

# BIO-PHYSICAL CONDITION OF ANDHI KHOLA WATERSHED TO ESTIMATE THE LIFE SPAN OF PROPOSED DAM

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## ABSTRACT

Soil erosion, which is a serious problem in hilly areas, becomes especially significant in a country like Nepal, because it is a country that is geologically young, endowed with 'slopey' fragile mountains, and built with rugged surface topography.

The main part of hydroelectricity project is the dam with its natural or man made lakes or reservoirs. Heavy rainfall, deforestation and human activities on the land effects the catchment of the reservoir area which in returns changes landuse causing deteriorating of the catchment and caused detrimental consequences on the reservoirs. The major one is deforestation followed by unstable agricultural practices. A reservoir needs to be managed effectively in order to reduce the effect of the sedimentation.

The erosion process in the rugged terrain watershed transports a lot of sediment to the reservoir and is the most important factor for reducing the net storage capacity of hydropower. Therefore, monitoring and prediction of siltation of the reservoir become important for the formulation of the strategies for the sustainable management of hydropower generation.

The study deals with the ways and means of predicting the soil erosion in Andhi Khola watershed in Nepal, using Landsat TM and SPOT satellite images, aerial photographs and GIS. The Landsat and SPOT images have been used in this study for predicting soil loss and aerial photographs were also used. The other data sets used in this study are scale 1:25,000, 1:50,000 topography maps, respectively, and a land system map of scale 1:50,000.

The study has been carried out using USLE model, which relates the phenomena of soil erosion to topography, soil and vegetation.

High-resolution satellite data for e.g. IRS or IKONOS have been found to be very effective in monitoring for land cover in hilly area. Special consideration in classification under shading effect is needed because of misinterpretation. Similarly, the use of GIS, by overlaying various maps related to factors affecting soil erosion, has been found to be very effective in analyzing the soil loss. Finally, with the parameters RKLSCP for soil erosion, the productive life span of the reservoir was estimated.

## INTRODUCTION

Mountain watersheds in Nepal occupy a permanent place in the geographical and economic setting of the country. They account for 68% of the total area and serve as homeland for 60% of the total population. Natural resources provided by the watershed ecosystem are the main sources of livelihood of the majority of the rural population.

The deteriorating occurs generally in terms of land degradation and ecological environment through soil erosion. Land is one of the major resources available to man particularly in an agricultural economy like Nepal. Many of the upland watersheds of Nepal are in a state of physical and biological deteriorating due to the exploiting of natural renewable resources by the local inhabitants, primarily in response to meeting their basic needs for food, fodder, fuelwood, fiber and shelter.

Effective monitoring of landuse/landcover changes is essential in order to have sustainable watershed management system. It is also important to assess the land suitability and analyze the possible trend for change, so that protective measure can be planned and implemented.

GIS can be combined with data gathered from Remote Sensing and Digital Elevation Model in order to provide a more complete model of the study area. The two technologies provide complementary capabilities. Remote sensing analysis is improved by the verification data with referenced from a GIS, applications verify from the information that Remote Sensing can generate. Finally, with the parameters RKLSCP for soil erosion, the productive life span of the reservoir can be estimated.

## **STUDY AREA**

The study area lies in Syangja district of Gandaki Zone in the Western Development Region. The area is located about 300 km. west from Kathmandu, the capital city of Nepal and 25 km. Southwest from Pokhara valley. The geographical location of the project is between  $27^{\circ} 45' 46''$  N to  $28^{\circ} 14' 05''$  N Latitude and  $83^{\circ} 30' 48''$  E to  $83^{\circ} 57' 17''$  E longitude.

## **MATERIALS**

### 1. Satellite Data:

⇒ Landsat Thematic Mapper (Landsat TM)  
Year of acquisition: 1991

⇒ SPOT multispectral  
Year of acquisition: 1991

### 2. Airphotos:

Year of acquisition : 1997

### 3. Topographic Map:

### 4. Landuse map:

### 5. Land System map

### 6. Geology map

### 7. Others

Meteorological data : Meteorological department, HMG, Nepal

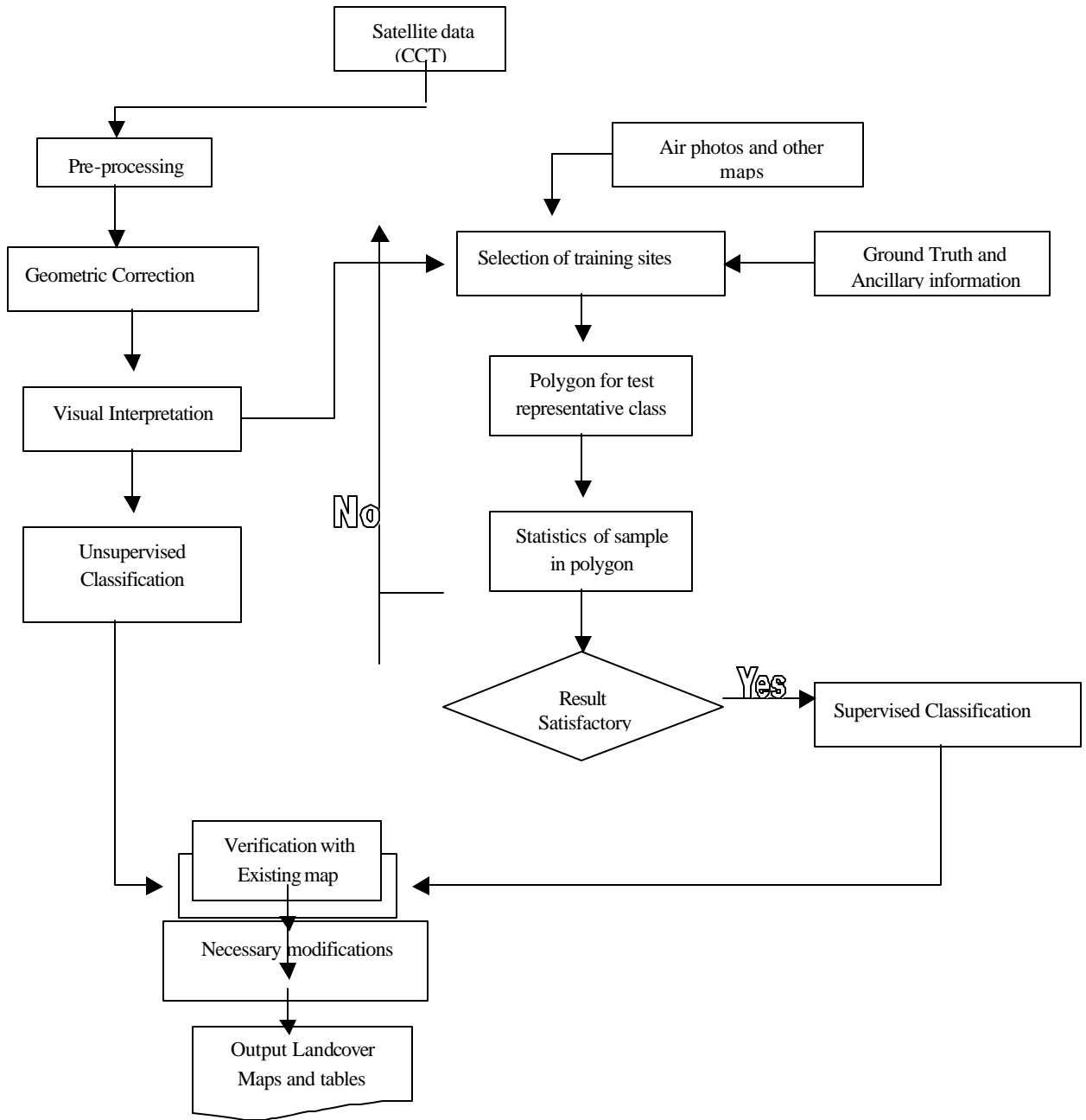
Census data : Central Bureau of statistics (CBS),HMG,Nepal

Other relevant data : Nepal Electricity Authority, Nepal

## **METHODOLOGY**

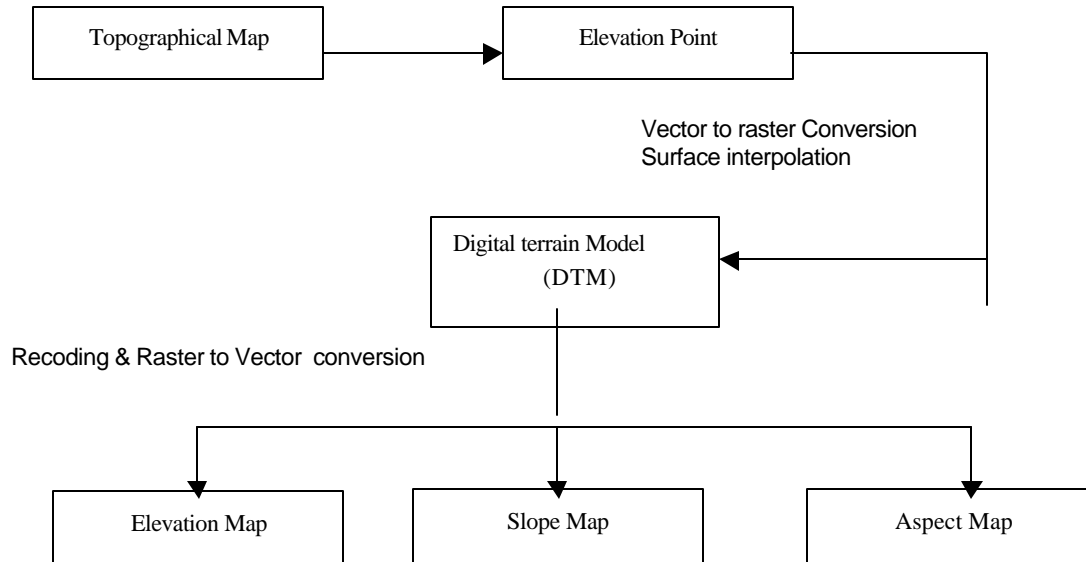
The methodology adopted for estimating the life span of the proposed Andhi Khola dam is as follows:

General steps for Digital Image :



The DTM model map was used for generation of slope, aspect and elevation maps and then converted to vector format to do the spatial analysis for the soil erosion.

The general procedure for making aspect, slope and elevation maps area as follows:



The Universal Soil Loss Equation (USLE) is used for the soil loss estimation. In spite of its several limitations, the USLE continues to be widely accepted method for estimating the soil loss.

The Universal Soil Loss Equation (USLE) – (Wischmeier and Smith, 1978) is the mathematical model most often used to predict the soil loss due to erosions from specific tracks or land under different land use management systems. The estimate from this equation is for the average annual soil loss per unit area as a function of the main factors affecting the rill and sheet erosion.

It computes soil loss as a product of six major factors, whose values are expressed numerically. The USLE is represented by

$$A = R * K * L * S * C * P$$

Where,

- A= Mean annual soil loss
- R= Rainfall Erosivity
- K= Soil Erodibility
- L= Slope Length
- S= slope gradient
- C= Land cover
- P= Erosion control practice factor

### **Rainfall Erosivity Index (R)**

Soil loss is related to rainfall through the detachment power of raindrops striking the soil surface and the entertainment of the detached soil particles by run-off water down slope.

It is found that maximum 30-minute intensity of rainfall is more correlated with soil loss than intensity of any other interval (Wischeier 1959).

The maximum 30 minute intensity was calculate by using the continuous reading of the rain gauge. The maximum 30 minute intensity of year 1997 was 64 mm/hr recorded on 24<sup>th</sup> July 1997. The average annual rainfall of the study area was made available from the year 1978 to 1997 from the Department of Hydrology and Metrology, Kathmandu which is 2917 mm. The Rvalue calculated is as follows:

$$\begin{aligned}
 R &= 0.276 * P * I_{30}/173.6 \\
 &= 0.276 * 2917 * 64/173.6 \\
 &= 296.81 \text{ Kgm.mm/m}^2.\text{hr}
 \end{aligned}$$

Morgan 1974

$$\begin{aligned}
 R &= (9.28 * P - 8838) * 0.102 * I_{30}/173.6 \\
 &= 685.58
 \end{aligned}$$

Roose 1975

$$\begin{aligned}
 R &= P * 0.5 \\
 &= 2917 * 0.5 = 1458.50
 \end{aligned}$$

Now, taking average of these three value

$$R = 813.63 \text{ Kgm.mm/m}^2.\text{hr}$$

Where,

R = Rainfall Erosivity  
P = Average Annual rainfall (mm)  
 $I_{30}$  = 30 minutes maximum rainfall intensity

### **The Soil Erodibility (K) Factor**

Soil Erodibility (K) defines the inherent resistance of the soil to both detachment and transport. In this study, an attempt has made to measure vulnerability status of the soil through the analysis of chemical and physical properties and morphological features. 10 different soil samples are collected from 10 different places, having a versatile range of land use, slope gradient and places of origin and the K factor for each soil unit was estimated using nomograph by Wischmeier and Smith (1978).

The soil Erodibility factor k is a measure of the susceptibility of soil particles to detachment and transport of rainfall and runoff. Texture is the principle factor affecting k, but structure, organic matter and permeability also contribute. K values range from 0.02 to 0.69.

For the soil Erodibility (K) factor purpose, regression equation given by Wischmeier and Smith (1978) is used for the study.

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

Where,

M = Mechanical particle-size parameter, equal to percent very fine sand (0.1 to 0.05) and silt (0.05 to 0.002 mm), times the quantity 100 – minus percentage of clay

i.e. ((% silt + % very fine sand) \* (100 - % clay))

a = Percent organic matter

b = Soil structure code (1 for very fine granular, 2 for fine granular, 3 for medium to coarse granular and 4 for blocky, platy or massive).

c = Profile permeability class (rapid as 1, moderate to rapid as 2, moderate as 3, slow to moderate as 4, slow as 5, and very slow as 6)

### **The topographic factors (LS) Slope Gradient and Length**

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network. However, the soil loss per unit generally increases substantially as slope length increases.

Soil erosion increases with increases in slope gradient (S) and slope length (L) resulting from respective increases in velocity and volume of surface run-off water.

The topographic factor L is given by

$$L = (l/22)^m$$

Where,

L = Slope length factor  
 l = slope length in meter  
 m = dimension less expression

According to McCool et al (1989) 'm' is calculated as

$$m = \frac{\sin\theta}{\sin\theta + 0.269 (\sin\theta)^{0.8} + 0.05}$$

where,

$\theta$  = field slope steepness in degree and equal to  $\tan^{-1}(s/100)$ ; where, s = field slope in %

The m value is increased by the 50% as suggested by McCool et al, (1989) for condition where rill erosion is greater than inter rill erosion.

The steepness 'S' factor for the different situations are given below:

S = 10.8 sin $\theta$  + 0.03      For Slope length <= 4 and slope < 9 %  
 S = 16.8 sin $\theta$  - 0.50      For Slope length > 4 and slope >= 9 %

The slope percent is taken according to the FAO standard.

LS =  $(l/22)^m (10.8 \sin\beta + 0.03)$  for slope < 9% and  
 LS =  $(l/22)^m (16.8 \sin\beta - 0.50)$  for slope >= 9%

Where L = Slope length in meter  
 S = Slope gradient in percent  
 $\beta$  = slope angle  
 m = F/(1+F)  
 F =  $(\sin\beta/0.0896)/(3\sin^{0.8}\beta + 0.56)$

In the USLE, the length of slope is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition occurs, or the runoff water enters a well-defined channel (Wischmeier and Smith 1978).

The values of LS factors calculated for different slope classes and slope lengths based on the equation are given in annex.

### **The Cover Factor (C)**

The cropping management factor 'C' depends upon the crown coverage, ground cover, crop sequence, length of the growing season and tillage practice etc. Hence, it is most complicated type as there are almost indefinite number of different ways of managing the growing crops. Vegetation cover intercepts raindrops dissipating their kinetic energy before reaching the ground surface.

The land use and land cover of the study area was generated from TM and SPOT satellite data. The following six (6) classes were classified from the satellite data and they are as follows:

- Forest
- Sparse forest
- Agricultural land
- Degraded forest
- Shrub
- River

Thus 'C' factor should be calculated by considering different types of vegetation cover.  
C factor value for different land use

<u>Land cover</u>	<u>Average C value</u>
1. Forest (canopy cover > 40%)	0.002
2. Degraded Forest (canopy cover 10-40%)	0.006
3. Shrub	0.014
4. Grazing Land	0.1
5. Agricultural (Upland)	0.463
6. Agricultural (Lowland)	0.411
7. Bare soil	1.00

1 – 4 Adopted from Wischmeier and Smith (1978)

5 – 6 calculation based on Morgan (1986)

Supervised classification, using the visual Interpretation (VI), can be carried out to generate the land cover, land use layer. This layer is converted to C layer through reclassification of each cover type into its corresponding C value.

### The conversion Factor (P)

In the study area the general practice of the farmers in the cropland is ploughing / tilling along the contour lines i.e. against the slope length or perpendicular to the slope length. In general, the protection offered by crops cultivated on slope against erosion should supported by soil conservation practices, which slow down the run-off water.

The Conservation Practice P can be found from the equation.

$$P = P_c * P_s * P_t$$

(Schwab, 1993)

Where,

$P_c$  = Contouring factor based on slope

$P_s$  = Strip cropping factor for crop strip width s

$P_t$  = Terrace sedimentation factor (1.0 for no terraces, 0.2 for terraces with graded channels of outlets and 0.1 for terraces with underground outlets).

As described by schwab et. al. (1993), p is calculated for agricultural land only and for all other lands it is assumed as 1 because there is no any control practices measures.

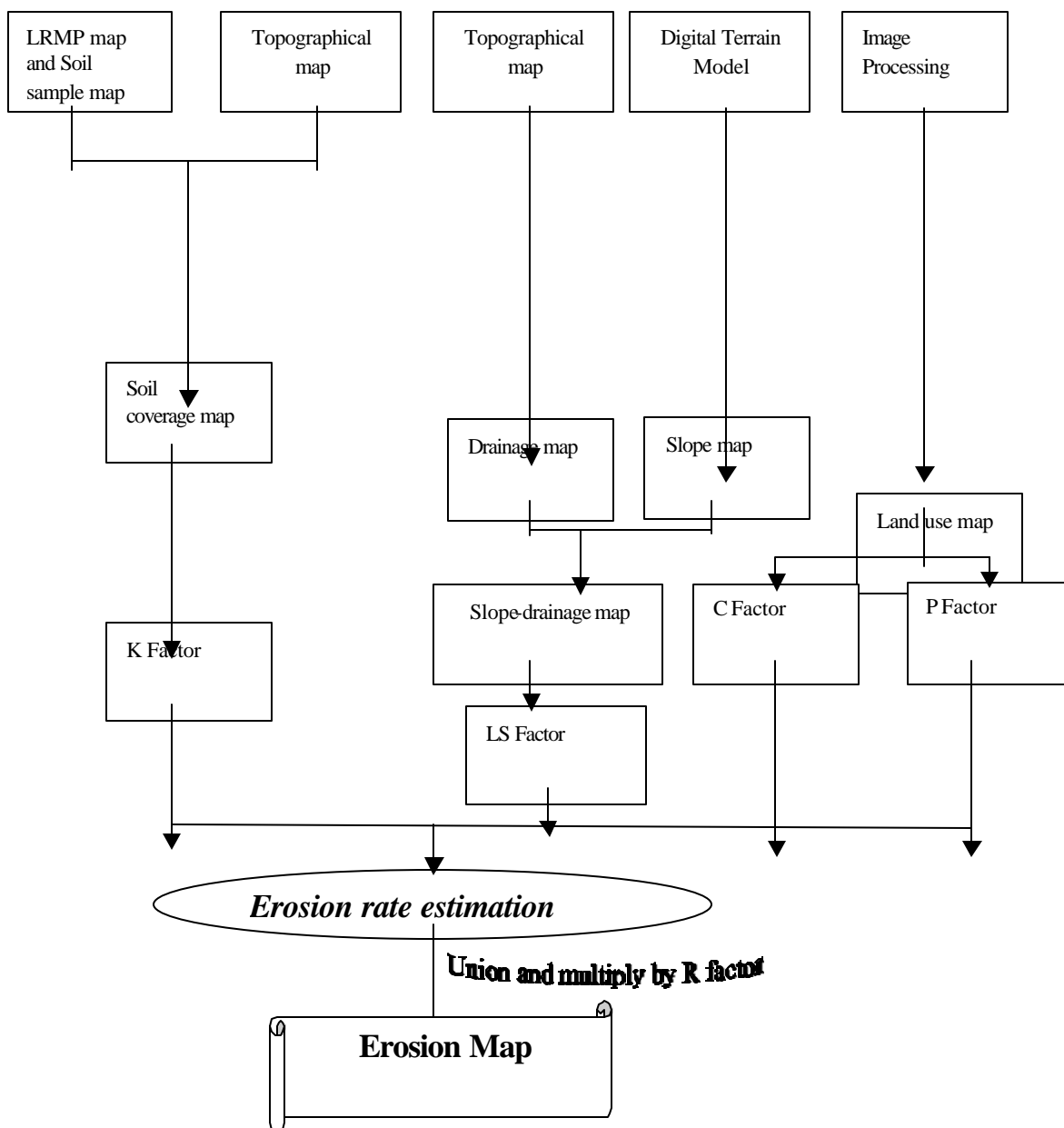
P factor value for different land use

Land use type	Slope %	Pc	Ps	Pt	P factor
Agriculture	1 – 4	0.55	0.50	0.4	0.11
	5 – 10	0.60	0.50	0.3	0.09
	11 – 20	0.75	0.50	0.5	0.18
	21 – 40	0.95	0.50	0.2	0.09
	> 40	1.00	0.50	0.4	0.20
All	All	1.00	1.00	1.00	1.00

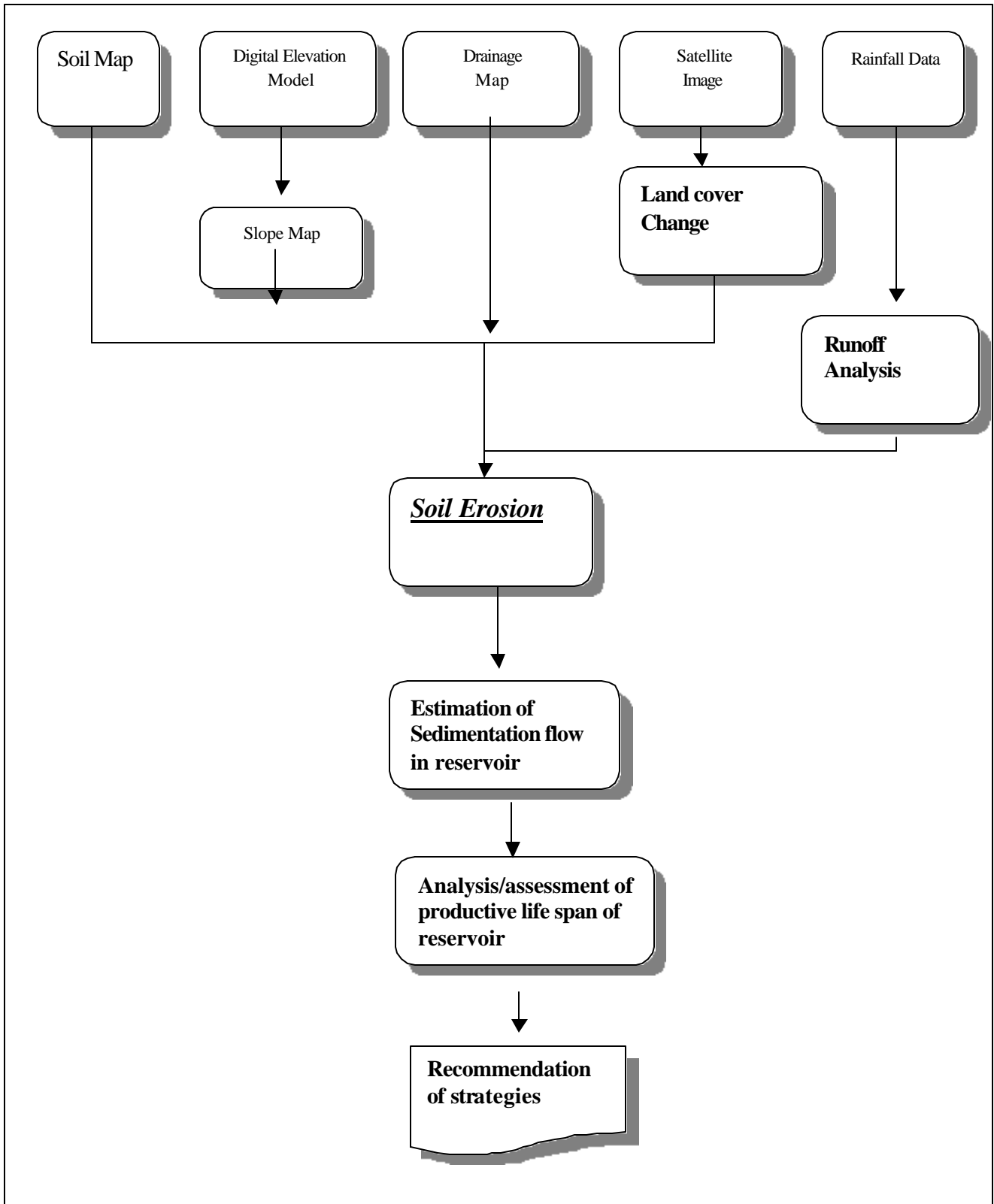
### Soil Erosion Map

In generation of the Soil Erosion Map, topography and land covers are the most important factors for determining the rate of soil erosion, as the soil erodibility and rainfall erosivity factors were constant. Thus the change of land cover and its location largely determining the amount of soil erosion.

The detail procedure to estimate annual soil loss by using USLE method is given below:



**Steps for Analysis/Assessment of productive life span of reservoir**



## RESULTS AND DISCUSSION

In general it is found that Remote Sensing and GIS can be useful tools to obtain soil erosion modeling with fairly correct ranges of values. In spite of the applicability of these tools in specified area, some caution should be taken while analyzing the data. The results obtained under various stages have been discussed below.

### Image processing:

Digital image processing of remote sensing data as well as visual interpretation of air photo was successfully used in deriving the land cover in this study. Land cover was the major variable for the soil erosion estimation.

### Visual interpretation and training sample:

As this study area is dominated by forest, agricultural land and river system so band 4,3,2 was used for Landsat TM and band 3,2,1 was used for the SPOT. The digital images were displayed in the bands mentioned above for the classification of images. The histogram of each band was also evaluated for the purpose of this study.

The TM images has cloud coverage and some shading effects due to mountainous relief correction of shading effect can be done by applying cosine correction as suggested by Meyer et. Al. (1993) but for this study instead of using cosine correction same classes were classified as different sub-classes depending upon shading and later merging of all the sub-class as single class.

There was no availability of images except 1991 so land cover of 1997 was delineated from the aerial photo of 1997. Visual interpretation was done with the help of stereoscopes and land cover delineation was done on the basis of tone, texture, shape and pattern. The mapping unit was selected by considering the scale of satellite images and LRMP land use map of 1984 was used as based map for this purpose.

### Classification of TM data with SPOT data:

For this study, Landsat TM and SPOT data were used for the land cover classification of the watershed. The SPOT data has 20-meter resolution that is better than TM data, which has 30-meter resolution. The classification was made with TM and SPOT data separately and the result obtained from both was quite similar.

### Land cover difference after classification on SPOT and TM

S.No.	Land use class	SPOT (Area, ha)	Percentage	TM (Area, ha)	Percentage
1	Forest	8464.59	17.67	7538.74	15.76
2	Sparse forest	12134.10	25.33	12045.12	25.15
3	Shrubs	2239.74	4.68	1456.89	3.04
4	Agricultural land	18802.60	39.25	16251.25	33.92
5	Deforest area	4631.04	9.52	4562.48	9.52
6	River	1698.12	3.55	1548.52	3.23
7	Cloud	0	0	4497.00	9.38
	Total	47900	100.00	47900	100.00

The results obtained from the SPOT was better than TM for the following reasons:

The TM data has cloud coverage of around 10 percent of the total area; SPOT data is free from cloud.

The TM data of the study area consists of mosaic of two scenes that was acquired in Nov. 1991 and Dec. 1991.

The SPOT data is of 20-meter resolution that gives better spatial details than TM data.

So, for land cover classification of 1991, SPOT data was used but classified TM data was used to verify the results and to compare with classified SPOT data. As there was some misclassification in SPOT data so classification of SPOT data was done again which afterwards gave good results.

Supervised classification and unsupervised classification was tried in this study. After evaluating of different results obtained from different techniques of classification, the results of maximum likelihood classification were used for the change detection and estimation of soil erosion.

#### GIS Analysis:

##### *Data conversion and ARC/INFO:*

RS and GIS tools were used for this study. For RS *ERDAS IMAGINE* and *ENVI 3.0* software and for GIS analysis both PC and UNIX based ARC/INFO were used. Thus the conversion of raster to vector and vice versa data conversion was done for analysis process. For the digitizing purposes PC based ARC/INFO was used. The PC based ARC/INFO does not have the capacity to handle the data which was changed from ERDAS to vector format because of big size, so UNIX based ARC/INFO were used for analysis purposes.

##### Sediment Yield estimation:

Eroded soil materials often move only short distances before a decrease in runoff velocity causes their deposition. They may remain in the fields where they originated or may be deposited on more level slopes that are remote from the stream system. The ratio of sediment delivered at a given location in the stream system to the gross erosion from the drainage area above that location is the sediment delivery ratio for that drainage area. Sediment delivery ratio is a runoff transport process, which makes it highly correlated with the volume of runoff and peak runoff rate. The ratio of sediment delivered at a given location in the stream system to the gross erosion from the drainage area above that location is the sediment delivery ratio for the drainage area (USDA, 1978). By computing this ratio for different drainage area it was summarized that the delivery ratio varies approximately as the 0.2 power of drainage area size (Wishmeier and Smith 1978).

The equation given by (Wishmeier and Smith 1978) is

$$Y = E(DR)/W_s$$

Where, Y = Sediment yield per unit area

E = Gross erosion

DR = Sediment delivery ratio

W<sub>s</sub> = Area of the catchment above the point

As from the USLE model, only the sheet erosion and rill erosion are calculated, the gross erosion can be calculated by the addition of the erosion from stream bank and gully erosion of particular catchment area (Morgan, 1986).

##### Estimation of project life span based on soil erosion:

The results obtained from USLE model are quite comparable with the results obtained by other different researchers at different locations. The USLE model has some limitations in terms of accuracy and the errors are caused due to the complexity of the terrain conditions.

The amount of rainfall and maximum 30 minute rainfall intensity varies from year to year but rainfall erosivity factor for the study was kept constant for 1991 and 1997 to make the linear comparison of soil erosion.

Moreover, for soil loss prediction from USLE model only sheet and rill erosion is been considered.

As per the calculation of Nepal Electricity Authority (NEA), NEA took the concentration of Kali Gandaki River to be same for the Andhi Khola and on this basis the dead storage was estimated. The concentration of Andhi Khola is much lower than that of Kali Gandaki river and river discharge also much lower.

However, on the basis of drainage area the dead storage was calculated. The measured suspended load for Kali Gandaki River damsite comes to be 37.5-M tonne for the year 1993. As in practice 15% of the suspended load is taken to be the bed load. So, the total sediment load of Kali Gandaki River would be 43-M tonne per year for the drainage area of 7618 km<sup>2</sup>.

Here, the study area has only the drainage area of 479 km<sup>2</sup> so with the simple proportion on the drainage area basis the total sediment load was assumed as 2.70-M tonne per year.

So, with this value the life of reservoir was set as 50 years, corresponding to the dead storage of 96 Million m<sup>3</sup>, which is equal to 135 M ton.

But as per the analysis, the total soil erosion from the drainage area was estimated as 45.1 tonne/ha/yr. for 1997.

So, soil loss = 45.1 \* 47900 (area) = 2160290 tons/year = 2.16 M ton

Therefore, from this the expected life span of the reservoir is to be 62 years.

Sediment data are available for one year (1995) and the result from this data is compared with the soil erosion rate form USLE model.

Sediment data (Andhi Khola) of 1995

Months/ 1995	Sediment Load (M tonne)
Jan	0.0045
Feb	0.0053
Mar	0.0082
Apr	0.0542
May	0.1421
Jun	0.3548
Jul	0.7151
Aug	0.3964
Sep	0.0285
Oct	0.0057
Nov	0.0053
Dec	0.0049
Total	1.725

The total suspended sediment load for the year 1995 calculated from the table above is 1.725-M tonne. The bed load is taken as 15% of the suspended load which is 1.725 M tonne, that would give the total sediment, load as 1.983-M tonne.

So, this figure is very close with the result from the USLE model.

From the USLE model the erosion was estimated as 45.1 tons/ha/yr. which is equivalent to 2.16-M tonne. From the observed sediment data from 1995 it was calculated as 1.983 M tonne and from the NEA, it was calculated as 2.70 M tonne.

#### Soil Loss Tolerance:

In nature the soil loss and soil formation are going side by side together. It is quite impossible to avoid soil erosion completely. To define the soil loss tolerance, there are different factors, which affect such as topography, soil type, land use, soil formation and so on.

In USA, as given by (Wishmeier and Smith 1978) the soil loss tolerance ranged from 2 to 5 tons/acre/yr. ( i.e.4.48 tons/ha/yr. to 11.2 tons/ha/yr.), while accordingly to Leban (1978), Tiwari (1991) and Pahari (1993) this value for Nepal is 15 to 20 tons/ha/yr.

The value of soil loss tolerance can be substituted in the USLE equation to adjust the USLE parameters. Among them principally all factors except rainfall erosivity can be modified as per the situation of the watershed.

In this study, although the soil loss during 1997 was 45.1 tons/ha/yr. but assuming that if there is all forest cover in slopes more than 20% and 40% then the situation would be like this.

Slope range (%)	Total area (hectare)	Average erosion ton/ha/yr.		
		Present	40% slope	20% slope
1 to 4	3245.03	1.30	1.30	1.30
5 to 10	4167.15	5.49	5.49	5.49
11 to 20	8497.05	18.75	18.75	18.75
21 to 40	16956.3	45.6	45.6	10.46
> 40	15034.47	79.86	12.31	12.31
Total	47900	45.1	23.89	11.03
Life span		62 years	117 years	255 years

So, if there will be forest in slope more than 40 percent then the rate of soil loss be 23.89 tons/ha/yr. thus the life span of the reservoir would increase to 117 years. If there will be forest in slope more than

20 percent then the rate of soil loss will be 11.03 tons/ha/yr. then the life span of the reservoir would increase to 255 years. So, the only option to reduce the soil loss is to have the good forest cover.