment modelling

The establishment of sediment load in hydropower reservoir by modelling necessitate the good overviews of different types of models capable of accomplishing the objectives according to the context of study area (data available…). In the current context of water management in the river basin, the importance of hydrological model that can be considered as a mathematical representation of a hydrological cycle of an entire river basin or a part of it is inescapable (Kombalavi, 2015).

The hydrological models can be classified in to three main categories:

### 2.7.1. Lumped models

The parameters for this model are the same within the basin. That is why the response is considered at the outlet of the catchment without explicitly accounting for the response of individual sub basins. The evaluation of the impact of spatial variability of model parameters is done by the use of certain procedures to calculate effective values for the entire basin.

One of the lumped model developed by Jakeman et al (1990), is IHACRES (Identification of Unit Hydrographs and Component flows from Rainfall, Evaporation and Stream flow data). The function of lumped hydrologic modelling the characterisation of the dynamic relationship between rainfall and stream flow, based on a transfer function/hydrograph and the model. The model requires data such us rainfall, temperature, or potential evapotranspiration (PET) to predict stream flow. The model can be used different times scales, minute, daily or monthly time step. The model can be used to assess impact of climate change and identify effects of land use changes (Kombalavi, 2015).

### 2.7.2. Semi-distributed models

This model allows the subdivision of the catchment in small sub basins. The main advantage of semi-distributed models is that their structure is more physically based than the structure of lumped models, and that they are less demanding on input data than fully distributed models. As examples of semi-distributed models, we have HEC-HMS, TOPMODEL and SWAT. HEC-HMS (Hydrologic Engineering Centre -Hydrologic Modelling System) developed by the U.S Army Corps of Engineering. That model is a public domain model established for the purpose of simulation of the precipitation-runoff processes of dendritic watershed systems. HEC-HMS (semi-distributed physically based model) is capable of modelling continuous processes and events. Based on the information of the HEC-HMS website (http://www.hec.usace.army.mil/software/hec-hms/), the model is able of representing physical features and the hydrologic elements (sub basin, reach, junction, reservoir, diversion, source, and sink) of the basin. The model meteorological data analysis is based on short wave radiation, precipitation, evapotranspiration, and snowmelt. However, not all these data are required during simulation. Along with hydrologic simulation, the model can perform optimisation, forecast stream flow, assess model uncertainties as well as sediment and water quality analysis. Finally, the model has a GIS connection known as Geospatial Hydrologic Modelling Extension (HEC-GeoHMS). According to Beven, (1997) TOPMODEL (TOPographical based hydrological MODEL) is based on the use of the digital terrain data. It has been widely used due to its simplicity based on the topographical index application and the possibility of visualising the predictions of the model in the spatial context. The SWAT model as part of the tools used in the present project is fully discussed in the following sections. (kombalavi, 2015).

### 2.7.2. Semi-distributed models

According to Akpoti et al. (2016), Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often-unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy. As an example of distributed model, we can cite HYDROTEL model. According to Fortin et al (2001), it is a spatially distributed hydrological model with physical bases specially developed to facilitate the use of remote sensing data and GIS data. HYDROTEL can be used to simulate stream flow, spatial distribution of hydrological variables.

## 2.8. Management options of sediment in a reservoir

Generally, reservoirs are built in the rivers for water supply; power generation, discharge regulation and flood control. The reservoir capacity can be divided in three portions: the dead storage volume (volume below the lowest outlet level, which cannot be removed), the active or live storage volume (volume between lowest outlet level and maximum surface level). (Van Rijn, 2013.)

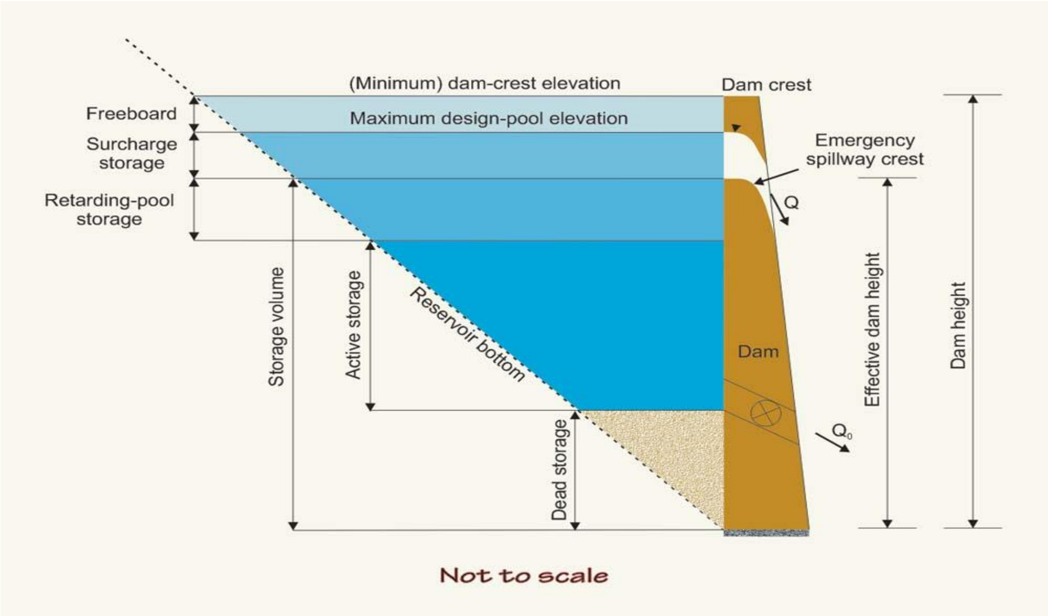



**Figure 2.5 Schematization of reservoir into compartments (Parra, 2014)**

Reservoir sedimentation is caused by the flow of water and sediment into the reservoir. Basically, all sediment (gravel, sand and mud) transported to the reservoir by a river is derived from the erosion of land surface. When the river flow enters a reservoir, its velocity and hence transport capacity are reduced and the sediment load is deposited in the reservoir. The amount of sediment deposited in the reservoir depends on the types of sediment in the rivers system, the shape of the reservoir, the detention time and the operating procedures. The principal sedimentation processes in the reservoir fall into three basic categories:

- Deltaic deposition of primarily coarse (gravel and sand) materials in the entrance section of reservoir;

Mainly the coarse sediment fractions are deposited in the head of the reservoir by backwater effects during high discharges, forming a delta. The delta proceeds into the reservoir while the foreset slope can be considered as an area of instability and slumping.

- Deposition of fine sediment (silt and mud) from homogeneous flow;
  A large part of the fine sediments transported in suspension or as wash load are transported beyond the delta after which they settle out to form the bottom set bed. They are more evenly spread than coarse sediment, but there distribution is highly dependent on reservoir circulation and stratification, for instance generated by river inflow and wind shear, or precluded by an ice cover. Also for this type of deposition, the quantification methods still yield rough predictions.
- Deposition of fine sediment (silt and mud) from stratified flow (turbidity current).
  Another important transport mode for fine sediments, i.e., silt and clay, is the turbidity current. It is formed when the turbid river inflow plunges below the clear reservoir water and continues as a density underflow. In addition, other processes can generate them, such as underwater slides (slumping of delta front) or coastal erosion. Turbidity currents are driven by an excess gravity force (negative buoyancy) due to the presence of sediment-laden water in a clear ambient fluid

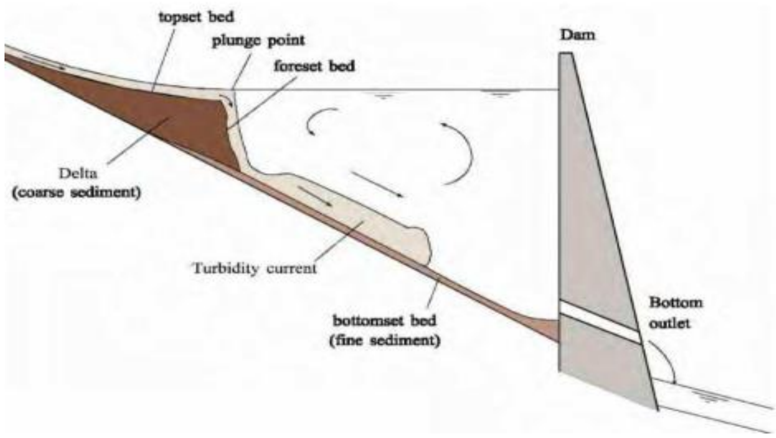



**Figure 2.6 Schematic presentation of principle of sedimentation processes in river-fed storage (Boroujeni, 2012)**

Often, more than 90% of the incoming sediment load is trapped and deposited in horizontal strata or thin bands across the bottom of the reservoir (van Rijn, 2013.).

Hydropower reservoir worldwide are threatened in their performance, because are loosing their storage capacity due to sedimentation process. Therefore, in order to ensure the viability of reservoir the good management of sedimentation becomes increasingly because of the sustainable development issues.

During the 1997 19th Congress of the International Commission on Large Dams (ICOLD), the Sedimentation Committee passed a resolution encouraging all member countries to the following measures:

i. Develop methods for the prediction of the surface erosion rate based on rainfall and soil properties.

ii. Develop computer models for the simulation and prediction of reservoir sedimentation processes.

Approximately 1% of the storage volume of the world's reservoir is lost annually due to sediment deposition (Morris and Fan, 1998) and some reservoirs have a much higher storage loss, e.g., the Sanmenxia Reservoir in China looses about 1.7% yearly. In some developing countries, where watershed management measures are not carried out effectively, reservoir storage is being lost at much larger rates. Although the reduction of sediment yield via a watershed, management program is the best option for reducing the rate of reservoir sedimentation.

Sediment management practices for reservoirs are often as different as their physical and technical conditions and social-economic and environmental aspects. Based on literatures and existence experiences, a tentative long-list of alternatives for sediment control of dam reservoirs can be found. The list is sub-divided into four general categories as follows:

i. Watershed rehabilitation (Structural and non- Structural Measures)

ii. Sediment flushing

iii. Sediment routing

iv. Sediment removal and disposal

Based on the above general categories some of the measures commonly used to reduce reservoir sedimentation are summarized in the following sections.

### 2.8.1 Soil conservation measure to control soil erosion

This strategy focuses on reducing sediment inflow to dam reservoir. In the upstream watershed of a reservoir, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering the reservoir: structural measures, vegetative measures, and tillage practice. Structural measures include terraced farmlands, flood interception and diversion works, gully head protection works, bank protection works, check dams, and silt trapping dams. Vegetative measures include growing soil and water conservation forests, closing off hillsides, and reforestation. Tillage practice includes contour farming, ridge and furrow farming, pit planting, rotation cropping of grain and grass, deep ploughing, intercropping and interplanting, and no-tillage farming. For a large watershed with poor natural conditions, soil conservation can hardly be effective in the short term (Boroujeni, 2012).


**Figure 2.7 Erosion Control Practices (Reeder, 2006)**

### 2.8.2 Bypass of incoming sediment

Rivers carry most of the annual sediment load during the flood season. Bypassing heavily sediment-laden flows through a channel or tunnel may avoid serious reservoir sedimentation. The bypassed flows may be used for warping, where possible. Such a combination may bring about high efficiency in sediment management. When heavily sediment-laden flows are bypassed through a tunnel or channel, reservoir sedimentation may be alleviated to some extent. In this method, however, the construction cost of such a facility may be high.

The sediment bypass concept with four main stages is explained below according to (Nakajima et al., 2015)

a) **Normal reservoir and hydropower plant operation;** the SBT remains closed, the mainly clear (with negligible suspended sediment) upstream inflow passes over the sill into the reservoir. Latent bed load is retained upstream. There is no limitation on hydropower exploitation.

b) **Upstream drawdown flushing and transfer**. When the upstream discharge reaches a level that triggers bed load, SBT (Sediment Bypass Tunnel) can be partially opened to transfer bed load (to ensure transport capacity in the SBT); lowering the water level upstream will accelerate bed load flushing, keeping the inlet structure free of deposits.

c) **SBT use under full load.** When the inflow discharge exceeds the SBT capacity, water level rises, the excess discharge flows over the sill into the reservoir and may require spillway operation. Bed load is continuously evacuated through the SBT. Suspended load is split, partially being evacuated through the SBT and the remainder settling close to the dam

d) **Reverse flushing with drawdown.** At the end of a flood event, water flowing back from the reservoir is evacuated through the SBT, keeping the zone between the sill and the inlet structure free of deposits. During all above-mentioned stages, hydropower operation over the useful capacity of the reservoir can continue.

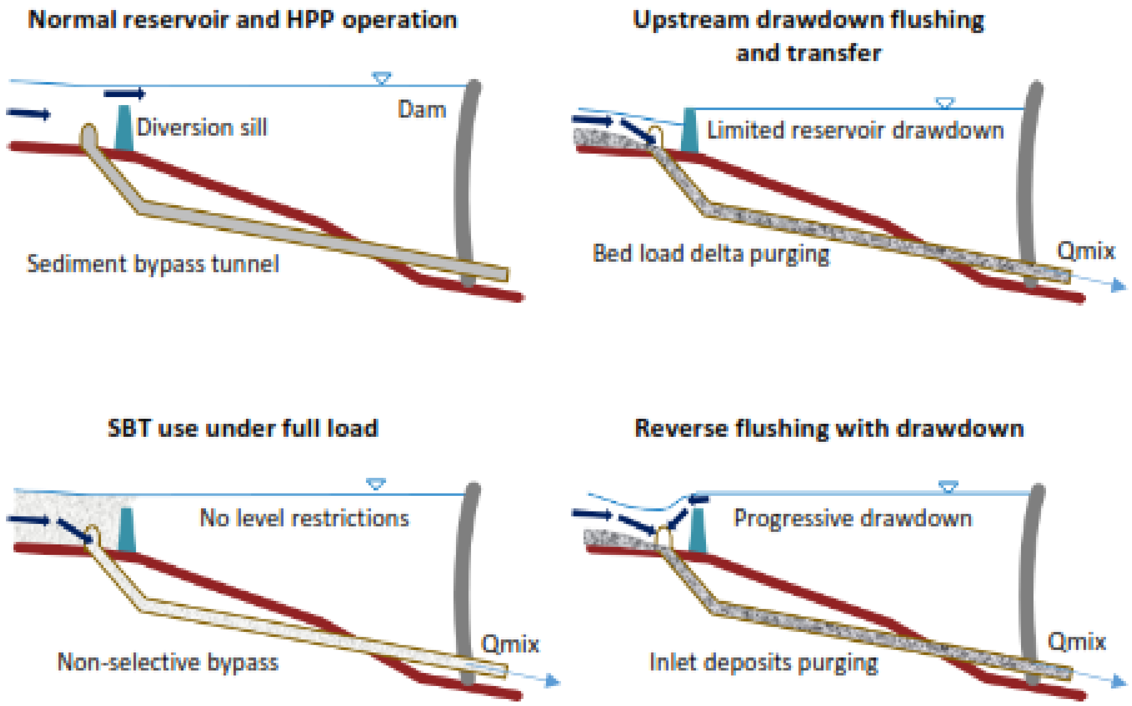



**Figure 2.8 Schematic drawing illustrating the sediment bypass concept (Nakajima et al., 2015)**

### 2.8.3 Sediment diverting

Sediment diverting (Warping) has been used around the world. It has a history of more than 1,000 years in China as a means of filling low land and improving the quality of salinized land. Now, this practice may have a dual role, not only improving the land but also reducing sediment load entering reservoirs. Warping is commonly carried out in flood seasons, when the sediment load is mainly concentrated, especially in sediment-laden rivers. Warping can also be used downstream from dams when hyper concentrated flow is flushed out of reservoirs.

### 2.8.4 Drawdown flushing

According to Boroujeni (2012), Drawdown flushing is a commonly used method of recovering lost storage of reservoirs. It may be adopted in both large and small reservoirs. The efficiency of drawdown flushing depends on the configuration of the reservoir, the characteristics of the outlet, the incoming and outgoing discharges, sediment concentrations, and other factors. Sometimes reservoir emptying operations may be used for increasing efficiency of the flushing. In the process of reservoir emptying, three types of sediment flushing occur: retrogressive erosion and longitudinal erosion, sediment flushing during detention by the base flow, and density current venting. Environmental impacts are the most constraints for drawdown flushing.

Two type of operational methods are applied.

- Under pressure: sudden release of water and sediment through low level outlets with high water level in the reservoir, only a relatively small flushing cone will be obtained.

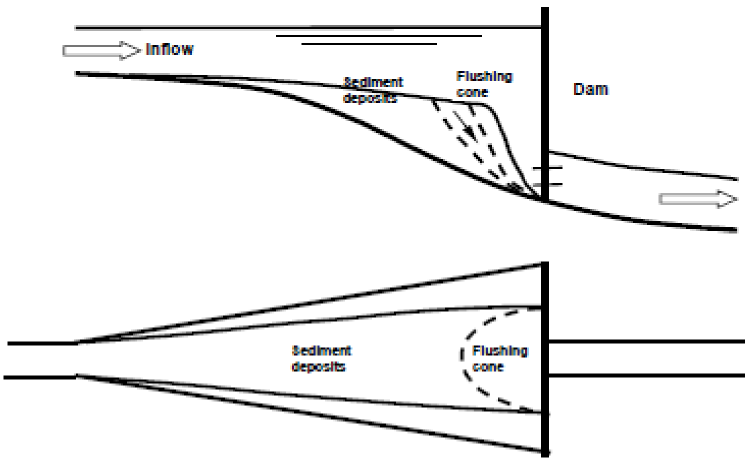



**Figure 2.9 Flushing without drawdown of water surface (Van Rijn, 2013.)**

- Free flow: erosion of sediment from bed in an empty reservoir (low water level in reservoir) by the interflowing water. When the original bottom gradient is approximately re-established, the operation should be stopped as the transport capacity will be greatly reduced and almost clear water will be flushed out, generally, only sediment is removed from the old river channel (flushing channel) and the banks on both sides of the main channel are not eroded.

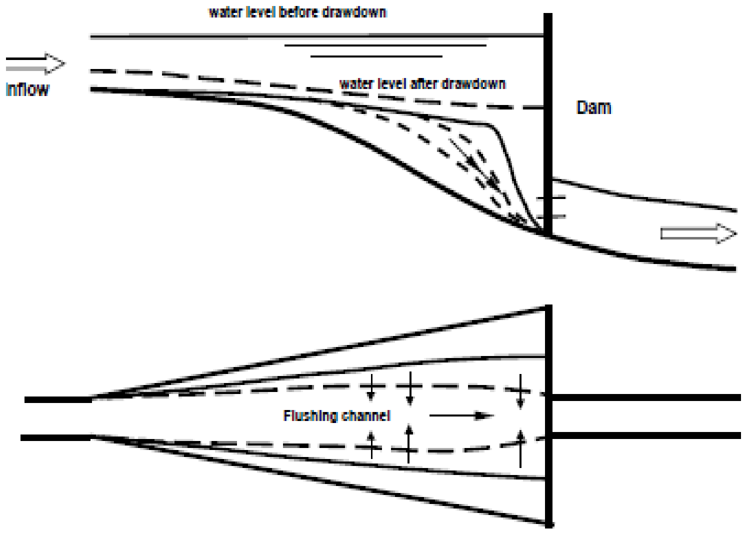



**Figure 2.10 Flushing with drawdown of water surface (Van Rijn, 2013.)**

All hydraulic methods to remove sediments from a reservoir require that water is released from the reservoir to transport sediments and almost all methods require a substantial or full drawdown of the reservoir (Van Rijn, 2013.). Therefore, flushing is not efficient for reservoir operation because the reservoir has to be emptied and it requires large volumes of water passing the dam. Furthermore, the reservoir should be rather narrow with relatively steep bed slope and steep valley side slope.

### 2.8.5 Venting density current

Density currents have been observed in many reservoirs around the world. A density current may carry a large amount of sediment and pass a long distance along a reservoir bed without mixing with surrounding clear water. The conditions necessary to form a density current, and allow it to reach the dam and be vented out if the outlet is opened in time, have been studied extensively, both from the data of field measurements and laboratory tests. Venting of density currents is one of the key measures for discharging sediment from several reservoirs in the worldwide. Density current venting may be carried out under the condition of impoundment, thus maintaining the high benefit of the reservoirs.

### 2.8.6 Siphoning dredging

Siphoning dredging makes use of the head difference between the upstream and downstream levels of the dam as the source of power for the suction of deposits from the reservoir to the downstream side of the dam. Siphoning dredging has a wide range of applications in small and medium-size reservoirs. Such an application is valuable to solve reservoir sedimentation and to fulfil the demand of irrigation if the head difference is adequate and the distance between upstream and downstream ends of the siphon is not too great.

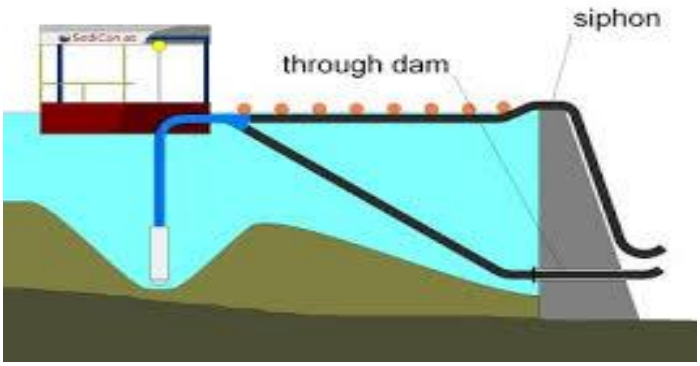



**Figure 2.11: Siphon dredging**

### 2.8.7 Dredging by dredgers

According to US national ocean service, Dredging is the removal of sediments and debris from the bottom of lakes, rivers, harbors, and other water bodies. In all situations, the operation is undertaken by specialist floating plant, known as a dredger. It is a routine necessity in waterways around the world because sedimentation the natural process of sand and silt washing downstream gradually fills channels and harbours.

Dredging often is focused on maintaining or increasing the depth of navigation channels, anchorages, or berthing areas to ensure the safe passage of boats and ships. Vessels require a certain amount of water in order to float and not touch bottom. This water depth continues to increase over time as larger and larger ships are deployed. Since massive ships carry the bulk of the goods imported into the country, dredging plays a vital role in the nation's economy.

Dredging is used to remove reservoir deposits when other measures are not suitable for various reasons. In general, dredging is an expensive measure. However, when the dredged material may be used as construction material, it may be cost effective.

# CHAPTER 3. METHODOLOGIES

## 3.1 Study Area

### 3.1.1 Geographical Location of the study Area

Lom Pangar watershed is located in Cameroon in major part precisely within the East and Adamaoua regions with a small part in Central Africa Republic, country that borders Cameroon in his eastern part. That geographical location gives to Lom Pangar the characteristic of trans-boundary river basin of 19700 km2. The Lom River runs throughout central Africa republic for a distance of about 5 km around before reaching the Cameroonian territory. That river basin is located between latitudes 4$^{o}$10''00N and 7$^{o}$11''00N and longitudes 12 $^{o}$30''00E and 15 $^{o}$02''00E. Since 2016, the hydropower reservoir has been constructed at the outlet of Lom Pangar river basin in the forestry part of East Cameroon.

The Lom Pangar hydropower dam is located at about 350 km in the North East of Yaoundé, the capital city of the country and precisely at around 120 km from the capital city of the East region Bertoua. The site of the Dam in Lom river is 5 km downstream from the confluence of Lom and Pangar River, and around 13 km in the East of the confluence of the rivers Lom and Djerem. The geographical location of the Dam is: latitude N 05 $^{o}$ 25' , longitude E 13 $^{o}$ 30' and has mains purposes are the regulation of the Sanaga River to increase the power generation of two hydropower plants located downstream during the dry season and generation of 51MW power for the eastern grid of Cameroon. It has 50 meters height and 610 km$^2$ seize.

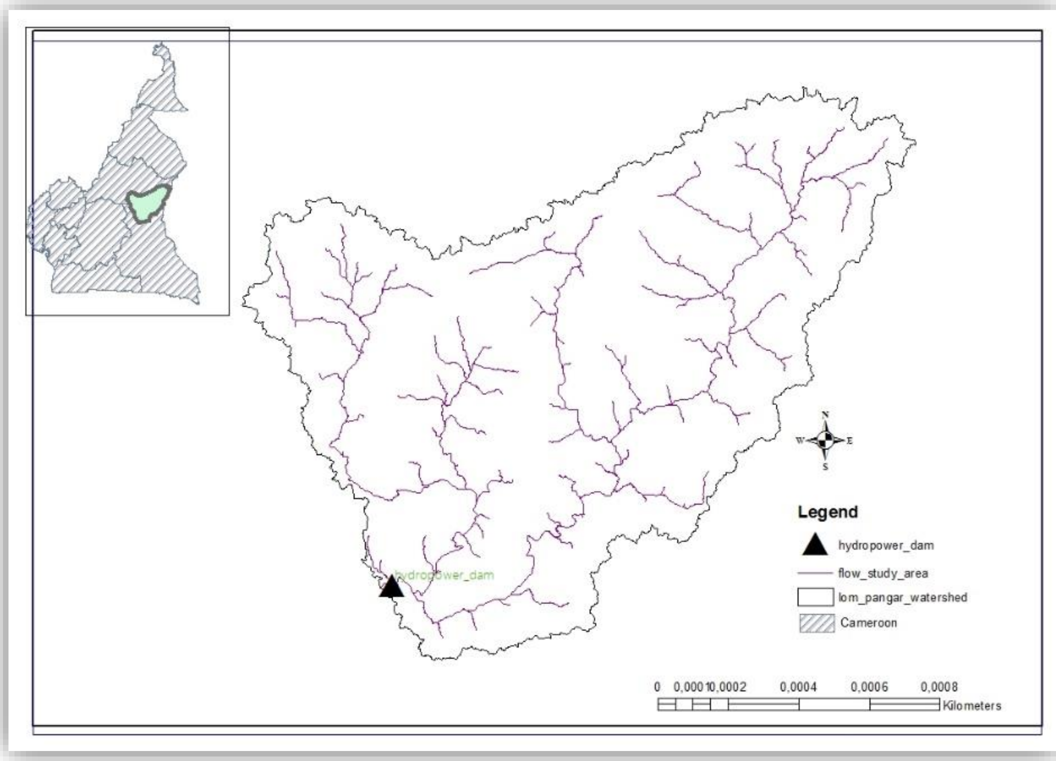



**Figure 3.1 Lom Pangar Watershed defined in ArcGIS 10.2.2**

### 3.1.2. Background of the Study Area

The primary study for the construction of Lom Pangar hydropower dam fixed the storage capacity at 7 billion CM of water for the height of 675.5 m. later on in the definitive study; it has been adopted at 6 billion CM for height of 672.7 m.

The principal objective of the Lom Pangar Hydropower development is to increase the guaranty discharge at the downstream hydropower of sangloulou, Edea and Nachtigal. To fulfil that objective, many infrastructures have been built for many purposes:

- Creation of the storage on the Lom river;
- Regulation of the discharge function of the need downstream at the Songloulou, Edea and Nachtigal hydropower;
- Extend the flood discharge of the project at 3475 m3/s for the return period of 1000 years ;
- Ensure the passage of the needed quantity of water;

- Ensure the regulation and taking of the water for the four-(4) onsite hydro generators capable to generate each 7.5 MW of electricity.
- Ensure the good aeration of water released downstream after usages.

Based on the optimization for the period of 1970 to 2003 the regulation performance in the greater Sanaga catchment are as follow.

- Average discharge at the Songloulou hydropower plant 1015 $m^3/s$;
- Guaranty discharge at the Songloulou hydropower plant (90%) 932 $m^3/s$;
- Average discharge at the Nachtigal hydropower plant 672 $m^3/s$;
- Guaranty discharge at the Nachtigal hydropower plant (90%) 583 $m^3/s$.


**Figure 3.2 Hydropower generation sites in the greater Sanaga catchment (EDC, 2010)**

### 3.1.3. Climate of the study Area

The entire Cameroon is located in the inter-tropical climate zone. However, that climate is not uniform throughout the country. For our study area located at latitude N 05°25' and the longitude E 13°30', it has an equatorial climate, characterized by the average temperature of 25°C and by four seasons (two rainy and two dry) with rainfall ranging from 1 500 to 2 000 mm; it has two rainfall maxima. It has in September long rains and in March–April, short rains; the first minimum is December–January and the second in July–August. This climate is characterized by dense hydrographic network (Molua and Lambi, 2015)**.** The year-round rainfall coupled with the high temperatures means the relative humidity is also high.According to FAO (2008), the climate is affected by Air masses**.** The Azores in the northern hemisphere and that of St. Helena in the southern control the flow of air masses over all Cameroon. Air masses from these high-pressure centres converge in a low-pressure zone, the Intertropical Convergence Zone (ITCZ), which has the nature of a front and is often termed the Intertropical Front. The Intertropical Front shifts following the movement of the pressure centres as the position of the sun controls the cycle of the seasons. The seasons in Cameroon depend on the dominant trade winds. The Harmattan blows from the anticyclone of the Azores and the Monsoon from the St. Helena anticyclone. These winds differ greatly because of their sources, the maritime south and the desert north. The Harmattan, the Northeast Trade Winds, which are hot and dry because they pass over the Sahara, are very stable, and blow from October till June. In January, the St. Helena anticyclone is far to the south. That of the Azores is reinforced and the Harmattan becomes stronger than the monsoon so the Intertropical Front is pushed further south to around 5°N. North Cameroon is covered by the Harmattan, which brings the dry season. The effects of the Harmattan are very intense in the north but become less severe southwards. This wind carries fine sand from the Sahara, leading to poor visibility. Some small streams dry up completely. Many big rivers reduce in volume, the vegetation turns brown and is scorched in some places. Not only rivers and vegetation suffer but humans as well. Days are very hot while the nights are very cold. In the south, especially in coastal areas, these adverse conditions are greatly mitigated because monsoon winds, though weak, provide occasional showers; atmospheric humidity is higher than in the north.

### 3.2. Detailed Methodologies

For this study, a model-based approach was used to assess soil erosion risk. The availability of input data is a critical selection criterion when assessing soil erosion risk at the regional (or national) scale. Even though a wide variety of models are available for assessing soil erosion risk, most of them simply require so much input data that applying them at regional or national scale becomes problematic. The well-known Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) was used because it is one of the least data demanding erosion models that has been developed and it has been applied widely at different scales. The USLE is a simple empirical model, based on regression analyses of soil loss rates on erosion plots in the USA. The model is designed to estimate long-term annual erosion rates. Although the equation has many shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Beverly et al., 2009). It also represents a standardised approach.

Soil erosion is estimated using the following empirical equation:

$$A = R.\ K.\ L.\ S.\ C.\ P \qquad (4)$$

Where:

A= Mean (annual) soil loss

R= rainfall erosivity factor (MJ/ha.mm/h),

K= erodibility factor (t.ha.h/ha/MJ/mm),

LS= slope length and steepness factor

C= the land use/land cover factor,

P = practice factor

The conservation factor P For this study was decided to be one to avoid any underestimation of sediment yield. That factor is defined as the ratio of soil loss from the area with conservation measures to the area without any management practices or conservation measures to control soil erosion.

The procedures used to estimate the factors are explained in detail in the following sub-sections. The next paragraphs give a brief overview.

### 3.2.1 Rainfall Erosivity factor

The USLE rainfall erosivity factor ($R$) for any given period is obtained by summing for each rainstorm the product of total storm energy (E) and the maximum 30-minute intensity ($I_{30}$). According to Renard and Freimund (1994) that R is the sum of individual storm EI-values for a year average over long time periods (more than 20 years) to accommodate apparent cyclical rainfall patterns. That EI term is the short form abbreviation for the energy multiplied by the maximum intensity in 30min. The intensities at which the rainfall occurred and the amount that occurred at each intensity can be calculated from recorded rainfall data. Analog traces of rainfall depth vs. time are examined and the rainfall depth and clock time registered whenever the slope of the pen line changes. These breakpoint rainfall data are processed to obtain rainfall intensity in millimeters per hour (mm $h^{-1}$) units for each increment. Rainfall intensity for a particular increment of a rainfall event ($I_r$) is calculated using the relation:

$$Ir = \frac{\Delta vr}{\Delta tr} \qquad (5)$$

where Atr is the duration of the increment over which rainfall intensity is considered to be constant in hours (h), and AVr is the depth of rain falling (mm) during the increment.

The calculation of Rainfall energy per unit depth of rainfall (er) can be done using the relation

$$er = 0.29(1 - 0.72 \exp(-0.05Ir)) \qquad (6)$$

Where er has units of mega joules per hectare per millimetre of rain (MJ $ha^{-1}$ $mm^{-l}$), and Ir is rainfall intensity (mm $h^{-1}$).

The following relation gives the computation of the total kinetic energy of rainstorm:

$$E = \sum_{r=1}^{m} e_r \Delta V_t \qquad (7)$$

Where er is the rainfall energy per unit depth of rainfall per unit area in mega joules per hectare per millimetre (MJ $ha^{-1}$ $mm^{-I}$), and AVt is the depth of rainfall in millimetres (mm).

In order to calculate the erosion index (E I) value for a particular storm ($MJ.mm.ha^{-1}.h^{-1}$), total storm kinetic energy (E) ($MJ\ ha^{-1}$) is multiplied by the maximum amount of rain falling within 30 consecutive minutes ($I_{30}$) expressed in millimetres per hour ($mm\ h^{-1}$) units.

The mathematical evaluation of the annual rainfall and runoff erosivity factor R ($MJ\ mm\ ha^{-1}\ h^{-1}\ year^{-1}$), is given by

$$R = \frac{1}{n}\sum_{j=1}^{n}\left(\sum_{k=1}^{m}(E)_k(I_{30})._k\right) \quad (8)$$

Where:

R – Rainfall erosivity factor

E – The total storm kinetic energy (MJ/ha)

$I_{30}$ – The maximum 30 minutes rainfall intensity

i – The index for the number of years used to compute the average

k – The index of the number of storms in each year

n – The number of years to obtain average

m – The number of storms in each year

Unfortunately, these parameters are rarely available at standard meteorological stations. Fortunately, long-term average R-values are correlated with more readily available rainfall by (Roose, 1980) for the west and central African countries. The relation of R was established in units of hundreds of foot tonf inch $acre^{-1}\ h^{-1}\ year^{-1}$ and the average annual rainfall in millimetres (P) over the 5-10 year period where recording rain gage records were available. The relation:

$$R = \left((0.5 \pm 0.05)P\right) \quad (9)$$

was found to work for 20 meteorological stations in Ivory Coast, Burkina Faso, Senegal, Niger, Chad, Cameroon, and Madagascar.

To convert results of that equation in US-units to SI unit, a conversion factor of $K_r$= 17**.**02 is used (Foster et al., 1981)

Based on the relation established for the 5-10 year periods of record, Roose (1980) used long-term annual precipitation records (20-50 years) to estimate average annual R-values. These values were used to develop an isoerodent map (in hundreds of foot tonf inch acre one h-i year-l units) used with the equation of R in our watershed for the present study.

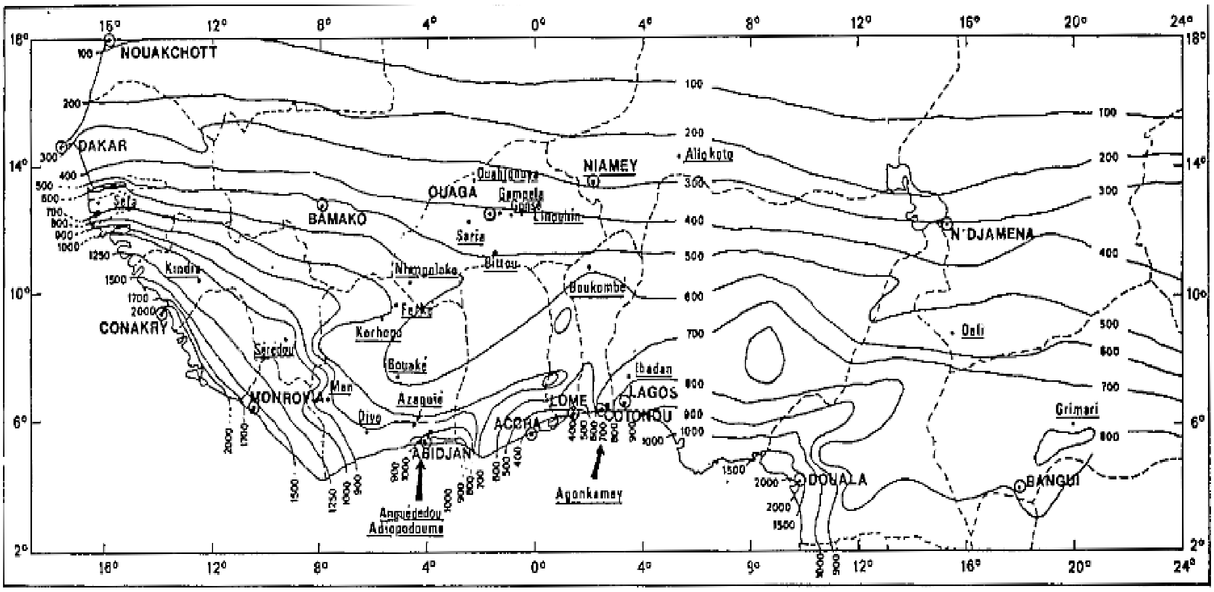



**Figure 3.3 Figure Mean annual Erosivity index (RUSA) in Western and Central Africa (Roose, 1980)**

### 3.2.2 Soil erodibility factor K

The K factor is defined as the rate of soil loss per unit of *R* as measured on a unit plot ('Wischmeier plot'). It accounts for the influence of soil properties on soil loss during storm events. The soil erodibility factor (*K*) is usually estimated using the nomographs and formula that are published in Wischmeier and Smith (1978).

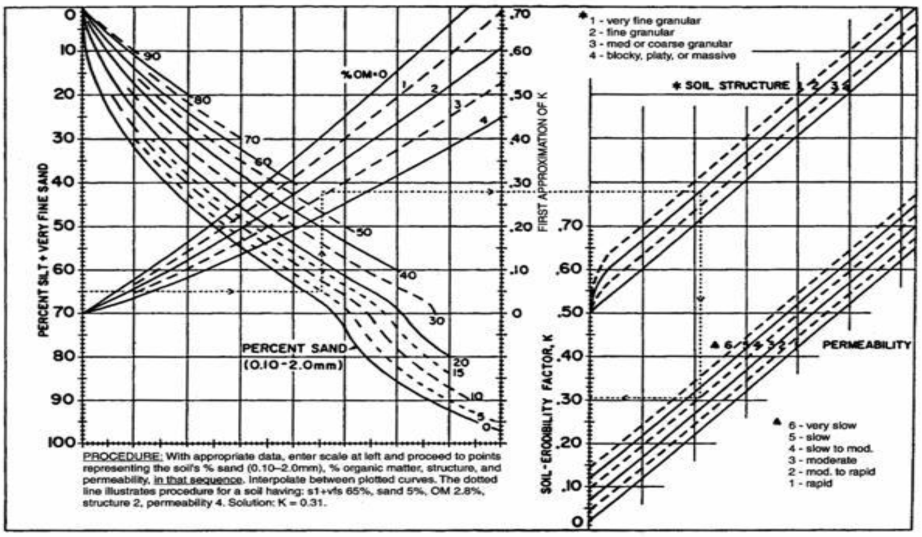



**Figure 3.4 Nomographs of Wischmeier to estimate Erodibility K in US unit**
(Wischmeier and Smith, 1978).

According to Kniff and Jones (2000) those equations developed by Wischmeier and Smith (1978) are suitable for large parts of the USA (for which the USLE was originally developed); they produce unreliable results when applied to soils with textural extreme as well as well-aggregated soils. Therefore, they are not ideally suited for use under others conditions. Bouyoucos (1935) performed a research to establish the K-values, which yielded the following equation. The equation needs only the texture of soil or average percentage of each soil particles (Sand, Silt, and Clay) in the catchment

$$K = \frac{SAN+SIL}{CLA} * \frac{1}{100} \qquad (10)$$

Where, K = Soil Erodibility factor (t.ha.h/ha/MJ/mm)

SAN= percentage of sand in the soil

SIL = percentage of silt in the soil

CLA = percentage of clay in the soil

In order to perform that calculation, HWSD+FAO soil map has been clipped for our area of study using ArcGis 10.2.2 under the tool Spatial Analyst Tool and extract by mask, using the shape file of Lom Pangar. Therefore, for the different soils identified in the catchment, the proportion of different component was obtained from the soil database.

### 3.2.3 Slope- and slope length factors

The slope and slope length factors ($S$ and $L$, respectively) account for the effect of topography on soil erosion. LS is a dimensionless factor which represents inclination (S in %) and slope length (L in m), It can be estimated from a digital elevation model (DEM).

According to Pelton et al., (2014) accurately calculating the LS factor turns out to be something of an art. It requires that the user pay close attention to gathering good empirical data about the landscape and choosing an appropriate method of calculating LS (of which there are many). The USLE is very sensitive to the choice of slope steepness values chosen during the LS factor calculation. For example, McCool et al., (1987) note that errors of 10% in the slope steepness values, can give an overall error in the soil loss equation of near 20%.

a) LS In the Original USLE

The LS calculation from the original USLE is provided in Equation (11).

$$\mathrm{LS} = \left(\frac{\lambda}{22.1}\right)^{m} (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065) \tag{11}$$

Where $\lambda$ is the horizontally measured plot length;

$\theta$ Is the slope angle, and

$m$ Is a variable plot exponent adjustable to match terrain and soil variants. $m$ Varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of $< 1\%$) (Wischmeier and Smith, 1978)

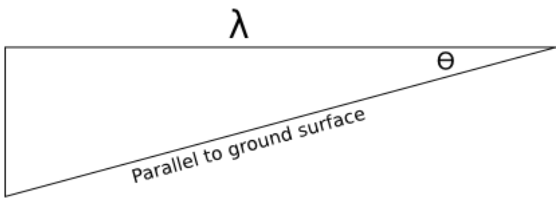



**Figure 3.5 Illustration of the values used in the calculations of LS**

b) The Revised USLE (RUSLE)

The topographic calculations for the RUSLE are shown separately in Equations (12) and (13).

$$L = \left(\frac{\lambda}{22.1}\right)^{m} \qquad (12)$$

Where,

L is the slope length factor,

$\lambda$ Is the horizontal plot length, and

$m$ Is a variable exponent calculated from the ratio of rill-to-interrill erosion, as described in (Renard et al., 1997)

$$\begin{aligned} S &= 10.8 \sin\theta + 0.03, \qquad \text{slope gradient} \leq 9\% \\ S &= 16.8 \sin\theta - 0.50, \qquad \text{slope gradient} > 9\% \end{aligned} \qquad (13)$$

Where,

$S$ is the slope factor, and

$\theta$ is the slope angle.

Depending on the measured slope gradient, a different equation for $S$ must be used. Choosing $S$ allows the (R)USLE to be more finely tuned for different terrains. This is important because the topographic factor (and the RUSLE entirely) is very sensitive to the slope factor $S$.

The (R)USLE method of calculating L and S terms are not directly applicable to the out-of-box functionality of ArcMap. However, there are programmatic methods for calculating the L and S factors from the empirical models in Equations (14) and (16).

c) Calculating the LS Factor using the Unit Stream Power Erosion and Deposition (USPED) model in ArcMap 10.2.2

We chose to use the Unit Stream Power Erosion and Deposition (USPED) model for calculating the LS factor because it was obvious that it could be done with the tools included in a normal ArcMap installation.

In comparison to the USLE and RUSLE, the USPED is a physically based model that incorporates a spatial component. In the USLE and RUSLE, $L$ is dependent on linear distance $\lambda_i$, which is the horizontal length from the start of sediment transport to point $i$ on the slope. Thus, they are inherently a single dimensional function. The USPED instead uses the area of upland contributing flow at distance $i$.

In the USPED model, the area is substituted in place of the former slope length.

The L calculation for point $i$ on a slope is shown in Equation 14

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m \qquad (14)$$

Where,

$L$ Is the slope length factor at some point on the landscape,

$\lambda_A$ Is the area of upland flow,

$m$ Is an adjustable value depending on the soil's susceptibility to erosion,

22.1 Is the unit plot length.

The $m+1$ comes from the fact that, in order to get a value for $L = \left(\frac{\lambda}{22.1}\right)^m$ that is considerate of the area of contributing upland flow on the slope up to point $i$, we must integrate $L$ over the interval $[0..i]$ .

$$\int_{i=0} L(i)\, dL \,/\, di \;= \frac{\lambda_{A_i}}{(m+1)22.1}\Bigg|_0^i . \qquad (15)$$

But, the extra $1\,/\,(m+1)$ changes the property of $L$ that it achieves unity when slope length (in this case slope area) is 22.1. Provisioning L with the extra $m+1$ term removes the equal term from the denominator.

The S calculation is shown in Equation (16).

$$S = \left(\frac{\sin\left(0.01745 \times \theta_{deg}\right)}{0.09}\right)^n \qquad (16)$$

Where

$\theta$ is the slope in degrees,

0.09 is the slope gradient constant, and

$n$ is an adjustable value depending on the soil's susceptibility to erosion (Oliveira et al., 2013).

It appears that using *m=0.4* and *n=1.4* is typical of farm and rangeland with low susceptibility to rill erosion.

If the slope values are in degrees (as with the ArcMap slope tool output), they need to be converted back to radians for the sin calculation. There are 0.01745 radians in one degree so the slope is multiplied by this constant.

Calculating the LS Factor in ArcMap 10.2.2 software follows following steps:

A depressionless DEM is required to perform the subsequent steps in finding the LS factor. A depressionless DEM is one in which there are no sinks present. Using the Fill tool produces a sink-free DEM, so the following steps should be followed in order to generate the LS_soil_map.

Step 1: Calculate Flow Direction from clipped Watershed DEM layer Using Flow Direction Tool, name this fd_ws_dem.

Step 2: Calculate Flow Accumulation with Flow Accumulation Tool using fd_ws_dem as your input raster. Name the output file fa_ws_dem

Step 3: Calculate slope of the watershed in degrees using Slope Tool. The clipped watershed DEM is used as the input layer. Make sure that Output Measurement dropdown menu is set to DEGREES. Name this output file, slope_ws

Step 4: Use the LS-factor formula below with help of Raster Calculator:

Power("flowacc"*[cellresolution]/22.1,0.4)*Power(Sin("sloperasterdeg"*0.01745)/0.09, 1.4)*1.4

### 3.2.4 Cover management factor C

The cover management C is defined as the ratio of soil loss from cropped land under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). The value of C mainly depends on the vegetation's cover percentage and growth stage. Vegetation cover is after topography the second most important factor that controls soil erosion risk ( Knijff and Jones, 2000). In the context of this study, the remote sensing was used to acquire satellite images and classify them function of different type of covers using Envi software in order provide for each cover type the corresponding C factor based on MODIS land use class.

Remote sensing (RS) in earth's perspective is the process of obtaining information about the earth surface features without being in direct contact with it, but using on board camera systems or sensors from the satellite platform. The data collected by these sensors are in the form of Electro Magnetic Energy (EME), which are emitted or reflected by the object at different wavelengths depending upon the object's physical properties. In addition, objects emit radiation depending upon their temperature and emissivity. Proper interpretation of the spectral signature leads to the identification of the object and further extraction of information from RS data (Issa et al., 2013).

For the mapping of Land Use and Land Cover (LULC) remote sensing imagery is a useful source of information due to its synoptic capabilities, i.e. the acquisition of information for large areas at one time.

There are three steps in preprocessing and the first one is Geocorrection. Geocorrection in Image preprocessing may include the detection and restoration of bad lines, geometric rectification or image registration, radiometric calibration and atmospheric correction, and topographic correction. If different ancillary data are used, data conversion among different sources or formats and quality evaluation of these data are also necessary before they can be incorporated into a classification procedure. The second one is layer stacking. Layer stacking is often used to combine separate image bands into a single multispectral image file. Layer stacking is also commonly used to combine image derivatives with spectral bands for further analysis.

The third one is Mosaicking If we take pictures of a planar scene, such as a large wall, or a remote scene (scene at infinity), or if we shoot pictures with the camera rotating around its centre of projection, we can stitch the pictures together to form a single big picture of the scene. This is called image mosaicking.

Supervised Classification uses a set of user defined spectral signatures to classify an image. Following figure describes the different steps for the classification of LANDSAT images.

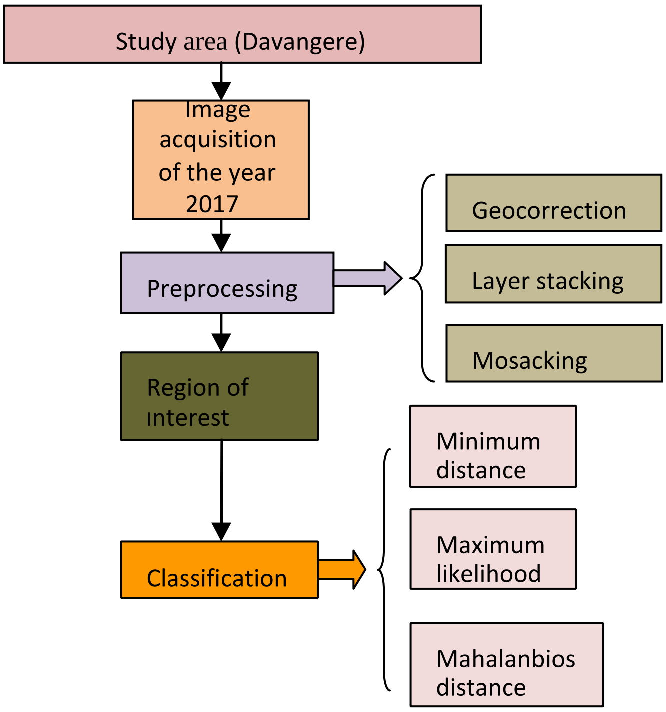



**Figure 3.6 Different steps for images classification (Veerendra et al., 2014)**

### 3.3 Sediment Delivery Ratio SDR

The sediment delivery ratio defined as the fraction of gross erosion that is transported from a given catchment in a given time interval (Lu et al., 1983). It is a dimensionless scalar and can be expressed as:

$$SDR = Y/E \qquad (17)$$

Where Y is average annual sediment yield per unit area and E is average annual erosion over that same area.

In general, the sediment detached from the soil aggregates of land of the watershed undergoes either deposition or is transported by the flow to reach to reach a certain cross section or stream.

SDR accounts for the amount of sediment that is actually transported from the eroding sources to the catchment outlet compared to the total amount of soil that is detached over the same area above that point. It often has a value between 0 and 1 due to sediment deposition caused by change of flow regime and reservoir storage.

Sediment delivery ratio is one of the keys factor with difficult computation in order to determine the sediment yield of the watershed. Currently, many researchers in the purpose of its determination have developed several methods. However, in the case of this study the relation developed by Vanoni (1975), was used. It was developed from the data from 300 watersheds throughout the world to develop a model by the power function. This model is considered a more generalized one to estimate SDR.

$$SDR = 0.42\ A^{-0.125} \qquad (18)$$

Where A = drainage area in square miles.

### 3.4 Trap efficiency of reservoir and its estimation

In the purpose of storing water for multiples uses, many reservoirs have been built throughout the world during the past 100 years. In most cases, sediment has been deposited in the reservoirs and decreased the volume of live storage; that phenomenon decreases not only the economic value of the reservoirs but also shortening their operational lives. In some cases, the amounts of sediment deposited in reservoirs have been similar to those that the engineers incorporated into their designs, and the reservoirs are functioning adequately. Other reservoirs have had higher rates of sediment deposition than estimated and are either providing smaller volumes of live storage during their design lives or have filled, or will fill, with sediments before the design periods are reached (Jolly, 1982). Both occurrences result in serious economic losses with adverse sociological effects.

According to Sultana and Naik (2015), trap efficiency (Te) is the proportion of the stream sediment that is trapped in the reservoir. For the purpose of this work, one of two (2) relations or methods established by bruwn's (1953) and brune's (1944) has been used.

### 3.4.1 Brune's Curve (1953*)* (Capacity-Inflow Method) for estimating the sediment trap capacity of the reservoir

Brune's curve method is most common method used for determining the trap efficiency of reservoirs. Brune drew the curves using the data from 44 normal ponded reservoirs in the United States and plotted Te against the reservoir C/I ratio. Brune plotted three curves consisting of one median and two envelop curves as shown in the figure 3.7. Brune developed an empirical relationship between trap efficiency and the ratio of reservoir capacity to the annual inflow, which is shown in the equations 19 & 20.

Brune's Curve for:

(a) Coarse-grained sediments.

$$Te = \frac{8000 - 36(\frac{C}{I})^{-0.78}}{78.85 + (\frac{C}{I})^{-0.78}} \qquad (19)$$

(b) Medium grained sediments.

$$Te = \frac{\left(\frac{C}{I}\right)}{0.00013 + 0.01\left(\frac{C}{I}\right) + 0.0000166\sqrt{\frac{C}{I}}} \quad (20)$$

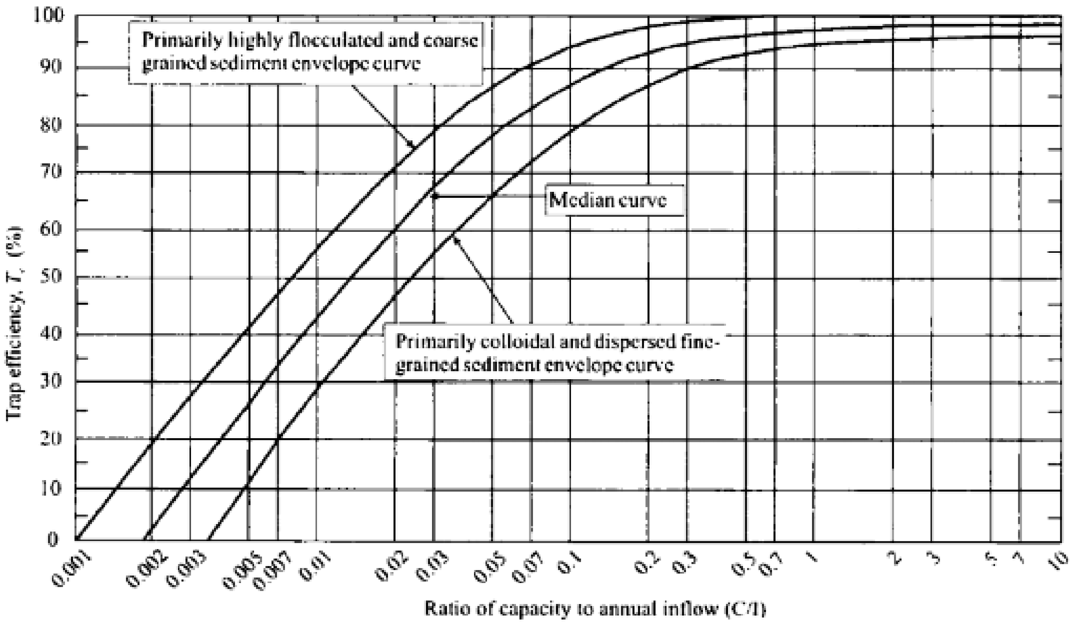



**Figure 3.7 Sediment trapping efficiency as per Brune (1953)**

### 3.4.2 Brown's Method for estimating the sediment trap capacity of the reservoir

The first trap efficiency (Te) estimation method was the pioneer work by Brown in 1944. USACE (1989) named this method as Capacity-Watershed method because Brown's curve relates the ratio of the reservoir capacity and the catchment or the watershed area (C/A) to the trap efficiency (Te). The figure 3.8 Curve can be represented by the equation 21 for estimating the value of trap efficiency Te (Gill, 1979; Campos, 2001; USACE, 1989)

$$Te = 1 - \frac{1}{\left[1 + K\left(\frac{C}{A}\right)\right]} \quad (21)$$

Where C, is capacity of the reservoir, A is the area of the catchment above the reservoir and K is a coefficient whose value varies from 0.046 to 1.0 depending upon different factors. According to USACE (1989), (i) K increases with the smaller and varied retention time, (ii) K increases as the average grain size increases and (iii) K increases with reservoir operation that prevents release of sediment through sluicing or prevents the movement of sediment towards the outlets by pool elevation regulation. A value of K = 0.1 is recommended for average conditions, and values of K = 1.0 for coarse sediment; K=0.1 for medium sediment; and K=0.046 for fine sediment is recommended by Gill, (1979). The Brown's method is simpler as only two parameters i.e., catchment area and reservoir capacity are required for the estimation of the trap efficiency.

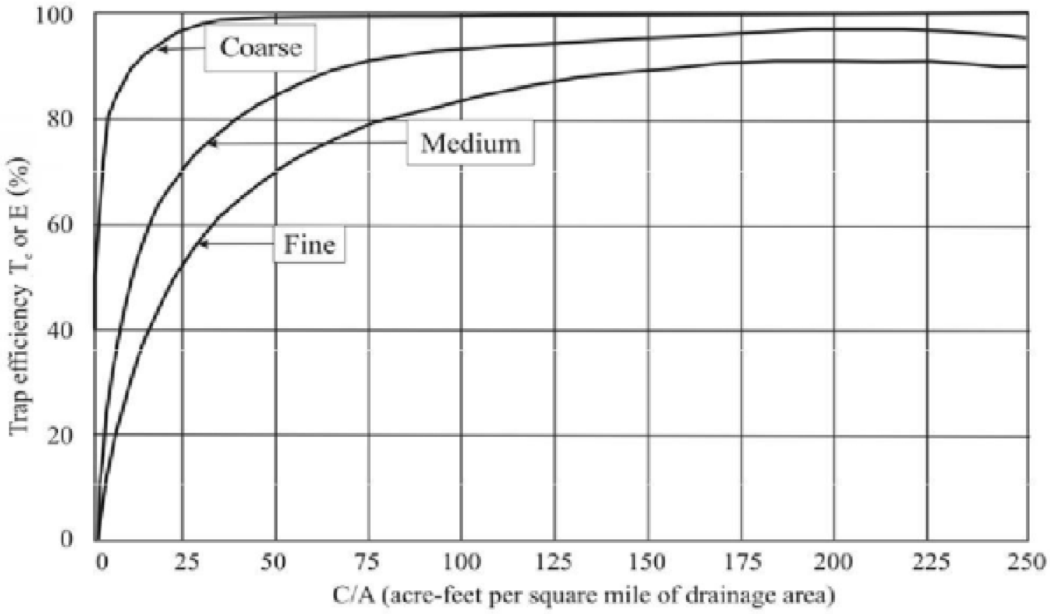



**Figure 3.8 Brown's (1944) trap efficiency curve (USACE, 1989)**

## 3.5 Land Uses Scenarios to Assess the Impact of Land Cover on Erosion

Land-use change is defined by the rate and amount of land converted into cultivation, grazing, and/or urban dwellings. Over the years, the natural resources and ecosystems have been modified through a broad array of land uses.

Causes of land-use change are many and vary from place to place but are largely driven by the demand for more land to meet and improve food security, alleviate poverty, and also enhance the human and social welfare at household and community levels. In sub-Sahara Africa, this is not surprising as close to 61% of population is largely rural, poor and dependent on traditional agricultural systems for survival.

In central Africa, timber explication is one of the major causes of land use change or degradation.

According to Kim et al. (2014), land use practices in a watershed influences streamflow and hence surface runoff in a catchment. Changes in land use influence the hydrologic response of the catchment through its effects on various hydrologic processes that include infiltration, interception, evapotranspiration, subsurface flow, per consequent erosion and sedimentation. As a result, water availability for various purposes that include irrigation, hydropower generation and ground water exploration are determined by the type of land use/ land cover prevailing in a catchment. (Beverly et al., 2009)

Considering the location of our study area in the forest zone subject to timber exploitation and mining, two land covers have been gotten for been used to compute the sediment yield.

The first scenario was to compute the sediment yield in the river using the cover map of 2015 before the re-allocation of land use in catchment.

The second scenario was to the land cover map of the after hydropower construction and the re-allocation of land use in catchment (2017) for the computation of the sediment yield in the river.

## 3.6 Data Collection

In order to achieve the above-mentioned objectives, spatial, weather, flow, soil have been collected as inputs for the model.

### 3.6.1. Rainfall Data Acquisition

The rainfall data was collected from the Electricity Development Corporation (EDC), the public institution in charge of the Dam construction in our study area. For that, daily data have been collected for an available period of 2 years for the determination of the rainfall erosivity factor, which is the detachment power of soil particles from aggregates. The data collected gives an average annual rainfall of 1550 mm. the station of collection is located at the outlet of the two rivers precisely at the hydropower dam.

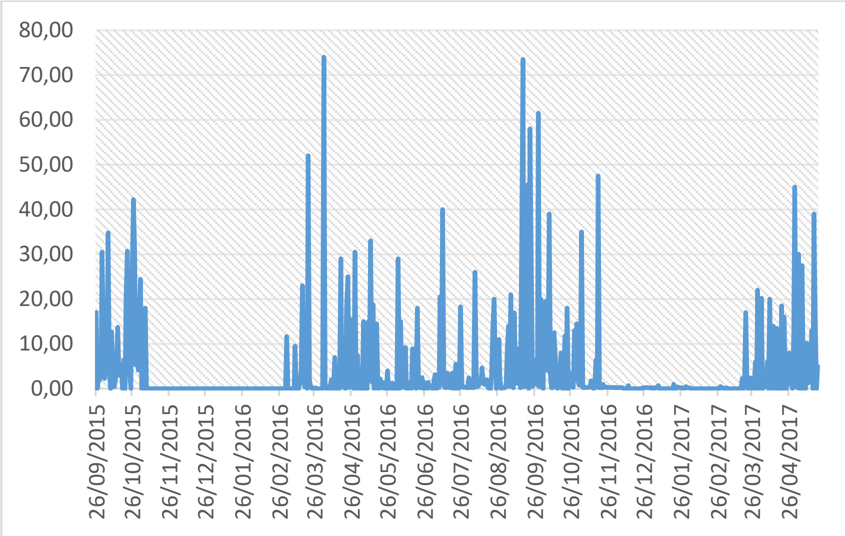



**Figure 3.9 Rainfall data of Lom Pangar Catchment**

Source: EDC, 2017

3.6.2 Temperature data and potential evapotranspiration

The penitential evapotranspiration data was collected from secondary source (World Bank, 2014) base on monthly timeframe. The available data was for a period between 1901 to 2009 with the annual average evapotranspiration of 1675mm.

Concerning the temperature data, it was collected from EDC based on the daily time frame. The data was available for a short period of four months.

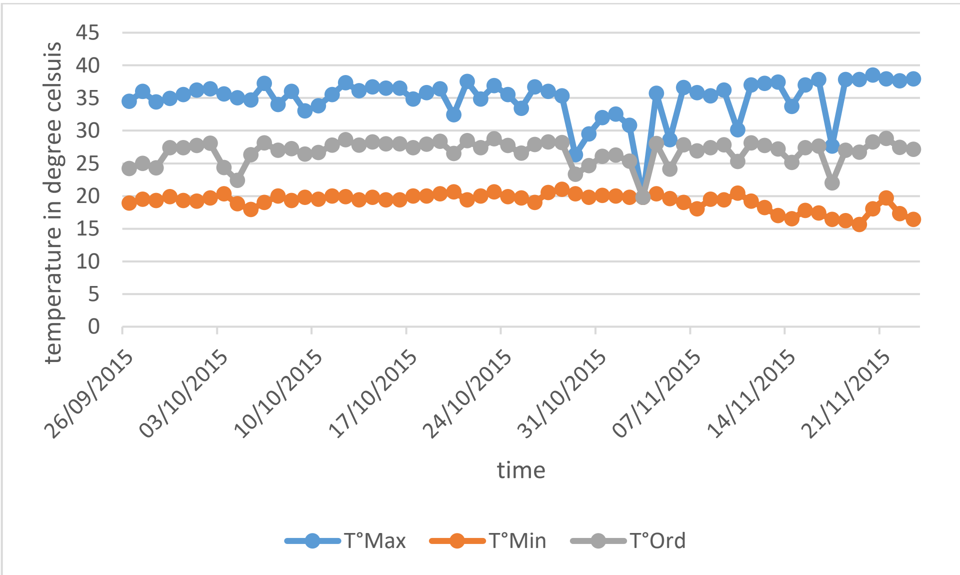



**Figure 3.10 Average monthly temperature in Lom Pangar Catchment**

Source: EDC, 2017

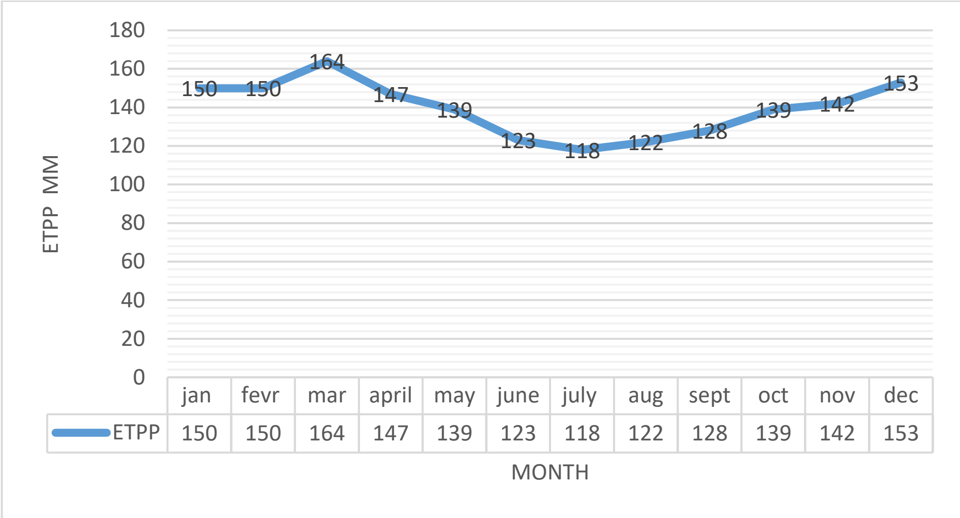



**Figure 3.11 Average monthly potential evapotranspiration in Lom Pangar Catchment between 1901-2009**

3.6.3. Digital Elevation Model (DEM)

The DEM map of Lom Pangar was obtained from the national institute for cartography of Cameroon in the format of SRTM (Shuttle Radar Topography Mission). It was used for the watershed delineation including stream definition, outlets and inlets as well the calculation of the sub basins parameters and the Slope Length and Slope Steepness factors (LS-factors). The DEM resolution is a very important characteristic, because affect the watershed delineation; stream network. The DEM obtained for our study has a resolution of 30m * 30m and was projected to WGS 84 UTM 32N.

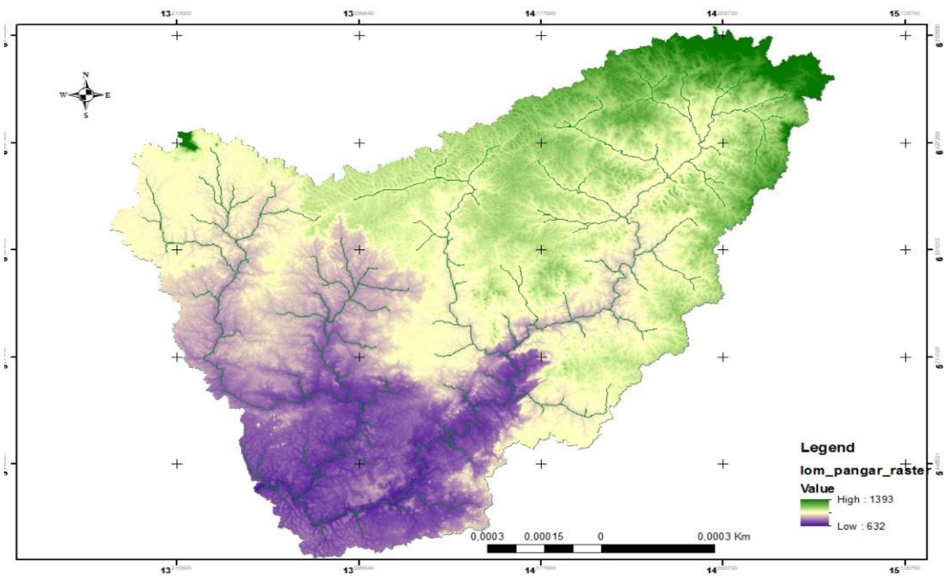



**Figure 3.12 DEM map of Lom Pangar River Bassin**

3.6.4. Soil Data

The soil data was downloaded from the harmonized soil data base website, result of a collaboration between the FAO with IIASA, ISRIC-World Soil Information, Institute of Soil Science, Chinese Academy of Sciences (ISSCAS), and the Joint Research Centre of the European Commission (JRC). The Harmonized World Soil Database is a 30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981).  FAO soil database. That input is useful in the model for the determination of the soil texture, water content hydraulic conductivity, bulk density as well as organic carbon for different layer according to different soil type.

The soil map was processed in ArcGIS 10.2.2 in order to clip the global raster soil map for ours study area and identify the different soil type present in the catchment. Based on the soil database, we have determined the proportion of different components of the soil (% silt, % organic matter, % clay) present in ours catchment. Based on that information and Soil Classification Ternary Diagram, different soil type have been identified in the catchment.

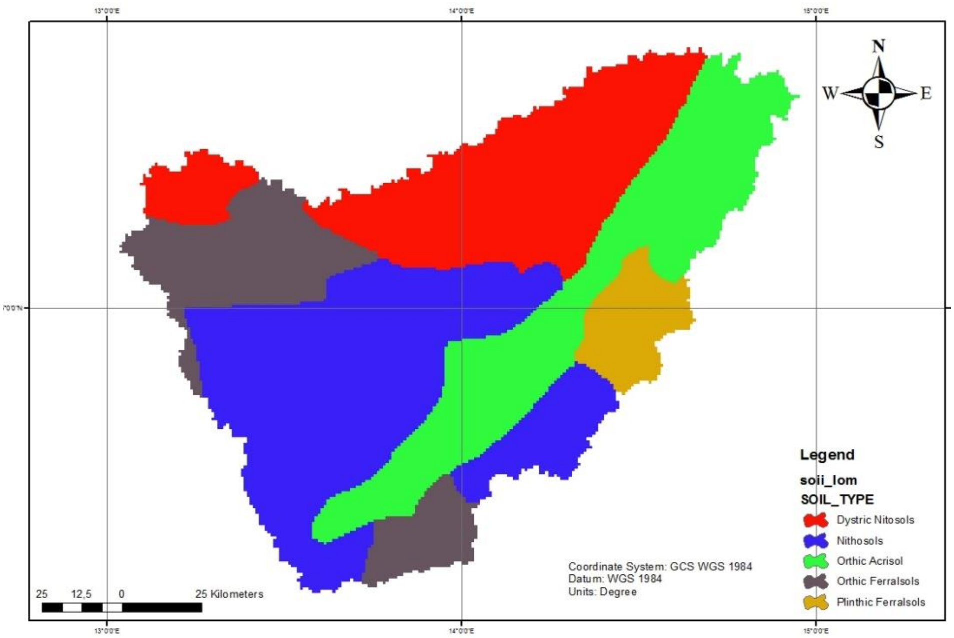



**Figure 3.13 Lom Pangar River Basin soil Map (HWSD +FAO)**

### 3.6.5. Landsat Data Acquisition for Land Use Cover Change

In order to assess land use cover change, the Landsat image of my watershed of interest was collected. That satellite data are produced by the United States Geological Survey (USGS) and freely available from the USGS Global Visualization Viewer (USGS GLOVIS) platform (http://glovis.usgs.gov/).

The USGS global visualization viewer is a quick and easy online search and order tool for selected satellite and areal data. The viewer allows user-friendly access to browse images from the multiple EROS data holdings. Through a graphic map display, the user can select any area of interest and immediately view all available browse images within the USGS inventory for the specified location. From the browse image viewer page, the user may navigate to either view adjacent scene locations or select a new area of interest. GloVis also offers additional features such as cloud cover limits, date limits, user specified map layer displays, scene list maintenance, and access to metadata. An ordering interface is provided for data that have processing options available. A downloading interface is provided for datasets that are available at no charge.

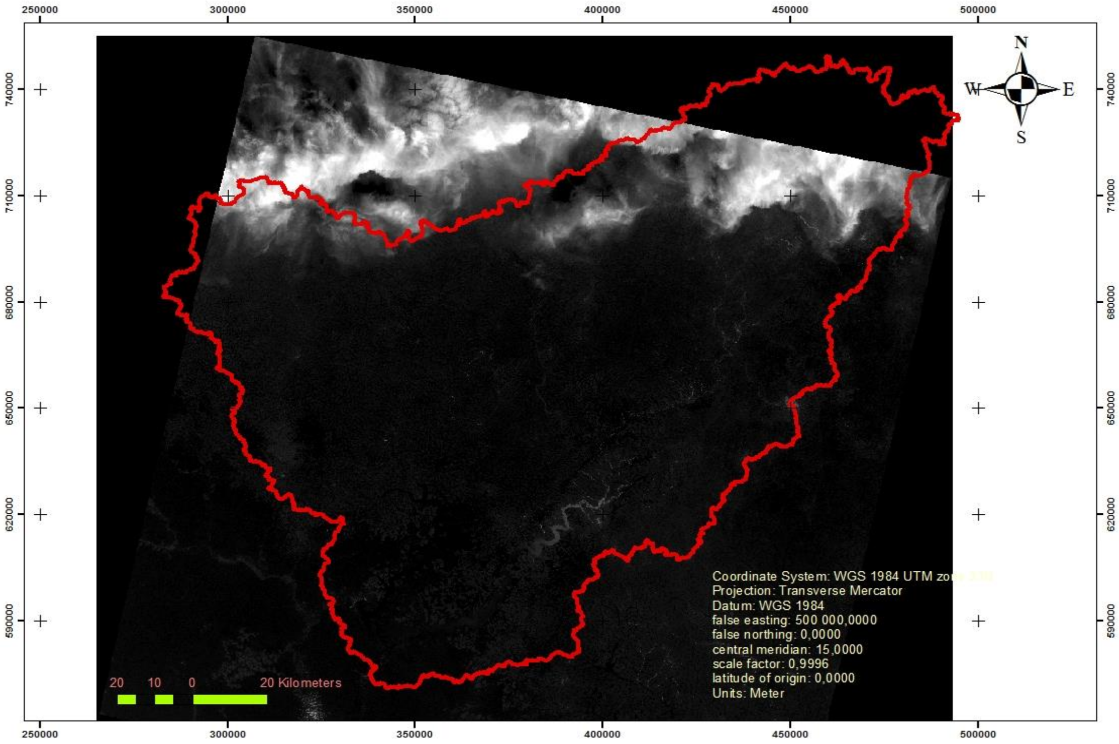
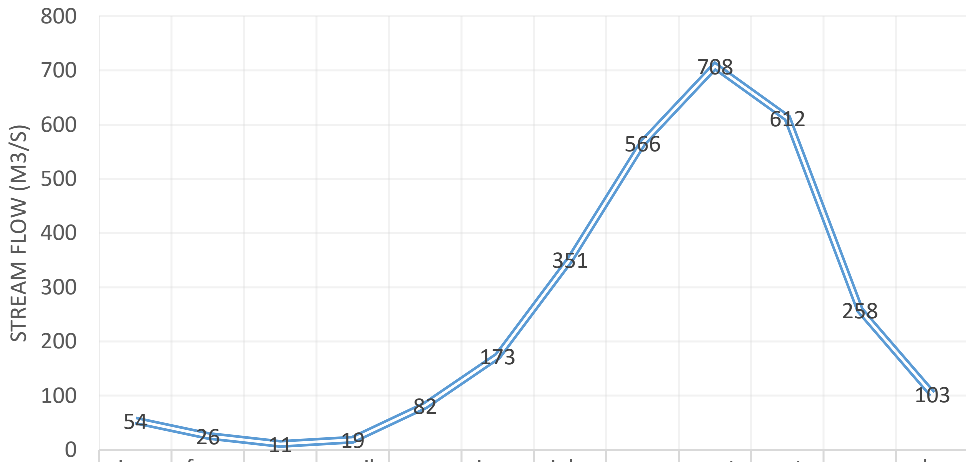



**Figure 3.14 Lom Pangar River Basin LandSat8 image**

### 3.6.6. Stream Flow Data

In 1980, Cameroon counted 74 hydrometric stations, but the measurement network severely declined after 1980 (Sighomnou et al, 2007); only 32 stations were operational in 2008 (MINEE and GWP, 2009). For the purpose of this study, flow data from 1971 till 2003 were obtained from the EDC and from previous studies conducted for the Lom Pangar reservoir project (World Bank, 2014). The stream flow data used in this work was monthly stream flow for more than thirty years of collection. That data is helpful for the computation of the average annual inflow in order to come up different trap efficiency in the reservoir.




| | jan | fevr | mar | april | may | june | july | aug | sept | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| flow (m3/s) | 54 | 26 | 11 | 19 | 82 | 173 | 351 | 566 | 708 | 612 | 258 | 103 |

**Figure 3.15 Monthly average flow in Lom Pangar catchment between 1971-2003**

### 3.6.7 Data quality assessment

In order to check the consistency of rainfall data for this study, the double mass curve should be applied. Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency and long-term trend test of hydro meteorological data. This method was first used to analyse the consistency of precipitation data in Susquehanna watershed United States by Merriam (1937), and Gao et al. (2013) made a theoretical explanation of it. The theory of the double-mass curve is based on the fact that a plot of the two cumulative quantities during the same period exhibits a straight line so long as the proportionality between the two remains unchanged, and the slope of the line represents the proportionality. This method can smooth a time series and suppress random elements in the series, and thus show the main trends of the time series. In recent 30 years, Chinese scholars analyzed the effect of soil and water conservation measures and land use/ cover changes on runoff and sediment using double mass curve method, and have achieved good results (Anon, 2010) In this study, because of non-availability of data it was difficult to check the data consistency.

# CHAPTER 4. RESULT AND DISCUSSION

## 4.1 Calculation of USLE Factors

### 4.1.1 Rainfall Erosivity Factor

Based on the equation developed by (Roose 1980) for Central and West Africa, the erosivity (k) value for Lom Pangar catchment is found to be 14 509.55 MJ mm $ha^{-1}$ $h^{-1}$ $yr^{-1}$. This value is found using the average annual rainfall of 1550mm. recorded at the gauge station located at the hydropower reservoir and assuming that the rainfall is uniformly distributed in the catchment.

### 4.1.2 Soil Erodibility factor (K-factor)

The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting Kfact, but structure, organic matter, and permeability also contribute. The soil erodibility factor ranges in value from 0.02 to 0.69 (Wijitkosum, 2012)

The erodibility factor for this study is obtained from the FAO map. For that, different soil texture have been identified in the catchment using ArcGis 10.22 to established different proportion of the mineral and organic component. Therefore based on USDA soil texture class, the k factors have been calculated according to Bouyoucos (1935). The erodibility value (K) for the entire catchment has been obtained according to different size of area and different soil texture with different K values as schown in Figure 4.1 and table 4.1.

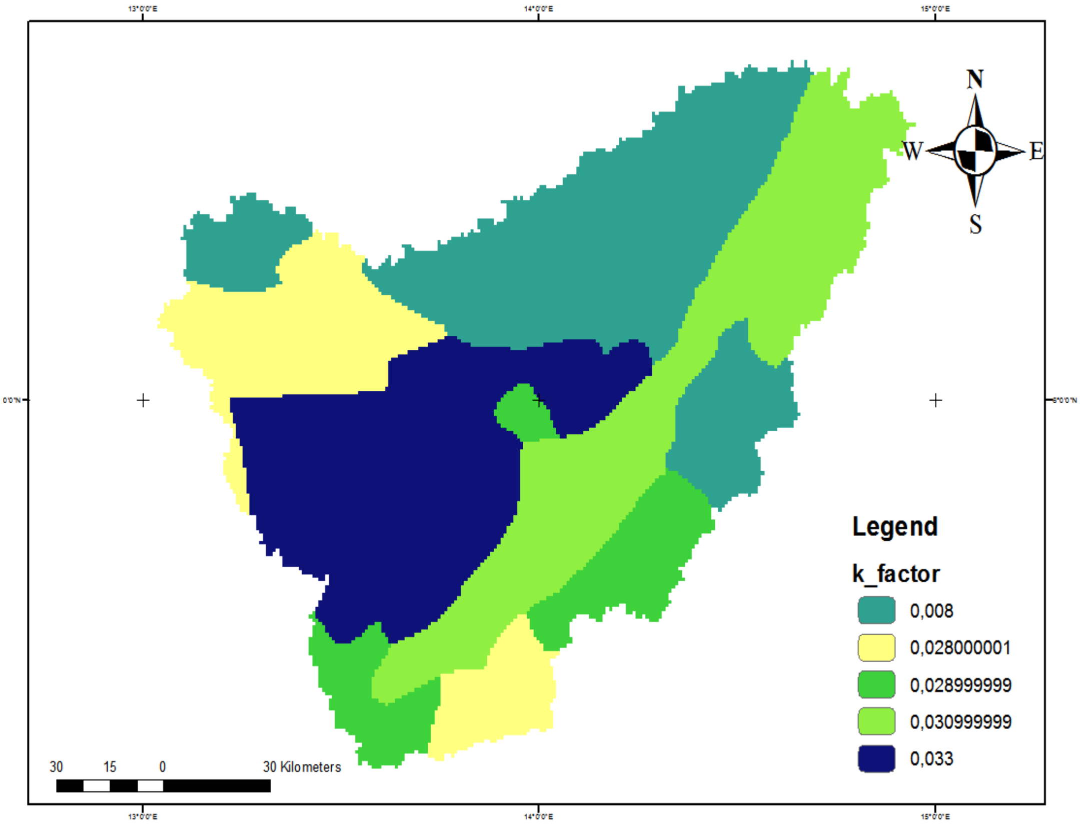



**Figure 4.1 Map of Different k_factor in Lom Pangar Catchment**

**4.1 Soil texture and average K_factor of Lom Pangar**

| MU_SOURCE1 | T_SAND | T_SILT | T_CLAY | T_OC | TOC | Area KM2 | % | k_factors | Av_k_factor t. ha.h (ha MJ mm) -1 |
|---|---|---|---|---|---|---|---|---|---|
| 481 | 60 | 14 | 26 | 1,06 | 1,8232 | 2857 | 14,19 | 0.028 | 0.024 |
| 1045 | 49 | 27 | 24 | 1 | 1,72 | 4570 | 22,70 | 0.031 | |
| 1162 | 60 | 14 | 26 | 1,06 | 1,8232 | 1887 | 9,37 | 0,029 | |
| 1568 | 22 | 23 | 55 | 1,32 | 2,2704 | 1014 | 5,04 | 0,008 | |
| 1569 | 22 | 23 | 55 | 1,32 | 2,2704 | 4935 | 24,51 | 0,008 | |
| 1571 | 44 | 33 | 23 | 0,99 | 1,7028 | 4870 | 24,19 | 0,033 | |
| | | | | | | 20000 | 100 | | |

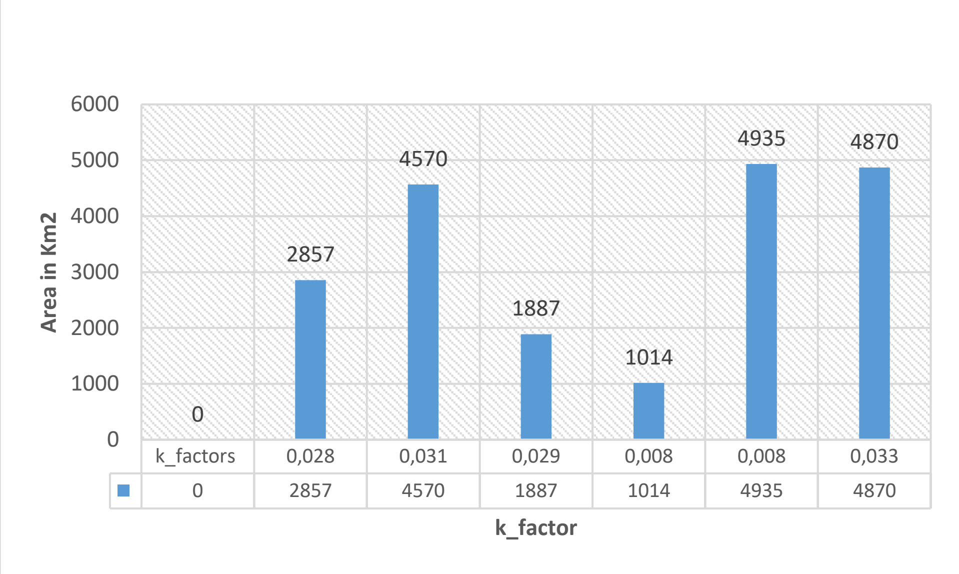



**Figure 4.2 K_factor function of Area**

### 4.1.3 Slope- and slope length factors

The slope effect L represents the effect of Slope length on erosion and the slope steepness factor (s) reflects the influence of slope gradient on erosion. The maximum slope rise in degree after processing in ArcGIS 10.2.2 is $62.35^{o}$ while minimum is $0^{o}$. Following the Methodology given in chapter three, the results are as shown in figure 4.4

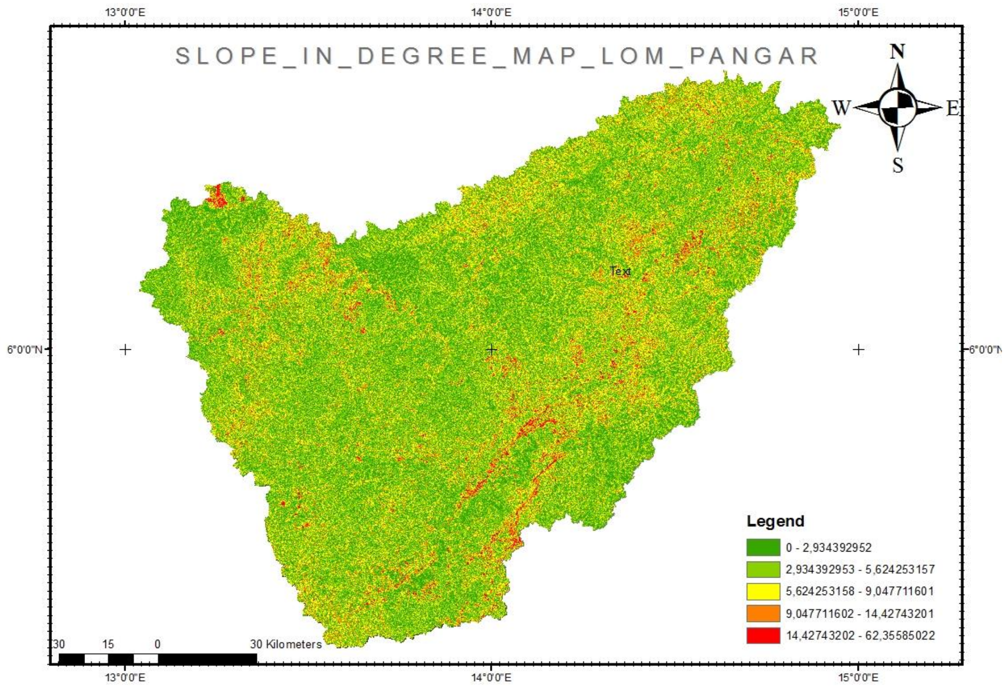
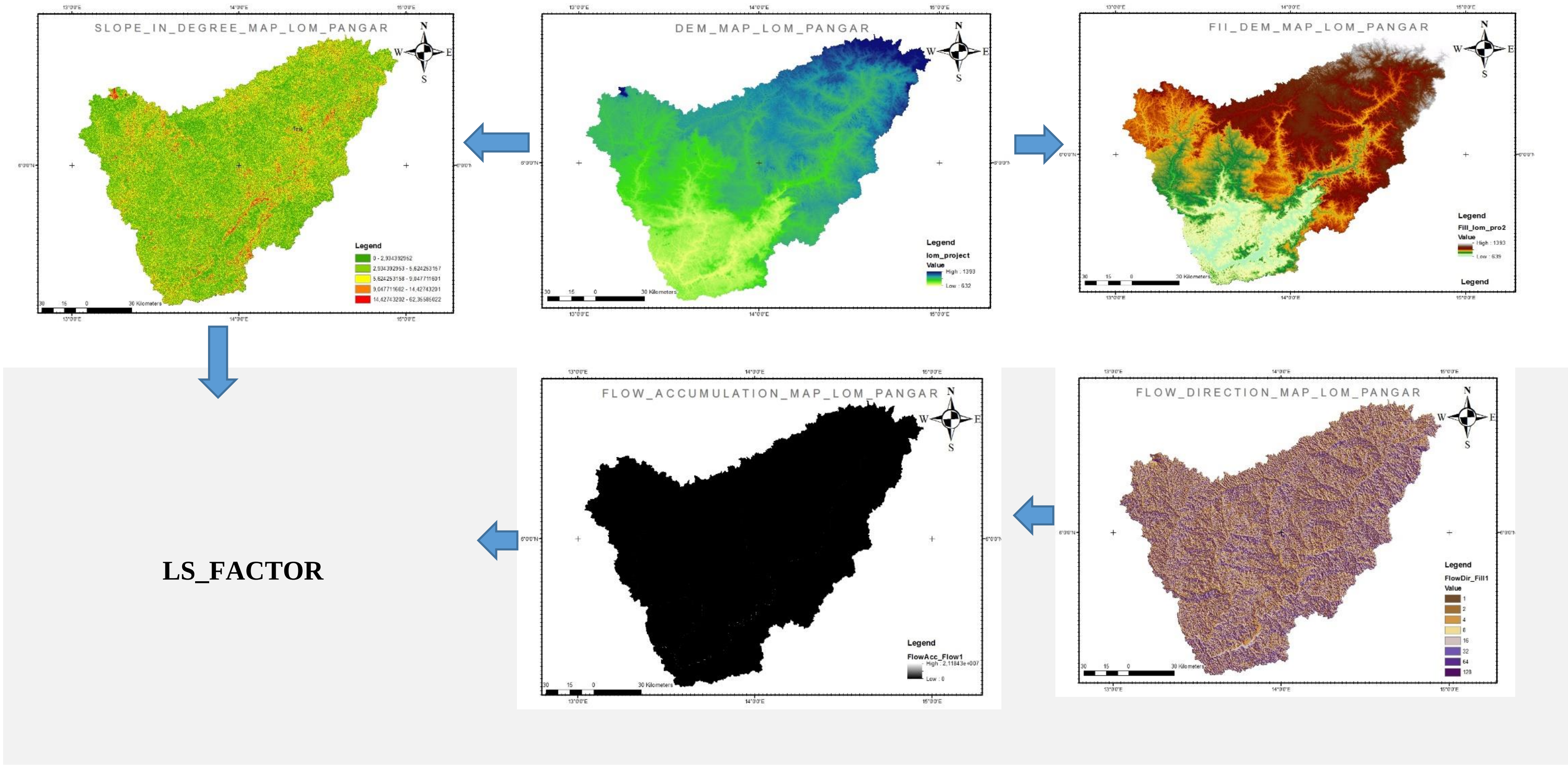



**Figure 4.3 Slope Steepness map of Lom Pangar**


SLOPE_IN_DEGREE_MAP_LOM_PANGAR
Legend
0 - 2,934392952
2,934392953 - 5,624253157
5,624253158 - 9,047711601
9,047711602 - 14,42743201
14,42743202 - 62,35585022
DEM_MAP_LOM_PANGAR
Legend
lom_project
Value
High : 1393
Low : 632
FII_DEM_MAP_LOM_PANGAR
Legend
Fill_lom_pro2
Value
High : 1393
Low : 635
FLOW_ACCUMULATION_MAP_LOM_PANGAR
Legend
FlowAcc_Flow1
FLOW_DIRECTION_MAP_LOM_PANGAR
Legend
FlowDir_Fill1
Value
1
2
4
8
16
32
64
128
LS_FACTOR

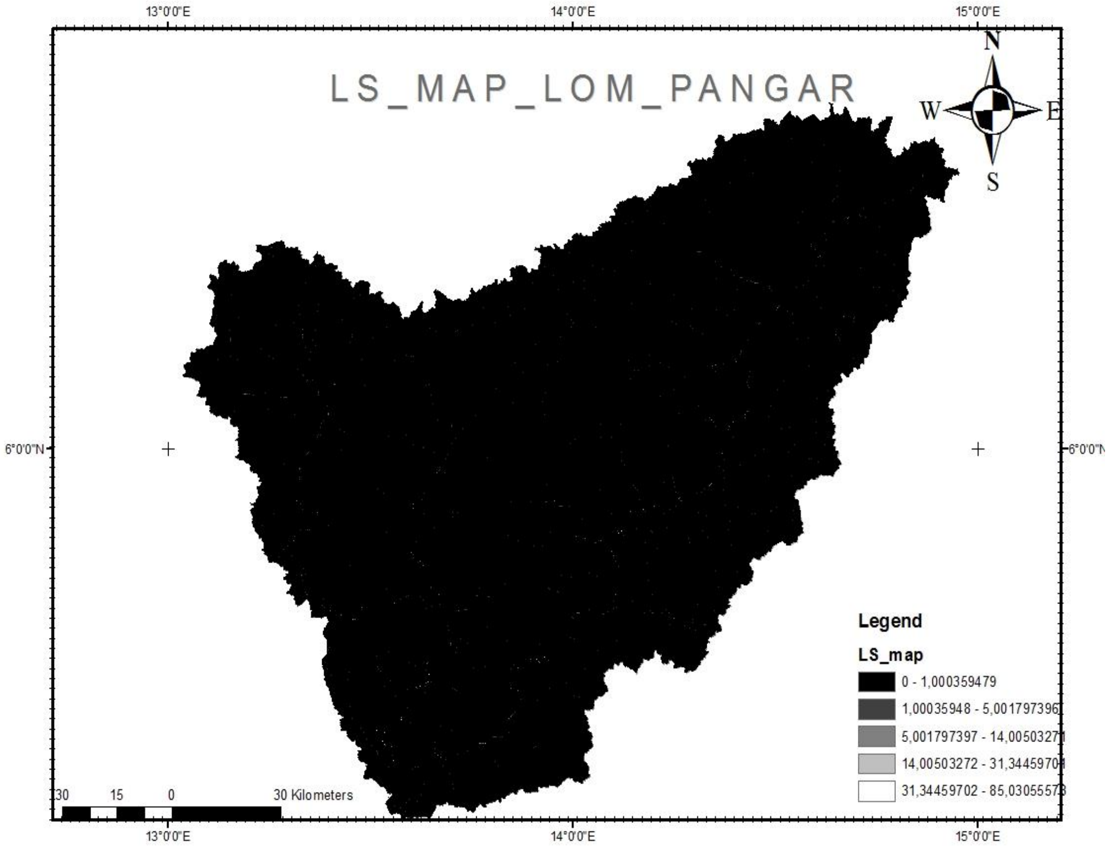



**Figure 4.4 Lom Pangar Catchment LS map**

The LS factor accounts for the effect of topography on erosion in (R) USLE. The slope effect L represents the effect of Slope length on erosion and the slope steepness factor (s) reflects the influence of slope gradient on erosion. Following the Methodology given in chapter three, the results are as shown in the above Figure. The maximum value of slope length factor is 85.0 while minimum is zero with an average of 3.64.

### 4.1.4 Plant cover factor C

Plant cover is effective in preventing erosion to the extent that it absorbs the kinetic energy of raindrops, covers a large proportion of the soil during periods of the year when rainfall is most aggressive, slows down runoff, and keeps the soil surface porous. However, it is difficult to assess the protective action of plant cover without a close look at the farming techniques involved.

After supervised classification, of the Landsat 8, it gave rise to four main classes, which were – forest that represent 35% of the total catchment, water_bodies covering 2.53% of the catchment area, savannah covering 55.2% and built up area covering 7.1% of the catchment.

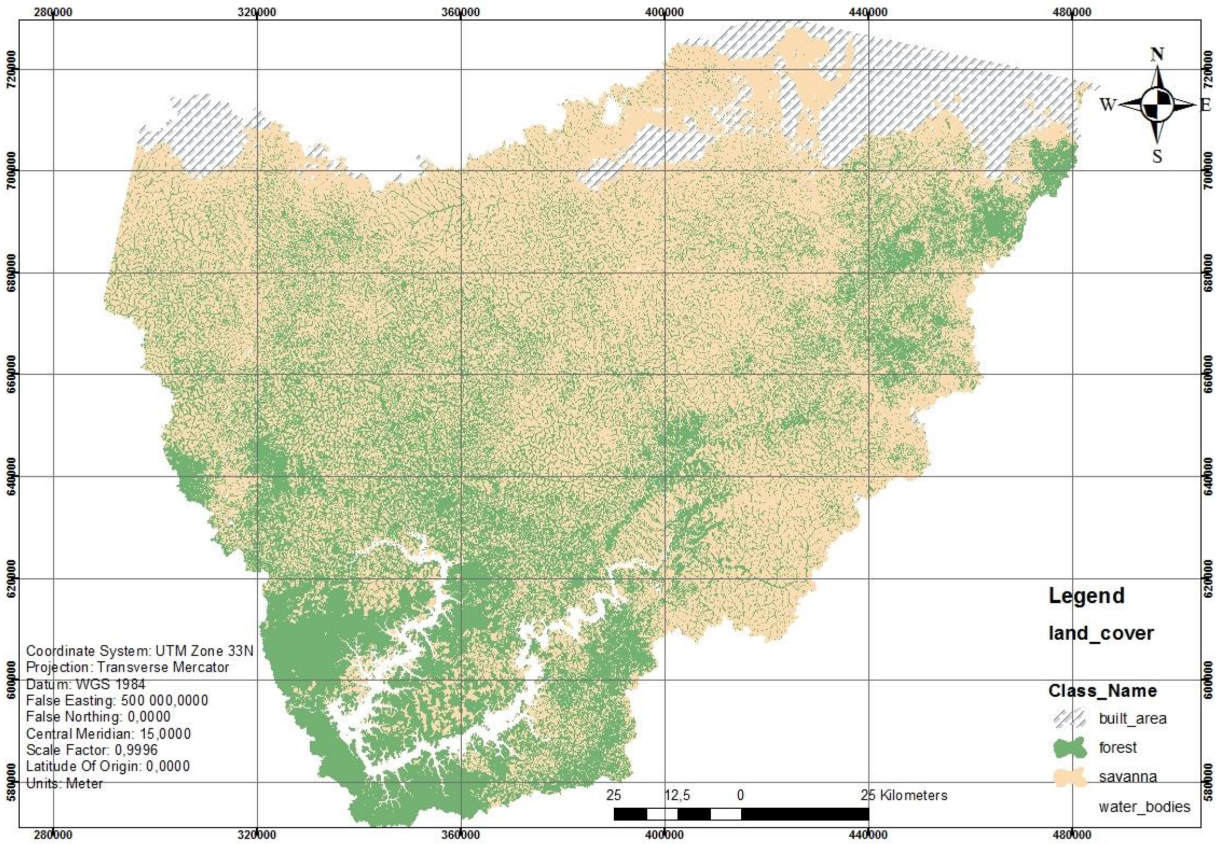



**Figure 4.5 Land cover map of Lom Pangar River Basin 2017**

After the identification of different land cover by classification of landsat8 images, the MODIS land use class and the modified land use type for C-factor has been used to allocate C-factor for each land cover.

The C factors are related to the land-use and are the reduction factor to soil erosion vulnerability. It is an important factor in USLE, since they represent the conditions that can be easily changed to reduce erosion. C factor is basically the vegetation cover percentage and is defined as the ratio of soil loss from specific crops to the equivalent loss from tilled, bare test-plots. The value of C depends on vegetation type, stage of growth and cover percentage. Therefore, it is very important to have good knowledge concerning land-use pattern in the basin to generate reliable C factor values.

As the C factor ranges between zero and one, the average value for the catchment based on the area covered by each land cover type has been found to be 0.08

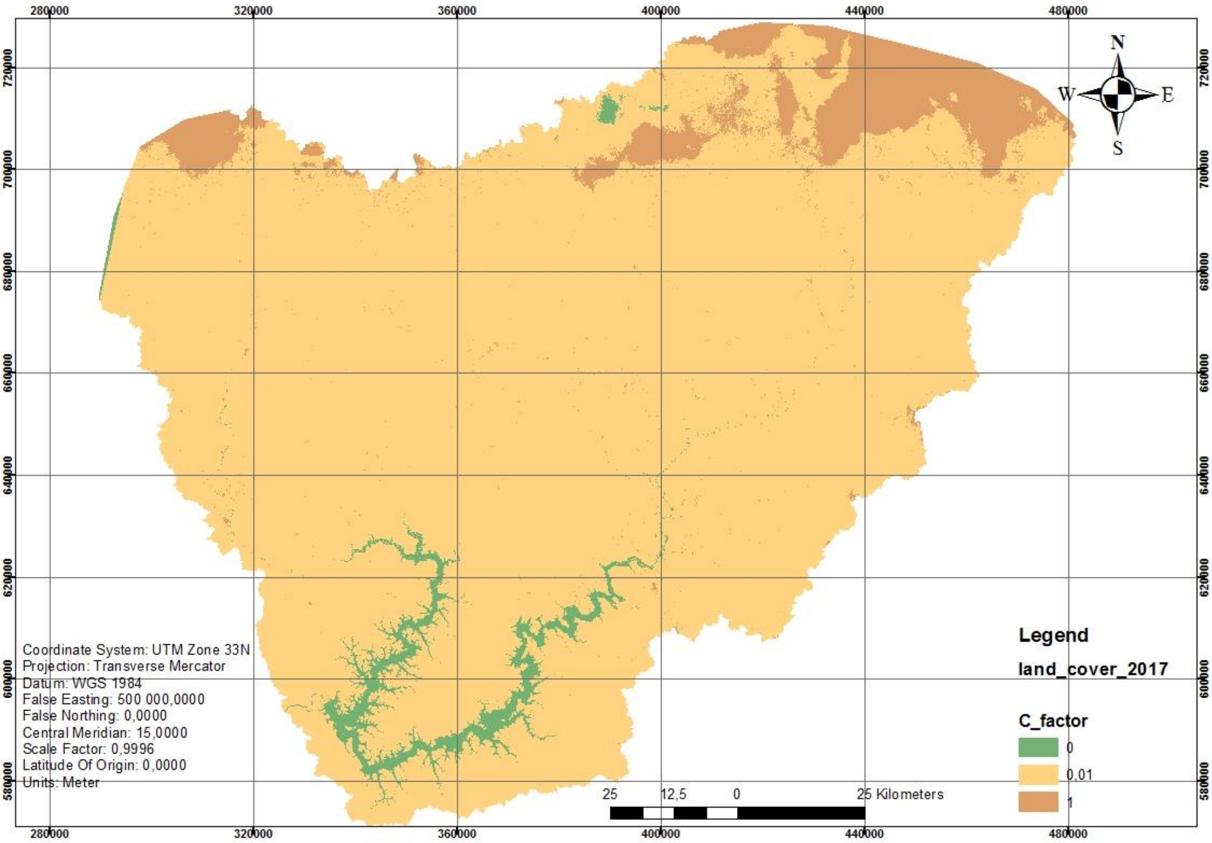



**Figure 4.6 C_factor Map 2017 Lom Pangar River Basin**

**Table 4.1: MODIS land use class and the modified land use type for C-factor computation**

| MODIS land use type | Modified land uses class | C_Factor |
|---|---|---|
| water | | 0 |
| evergreen needle leaf forest | Forest | |
| evergreen broadleaf forest | | |

| | | |
|---|---|---|
| deciduous needle leaf forest | | 0.01 |
| deciduous broadleaf forest | | |
| mixed forest | | |
| closed shrublands | Shrublands | 0.06 |
| open shrub lands | | |
| woody savannas | Savannas | 0.01 |
| savannas | | |
| Grass lands | | 0.01 |
| permanent wetlands | | 0.01 |
| Croplands | Cultivated land | 0.15 |
| cropland/Natural vegetation mosaic | | |
| urban and built-up | | 1 |
| barren or sparsely vegetated | | 1 |

## 4.2 Soil loss from the catchment

After the determination of different USLE factors, the average rate of soil loss from the Lom Pangar catchment per hectare has been found to 101.4 ton/ha/year. The table below gives the summary of different factors.

**Table 4.2: Values of different USLE factor and total soil loss**

| USLE_Factors | Values |
|---|---|
| **R= rainfall erosivity factor (MJ/ha.mm/h),** | 14509.55 |
| **K= erodibility factor (t.ha.h/ha/MJ/mm),** | 0.024 |
| **LS= slope length and steepness factor** | 3.64 |
| **C= the land use/land cover factor,** | 0.08 |
| **P= conservation measure (practice factor )** | 1 |
| **A= Mean (annual) soil loss t/ha/year** | 101.4 |

Based on the above result, it can be established according to the surface area that the Lom Pangar catchment loses 202.8 million ton of soil per year.

### 4.3 Sediment Delivery Ratio (SDR)

The sediment eroded from a watershed undergoes either deposition, either transportation to reach the cross section of the stream. The ratio between the observed sediment yield at a cross section of a stream and the total quantity of soil eroded in the catchment above that section is the sediment delivery ratio. Using the equation developed by Vanoni (1975), the sediment delivery ration for our catchment of study is 14%.

Using that result, it be can computed and concluded that the Lom Pangar river annual sediment yield is 28.392 million ton.

### 4.4 Process of Reservoir Sedimentation

- The process of sedimentation starts from rainfall that results into runoff after some of it might have percolated or evaporated.

- The storm runoff loaded with sediment particles enters a reservoir and the inflow is spread over a larger channel or reservoir cross-section, and its velocity is quickly reduced.

- This may lead to reduction in the transport energy and causes the large sediment particles and aggregates to settle to the bottom.
- The remainder of the inflow moves along the bottom of the reservoir towards the dam until it reaches an elevation in the reservoir where the density of the inflow equals the density of the reservoir water.
- As the inflow, velocity is further reduced, the larger particles left in the remaining flow will settle to the bottom, decreasing the inflow density.
- Some of the flow may move horizontally into the reservoir before the bulk of the remaining flow.
- This process is very dynamic that is, constantly changing and adjusting. When the flow reaches the point of equal density, it flows horizontally into the reservoir somewhat like a wedge between the lighter and denser water and raises the water in the reservoir above it (Morris and Fan 1998).

## 4.5 Change of storage volume of the reservoir

The storage volume of the reservoir at the specific time is function of the sediment load in the water, the capacity of the reservoir to retain that sediment known as its trap efficiency. That trap efficiency change by decreasing with the time because of the storage capacity of the reservoir that decrease. The table 4.3 below gives the change of storage of Lom Pangar reservoir based on the quantity of sediment trapped in the time. That sediment trapped is the material at the origin of the change in storage of the reservoir. The sediment yield in the stream reaches the reservoir and based on the ratio of the capacity of the reservoir and the annual volume of water getting in the reservoir, the proportion in percentage of sediment trapped by the reservoir known as the trap efficiency is determined. Follow that, the quantity is multiplied with the density of sediment to evaluate the volume occupied in the reservoir.

**Table 4.3 Calculation of Change of Storage**

| Period (years) | Storage Capacity x10$^6$ (m$^2$-m) | Av. Annual Inflow (I) x10$^6$ (m$^2$-m) | C/I Ratio | Brune's Trap Efficiency *E* (%) | Av. Annual Sed. Inflow (ISA) x10$^6$ (m$^2$-m) | Sed. Inflow for Period (ISP) x10$^6$ (m$^2$-m) | Sediment Trapped {Strap (i)} x10$^6$ (m$^2$-m) | % of initial Capacity %$C_{(1)}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1-5 | 6000 | 7789.4 | 0.77 | 95.5 | 24.69 | 123.45 | 117.89 | 100.00 | |
| 5-10 | 5882.1 | 7789.4 | 0.75 | 95 | 24.69 | 123.45 | 117.3 | 98.03 | |
| 10-15 | 5764.8 | 7789.4 | 0.74 | 94 | 24.69 | 123.45 | 116 | 96.08 | |
| 15-20 | 5648.8 | 7789.4 | 0.72 | 93 | 24.69 | 123.45 | 114.8 | 94.15 | |
| 20-25 | 5534 | 7789.4 | 0.71 | 92 | 24.69 | 123.45 | 113.57 | 92.23 | |
| 25-30 | 5420.4 | 7789.4 | 0.69 | 91.5 | 24.69 | 123.45 | 112.9 | 90 | |
| 30-35 | 5307.5 | 7789.4 | 0.68 | 91 | 24.69 | 123.45 | 112.3 | 88.45 | |
| 35-40 | 5194.9 | 7789.4 | 0.66 | 90 | 24.69 | 123.45 | 111.1 | 86.58 | |
| 40-45 | 5083.8 | 7789.4 | 0.65 | 89.8 | 24.69 | 123.45 | 110.8 | 84.7 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 45-50 | 4973 | 7789.4 | 0.63 | 89.5 | 24.69 | 123.45 | 110.5 | 82.8 | |
| 50-55 | 4862.5 | 7789.4 | 0.62 | 89 | 24.69 | 123.45 | 109.8 | 81 | |
| 55-60 | 4752.4 | 7789.4 | 0.61 | 88.5 | 24.69 | 123.45 | 109.2 | 79.2 | |
| 60-65 | 4643.2 | 7789.4 | 0.59 | 88 | 24.69 | 123.45 | 108.6 | 77.3 | |
| 65-70 | 4534.6 | 7789.4 | 0.58 | 87.5 | 24.69 | 123.45 | 108 | 75.5 | |
| 70-75 | 4426.6 | 7789.4 | 0.56 | 87 | 24.69 | 123.45 | 107.4 | 73.7 | |
| 75-80 | 4319.2 | 7789.4 | 0.55 | 86.8 | 24.69 | 123.45 | 107.2 | 72 | |
| 80-85 | 4212 | 7789.4 | 0.54 | 86.5 | 24.69 | 123.45 | 106.7 | 70.2 | |
| 85-90 | 4105.3 | 7789.4 | 0.52 | 86.3 | 24.69 | 123.45 | 106.5 | 68.4 | |
| 90-95 | 3998.8 | 7789.4 | 0.51 | 86.2 | 24.69 | 123.45 | 106.4 | 66.7 | |
| 95-100 | 3892.4 | 7789.4 | 0.49 | 86 | 24.69 | 123.45 | 106.17 | 64.8 | |
| 100-105 | 3786.23 | 7789.4 | 0.48 | 85.8 | 24.69 | 123.45 | 105.9 | 63 | |
| 105-110 | 3680.33 | 7789.4 | 0.472 | 85.7 | 24.69 | 123.45 | 105.8 | 61.3 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 110-115 | 3574.53 | 7789.4 | 0.46 | 85.6 | 24.69 | 123.45 | 105.7 | 59.5 | |
| 115-120 | 3468.8 | 7789.4 | 0.45 | 85.5 | 24.69 | 123.45 | 105.5 | 57.8 | |
| 120-125 | 3363.3 | 7789.4 | 0.43 | 85.4 | 24.69 | 123.45 | 105.4 | 56 | |
| 125-130 | 3257.9 | 7789.4 | 0.42 | 85.3 | 24.69 | 123.45 | 105.3 | 54.2 | |
| 130-135 | 3152.6 | 7789.4 | 0.41 | 85.2 | 24.69 | 123.45 | 105.2 | 52.5 | |
| 135-140 | 3047.4 | 7789.4 | 0.40 | 85.1 | 24.69 | 123.45 | 105.05 | 50.7 | End of Useful life |

Col. (1) = Time period

Col. (3) = average discharge (m3/s) *60*60*24*365

Col. (4) = Col (2)/ Col (3)

Col. (5) = values read from Brune's trap efficiency curve (Figure 3.7)

Col. (6) = Mass of sediment/specific weight of sediments (1150 kg/$m^3$ )

Col. (7) = average annum sediment inflow*time period= col(6)*(col(1) =5years)

Col. (8) = Col. (5)*Col (7)

Col. (9) = Col. (2)/ storage capacity of the reservoir

### 4.6 Useful life of the reservoir

The useful life is the time period when the dead storage is filled completely with sediment (Issa et al., 2013) . Determining the useful life of a reservoir is an important design parameter which may crucially affect the economic feasibility of a water resources project. Sedimentation of a reservoir that ultimately determines its useful life is a complicated phenomenon and depends on a number of variables of which reliable information is generally not available. Of these variables, the inflow rates of water and sediments are probably the two most important factors. Both of these vary with time. Sedimentation is controlled by the future discharges of water and the sediments in a river, and there is no way of predicting these factors reliably (Gill, 1979)

The useful life of Lom Pangar reservoir, purpose of the present study was established base of the soil loss from the entire catchment obtain using the universal soil loss equation and the trap efficiency curve for the estimation of the retention. The above table 4.3 show the result that establishes the useful life to be 140 years. The following figure 4.7 shows the storage profile of our reservoir with the time due that sediment trap from the inflow.

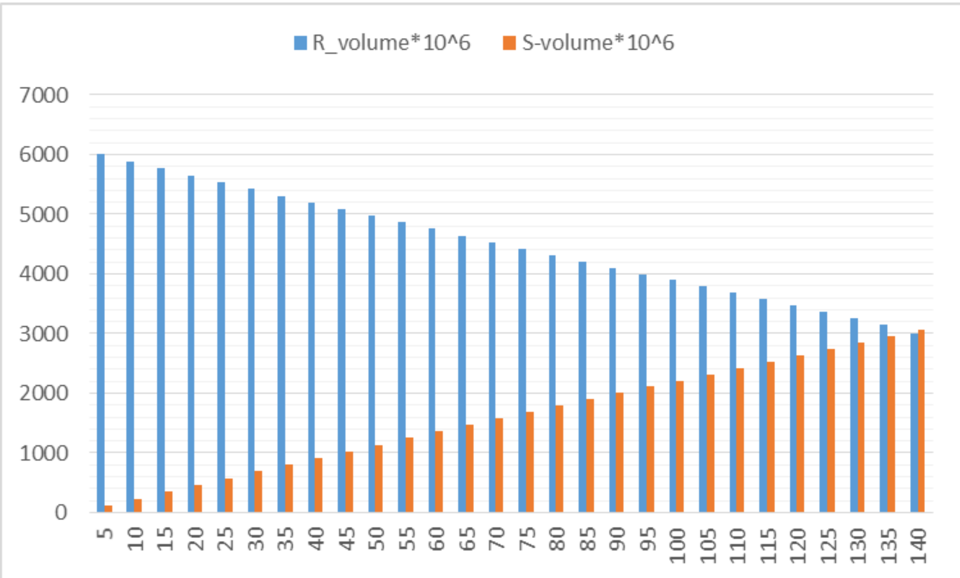



**Figure 4.7 Lom Pangar reservoir profile**

## 4.7 Impact of land use change on erosion

Land cover or vegetation cover is considered like the factor that significantly affects the soil displacement by rain in many researches (Wijitkosum, 2012). The reduction of vegetation cover can increase soil erosion. This relationship is a reason why vegetation cover and land use have been widely included in soil erosion studies and finally concluded that land use can greatly affect the intensity of runoff and soil erosion.

Vegetation controls soil erosion by means of its canopy, roots and litter components; vegetation also influences erosion in terms of the composition, structure and growth pattern of the plant community Similarly, natural vegetation is more effective than most plantings in reducing soil erosion because of its stratified structure. Such a structure can absorb much more of the raindrop energy by multi-interception than can a structure with a single layer (Wijitkosum, 2012).

Cameroon is often called « Africa in miniature » because of its large diversity of geography and climate, which brings benefits in terms of both agricultural production and biodiversity. According to (REDD-PAC, 2000) Forests occupy about 35 million hectares including 19 million hectares of dense humid forests. One third of the humid forests are under exploitation, and Cameroon is the second largest timber producer in the region.

According to conservative projections, close to 28 million people will be living in Cameroon in 2030, with a strong increase in urban populations and average per capita GDP. A larger and richer population generates an increase in local consumption of agricultural products, which is translated into an increase in cultivated areas.

Clearly, the increase in population as shown in figure 4.8 leads to the expansion of the needs for food, energy and construction material (timbers). Those needs can be satisfied by modifying our surrounding environment by agriculture, mining, timber exploitation with serious consequences such as deforestation, green house gas emission and soil degradation.

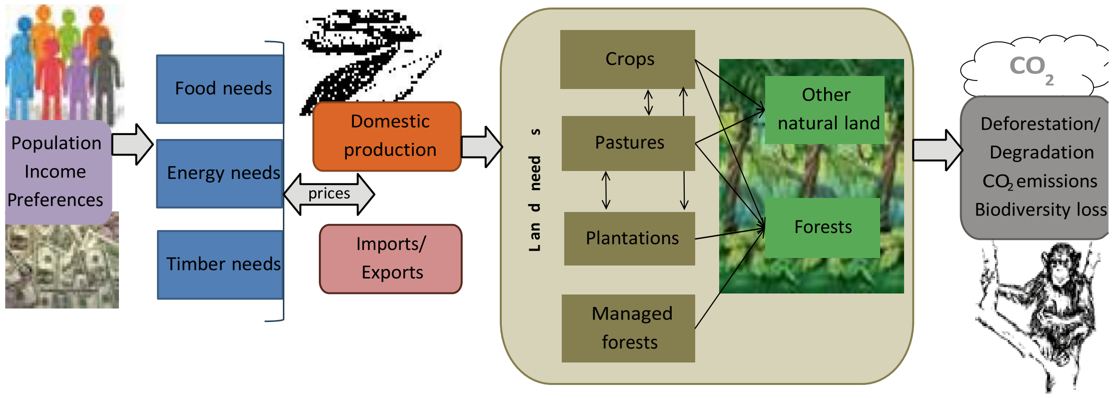



**Figure 4.8 Scenario of Land use/ land cover Change (REDD-PAC, 2000)**

The application of the remote sensing technique for interpreting the satellite images taken by Landsat8 in 2015 and 2017 in our study area in the eastern part of Cameroon (Lom Pangar) revealed that the land use in the study area could be classified into 4 types as follows.

– Forest area where most areas are the tropical rain forest in natural forest

– Community, which consists of residential buildings and bare land covering the non-vegetation area.

– Savanna area which is a rolling grassland scattered with shrubs and isolated trees

– Water bodies covering natural and man-made water bodies

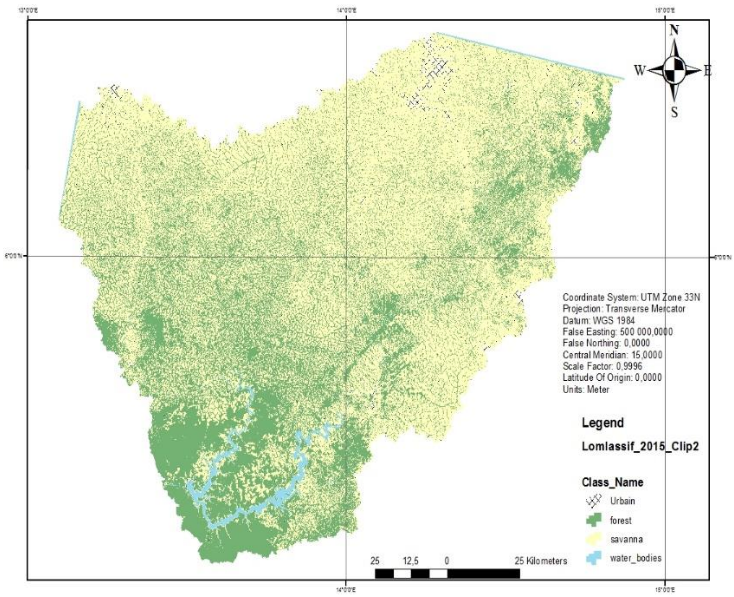



**Figure 4.9 Land Cover Map 2015**

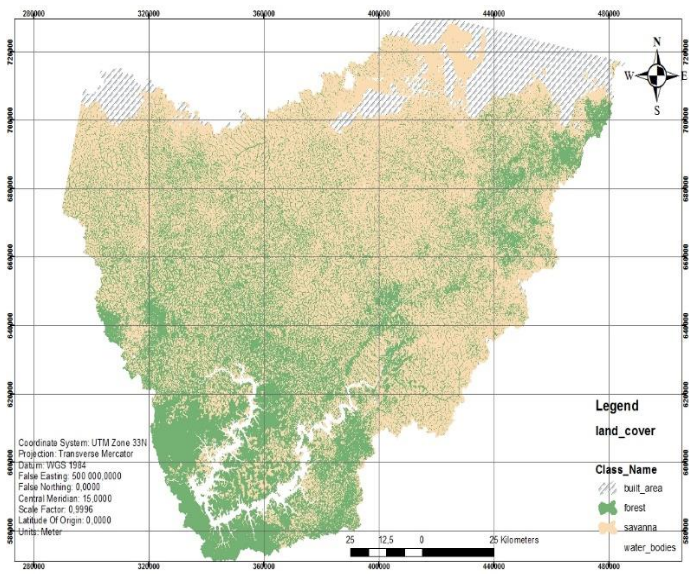



**Figure 4.10 Land Cover Map 2017**

According to the land use study of the two periods, it was found out that the largest area of the site in 2015 and 2017 was the savanna that area covered 63.1% of total area in 2015 and 55.2% of total area in 2017. In addition, built up and bare soil that area covered 1.27% of total area in 2015 and 7.1% of total area in 2017. Details of land use of the site are shown in the table 4.4 and figure 4.9, 4.10.

**Table 4.4 change in Land cover**

| | Area | |
|---|---|---|
| Land use | 2015 | 2017 |
| **Forest** | **34.1%** | **35%** |
| **Savanna** | 63.1% | 55.2% |
| **Built up Bare land** | 1.27% | 7.1% |
| **Water** | 1.5% | 2.53% |
| **Total** | 20 000Km$^2$ | |

Based on the different changes observed in our catchment of study, the consequence on the quantity of soil lost per ha per year is given in the table 4.5

**Table 4.5 Impact of Land Cover Change on Soil Loss**

| USLE_Factors | Values | |
|---|---|---|
| | 2017 | 2015 |
| R= rainfall erosivity factor (MJ/ha.mm/h), | 14509.55 | 14509.55 |
| K= erodibility factor (t.ha.h/ha/MJ/mm), | 0.024 | 0.024 |
| LS= slope length and steepness factor | 3.64 | 3.64 |
| C= the land use/land cover factor, | **0.08** | **0.0224** |
| P= conservation measure (practice factor ) | 1 | 1 |
| A= Mean (annual) soil loss t/ha/year | **101.4** | **28.4** |

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

Sedimentation is worldwide known as phenomena that affect seriously reservoirs. This affects reservoir by reducing the capacity storage of the infrastructure, which in our case is used to regulate the flow and stabilise the production of power in the greater Sanaga catchment. To reach our objectives and define the useful life of Lom Pangar reservoir, the USLE model known widely have been used in our case to evaluate the soil loss from the catchment. The first component of the USLE to be identified was the erosivity factor with the value of 14 509.55 MJ mm $ha^{-1}$ $h^{-1}$ $yr^{-1}$ obtained using the Roose equation and the rainfall data collected at the dam. Following that, was generated the value of the erodibility factor from the FAO map using ArcGIS for processing and weighted with the seize of area covered with different soil properties in the catchment. After the processing of FAO map, six differents soil type have been identied with different proportion of mineral component and per consequent different value of erodibility factor. The average value for the catchment was found to be 0.024 t. ha.h (ha MJ mm)$^{-1}$. The next parameter was the LS factor generated from the DEM map of the catchment with ArcGIS and the average value was 3.64. Another component was the cover factor, developed using Envi software to classify LANDSAT images. For that, the image processing raised four different type of cover (built up area, savannah, water bodies and forest) with different C values according to MODIS table of Land use. The average value was generate and weighted with different seize of area covered by different land cover to be 0.08. The last parameter P (practice factor) was assumed to be one with the objective to do not underestimate sediment from the catchment.

Following that, the USLE generated a possible soil loss of 101.4 million ton per year in Lom Pangar. That total soil does not reach the outlet and the quantification of the amount reaching the outlet was done using the sediment delivery ratio formula of Vanoni (1975) based on the area of the catchment. The result gave a ratio of 14% of the total sediment that reaches the outlet. That amount represents 28.3 million ton/year that reaches the reservoir.

Having the total sediment reaching the outlet, the reservoir capacity that is 6 billion $m^3$ and the average annual inflow of 7789.4 million $m^3$ per year, the useful lives of revoir was developed based on the Brune's trap efficiency curve to be 140 year after the dam construction. That value represents an average change of storage of 0.36% per year smaller than the 1% of annual worldwide reduction of water reservoir. Based on the construction design parameter, the useful life of reservoir is generally 100 years; per consequent, it can be retained from our result that the sediment is not a major problem in Lom Pangar reservoir.

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## Annexes

### Table 5.1: Monthly flow data (mˆ3/s)

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | | | | | | | | | | | | $m^3/s$ | mm/yr |
| 1971 | 102 | 66 | 89 | 108 | 79 | 113 | 382 | 443 | 646 | 620 | 257 | 113 | 253 | 404 |
| 1972 | 49 | 21 | 7 | 34 | 63 | 205 | 248 | 405 | 506 | 533 | 174 | 78 | 194 | 311 |
| 1973 | 58 | 32 | 9 | 15 | 99 | 222 | 376 | 492 | 565 | 443 | 143 | 64 | 211 | 338 |
| 1974 | 38 | 18 | 3 | 23 | 92 | 186 | 362 | 559 | 738 | 713 | 269 | 100 | 260 | 416 |
| 1975 | 71 | 35 | 2 | 21 | 90 | 155 | 392 | 497 | 757 | 690 | 282 | 145 | 263 | 421 |
| 1976 | 58 | 37 | 13 | 9 | 62 | 171 | 314 | 522 | 640 | 802 | 441 | 162 | 271 | 433 |
| 1977 | 103 | 49 | 10 | 5 | 50 | 156 | 416 | 586 | 718 | 583 | 213 | 93 | 250 | 400 |
| 1978 | 45 | 15 | 2 | 69 | 119 | 334 | 379 | 566 | 819 | 550 | 253 | 113 | 273 | 437 |
| 1979 | 73 | 35 | 14 | 28 | 200 | 249 | 525 | 663 | 755 | 629 | 395 | 156 | 312 | 499 |
| 1980 | 100 | 53 | 27 | 11 | 118 | 160 | 436 | 593 | 972 | 929 | 386 | 152 | 330 | 528 |
| 1981 | 90 | 47 | 7 | 17 | 128 | 224 | 565 | 807 | 1,080 | 837 | 368 | 150 | 362 | 579 |
| 1982 | 56 | 26 | 27 | 19 | 108 | 149 | 353 | 652 | 819 | 810 | 281 | 120 | 287 | 459 |
| 1983 | 64 | 35 | 8 | 2 | 31 | 175 | 303 | 451 | 731 | 391 | 120 | 55 | 198 | 317 |
| 1984 | 19 | 9 | 5 | 25 | 58 | 82 | 238 | 404 | 544 | 494 | 193 | 71 | 179 | 287 |
| 1985 | 50 | 15 | 6 | 37 | 44 | 139 | 401 | 625 | 802 | 478 | 256 | 108 | 248 | 397 |
| 1986 | 65 | 32 | 39 | 34 | 43 | 108 | 237 | 467 | 588 | 608 | 281 | 99 | 218 | 349 |
| 1987 | 46 | 24 | 4 | 13 | 15 | 146 | 206 | 442 | 630 | 626 | 175 | 73 | 201 | 322 |
| 1988 | 57 | 19 | 4 | 23 | 115 | 161 | 317 | 716 | 725 | 724 | 215 | 92 | 266 | 425 |
| 1989 | 36 | 16 | 1 | 8 | 105 | 231 | 312 | 745 | 966 | 778 | 228 | 96 | 295 | 472 |
| 1990 | 45 | 20 | 6 | 6 | 140 | 220 | 430 | 675 | 726 | 544 | 353 | 139 | 277 | 443 |
| 1991 | 54 | 26 | 18 | 33 | 155 | 310 | 468 | 620 | 682 | 616 | 285 | 112 | 283 | 453 |
| 1992 | 55 | 28 | 17 | 16 | 80 | 162 | 392 | 617 | 768 | 600 | 339 | 121 | 268 | 428 |
| 1993 | 60 | 32 | 23 | 21 | 82 | 237 | 421 | 671 | 708 | 524 | 231 | 102 | 261 | 418 |
| 1994 | 48 | 24 | 14 | 16 | 66 | 184 | 363 | 581 | 896 | 663 | 259 | 101 | 269 | 431 |
| 1995 | 56 | 29 | 10 | 13 | 56 | 136 | 298 | 393 | 494 | 434 | 250 | 88 | 189 | 303 |
| 1996 | 36 | 16 | 11 | 18 | 60 | 215 | 328 | 441 | 483 | 676 | 208 | 88 | 217 | 347 |
| 1997 | 49 | 21 | 4 | 37 | 101 | 141 | 313 | 416 | 515 | 355 | 265 | 88 | 193 | 309 |
| 1998 | 48 | 20 | 3 | 4 | 32 | 89 | 226 | 636 | 733 | 707 | 212 | 91 | 235 | 376 |
| 1999 | 44 | 23 | 11 | 18 | 113 | 133 | 275 | 504 | 584 | 609 | 297 | 109 | 228 | 365 |
| 2000 | 54 | 29 | 13 | 27 | 91 | 147 | 253 | 516 | 563 | 463 | 140 | 60 | 197 | 316 |
| 2001 | 28 | 15 | 2 | 4 | 37 | 101 | 277 | 466 | 462 | 456 | 124 | 53 | 170 | 272 |
| 2002 | 31 | 12 | 2 | 18 | 67 | 162 | 339 | 513 | 714 | 557 | 250 | 93 | 231 | 370 |
| 2003 | 45 | 26 | 8 | 9 | 26 | 91 | 349 | 700 | 759 | 675 | 294 | 106 | 259 | 414 |
| Average | 54 | 26 | 11 | 19 | 83 | 173 | 351 | 566 | 708 | 612 | 258 | 103 | 248 | 398 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

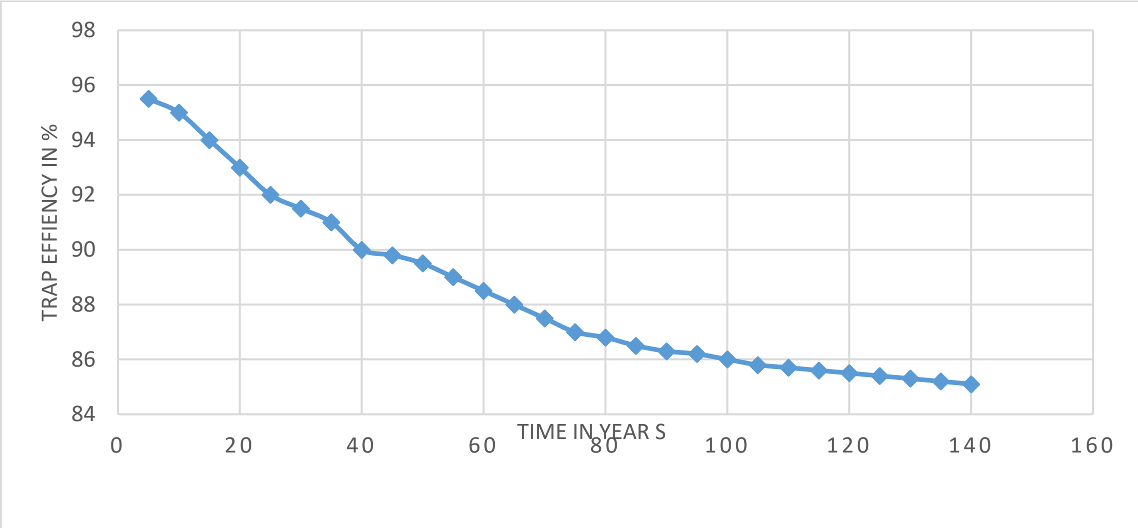


**Figure 5.12 Trap Efficiency function of the time**

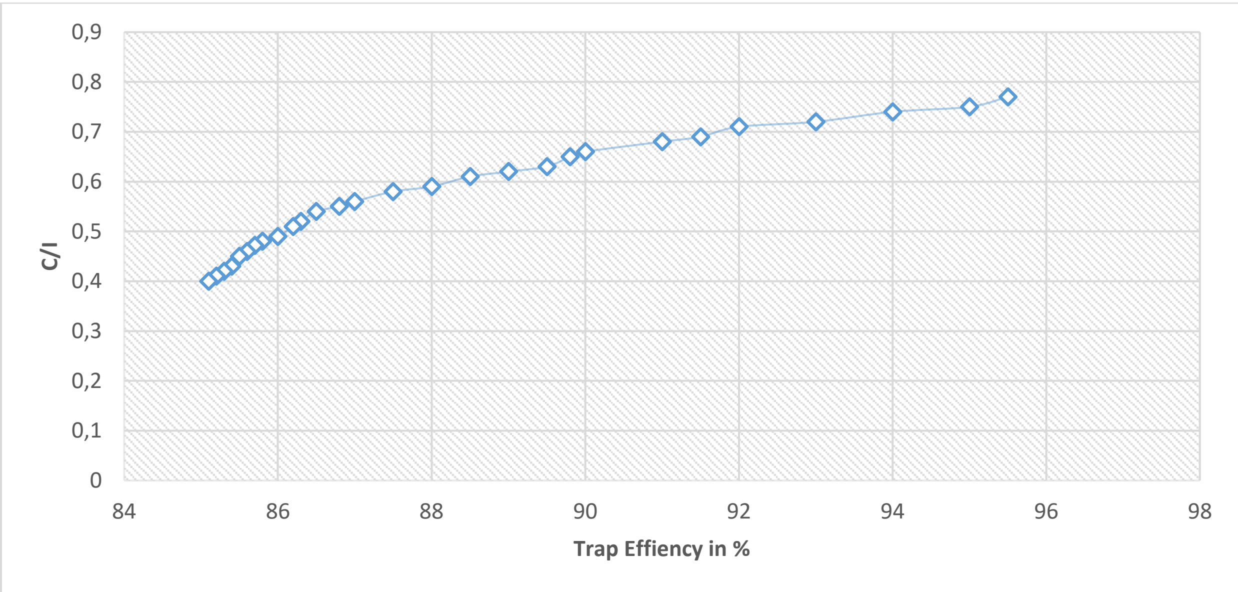


**Figure 5.13 Trap Efficiency function of the capacity Inflow Ratio**