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Ministry of Forest and Environment

Department of Forest and soil conservation

Federal Watershed Management Resource Centre

Kulekhani, Makwanpur, Nepal

MEASUREMENT OF SEDIMENT DEPOSIT IN A SECTION OF KHULEKHANI RESERVOIR AREA MAKWANPUR DISTRICT

Submitted by:
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Abbreviations

DSCWM: Department of Soil Conservation and Watershed Management

ETS: Electronic Total Stations

KHEP: Kulekhani Hydroelectric Project

MOFE: Misistry of Forest and Environment

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Abstract

The Kulekhani watershed area covers 126 sq. km in Bagmati province, Makwanpur district, Nepal. Chitlang khola, Bisenkhel khola, Palung khola, Thado khola, Chalkhu khola are the tributaries of the Kulekhani reservoir. These kholas transport the sediments and deposited in the reservoir. As sediment accumulates in the reservoir, storage capacity is reduced. The continued deposition develops distribution patterns within the reservoir which are greatly influenced by both operations of the reservoir and timing of large flood inflows. Debris flows in 1993 and landslides influenced the deposition of sediment in the Kulekhani reservoir (Dhital, 2003). Deposition of the coarser sediments occur in the upper or delta reaches while finer sediments may reach the dam and influence the design of the outlet works.

The methodology of the study comprises several steps such as; desk study, literature review, and followed by the field works. A walk over survey was conducted for the measurement of flood plain area (deposits). It includes the measurement of sediment thickness along the riverbanks and measurement of length of flood plain across from the riverbed. The stream discharge was measured and calculated using formula. Six pits were excavated for examining the sediment composition and the depth of sediment. Pits were excavated by observing the sites where the data are necessary. It was a random selection based on field condition as per need based. An assessment of landslides and erosion activities were conducted around the periphery of the Kulekhani reservoir.

The sediment transportation from the watershed areas were observed to be very active after observing the sediment deposition layers at the tributaries of Thado Khola, Chalkhu Khola, Dhasku Khola and Palung Khola. Total volume of sediment along the flood plain was calculated by field measurement was found to be 46,627.1 cubic meter, where right bank shares 30526.25 cu. m. and left bank shares 16100.85 cu. m. The discharge measurement in contributing streams shows the maximum sediment transport from Palung Khola and Chiltang Khola. This study shows that Thado Khola also contributes huge amount of sediment into the reservoir. The study suggests that the slope failures and stream-bank cutting contribute tremendously to the sediments in the reservoir. Hence, it is very important to stabilize these activities for reducing sediment deposition. Special emphasis should be given to the prevention and reclamation of landslides and gullies.

CHAPTER 1: INTRODUCTION

1.1 Background

The Kulekhani watershed area covers 126 sq. km in Bagmati province, Makwanpur district, Nepal. The watershed area has a monsoon climate with an annual rainfall of about 1400 mm. About 80% of the total rainfall occurs between june to september each year. The outlet of the Kulekhani Reservoir is at about 1500 meters elevation and the south-western ridge of Palung Khola marks the summit at 2621 masl. Tasar, Bisingkhel and Chitlang Khola are the major tributaries of the reservoir. The average slope of the tributaries ranges from 1.2 % to 21.3 %. The original gross capacity of the reservoir was 85.3 million m^3 of which 73.3 million m^3 is live and 11.2 million m^3 is dead volume. The reservoir, designed for a life-span of 50 years, is expected to last 100 years.

The watershed area lies in a fragile physiographic region, which experiences intense monsoon rainfall events. The watershed area has been intensively used in response to meeting people's basic needs for food, fodder, fuel woods, fiber and shelter. As a result, the erosion processes in the watershed transport an enormous amount of sediment to the reservoir. Sedimentation monitoring plays an important role in developing strategy for watershed management and hydropower generation. Sediment transported by the upstream river system of Kulekhani watershed into a reservoir is deposited or transported at a reduced rate further into the reservoir; the distance being dependent on the decreased water velocities. As sediment accumulates in the reservoir, storage capacity is reduced. The continued deposition develops distribution patterns within the reservoir which are greatly influenced by both operations of the reservoir and timing of large flood inflows. Debris flows in 1993 and landslides influenced the deposition of sediment in the Kulekhani reservoir (Dhital, 2003). Deposition of the coarser sediments occur in the upper or delta reaches while finer sediments may reach the dam and influence the design of the outlet works. A major secondary effect is the downstream degradation of the river channel caused by the releases of clear water.

Slope failures and stream-bank cutting contribute tremendously to the sediments in the reservoir. It is very important to stabilize these activities particularly where there are dams. Implementation through people's participation is the main strategy, and productivity conservation is the main theme, of the soil conservation program. However, local people are not keen to participate in stabilizing landslide and stream-bank erosion as these activities are very expensive and less oriented towards productivity conservation. The benefits, they feel, do not justify the efforts required. Special emphasis should be given to the prevention and reclamation of landslides and gullies. Stream bank protection and the construction of sediment traps are needed to protect the hydro-power capacity of the reservoir. Implementation of such activities needs to be borne by projects (such as hydro-power) which are directly affected by the sedimentation.

Sediment-trapping dams alone may not be economical. Maintenance of buffer strips such as level terraces across the slope can play an effective role in trapping sediment. The terraces are typical of the traditional Nepali farming landscape and has proved important in trapping sediment. Therefore, based on the topography and sediment source, construction of level terraces across the slopes in appropriate areas might prove fruitful in trapping sediment as well as permitting appropriate land-use.

1.2 Objectives

The major objective of the study is to conduct measurement of sediment deposited in the Kulekhani reservoir area are:

- Study of sediment deposition in the Kulekhani reservoir
- Measure the volume of sediment along the flood plain from the river bed level

1.3 Scope of the study

The scope of this study involves,

a) Walk over survey around the site area
b) Observation of current landslide and erosion activities in the periphery of reservoir
c) Measurement of discharge from the contributing streams
d) Pit excavation for examining the sediment composition along the flood plain
e) Measurement of flood plain area to calculate the volume of sediment
f) Discussion between study team and stakeholders

1.4 Rationale of the study

The recent activities of erosion and landslide activities have increased the sediment transport to the reservoir while decreasing the capacity of the reservoir. The active and excessive anthropogenic activities have initiated new slides and erosional activities. Hence, a proper study is necessary to understand the recent sediments transport to the reservoir and identify the sources of it.

1.5 Limitations

This study limits to a section of reservoir area, due to some limitations as follows:

- Time constraints and resources to cover the whole reservoir area
- No comparable data for this study though numbers of literatures are published on it
- This study limits in a section of Khulekhani reservoir due to which it cannot be compared to previous studies
- Limited budget for the study throughout the reservoir area

CHAPTER 2: LITERATURE REVIEW

A recent disaster due to soil erosion and flooding occurred in July 1993, causing the worst disaster in Nepalese history. Very heavy rainfall of 540mm in a day, the maximum ever recorded in Nepal, occurred in some parts of the central and eastern regions from 19 to 21 July, 1993. This event caused numerous landslides, land collapses, debris flows and flooding. Another deluge occurred on 8 and 9 August, about three weeks after the initial heavy rain. The peak flood levels were highest in many rivers, even exceeding the design water level and causing complete destruction of barrages, embankments and other structures (DPTC, 1994b).

Sedimentation

The Department of Soil Conservation carried out sedimentation surveys in March and December 1993, October 1994 and November 1995 using 18, 30, 32 and 39 lines of measurements respectively. The base map of the reservoir was prepared from enlarged aerial photographs taken in 1986. The distances of survey lines were measured using electronic total stations (ETS) instrument.

Compared to the estimated average sediment delivery rate in the Phewa Tal watershed, which is 17.37 m^3 per hectare (1990 to 1994), the sediment delivery rate for Kulekhani was exceptionally high even before the disastrous rainfall event of 19-20 July, 1993. One reason why the Kulekhani watershed has significantly higher rates is that 34% of the watershed area is under sloping agriculture, compared to just 0.3% in the Phewa watershed. Similarly, the soils in the Kulekhani watershed are much sandier than in Phewa watershed.

During the dry period, the use of water for the hydropower generation reduces the water level in the reservoir by more than 40 meters. This exposes the sediment to erosion agents. Therefore, the pre-monsoon storms flush the sediments from the end part of the reservoir to the front and mid parts of the reservoir. In addition, when hydropower is generated in the dry period, the sediment from the end part of the reservoir is transported to the front and mid parts of the reservoir due to the reduced water level. During the monsoon, the water level in the reservoir will rise and the sediment begins to be deposited once more in the end part.

In December 1993, about 1.5 million m^3 of sediment were deposited in the reservoir above the dead volume area. The survey indicated that during the 1994 monsoon, about 1.05 million m^3 of sediments entered the dead volume area, of which 144 thousands m^3 of sediment was flushed from the end part of the reservoir. Similarly, the November 1995 survey showed that about 1.07 million m^3 of sediments were deposited in the dead volume area, of which about 54 000 m^3 of sediment eroded from the area upstream of the dead volume area. Therefore, management of sediment within the reservoirs is also equally essential for the reservoir protection. About 14.47 million m^3 of total capacity of the reservoir has been reduced since its construction. Similarly, 8.16 million m^3 and 5.98 million m^3 of dead volume, which amounts to 73% and 53% of the designed dead volume respectively, have reduced with the corresponding lower level of intake (1471 masl) and upper level of intake (1476 masl) as dead level respectively. Reduction in live volume produces less electricity whereas filling of dead volume will stop hydro-power generation. Therefore, all feasible measures to stop sediment (either from the watershed or reservoir) reaching the dead volume area should be made.

Record of 24 hours rainfall events (June-October) reveals that such intensive events are the characteristics of monsoon climate of Nepal. Therefore, it is essential that the necessary long-term conservation programmes are devised, especially for nationally important projects such as hydropower generation. Such conservation programmes need to be implemented long before and after the completion of such projects.

Huge amounts of sediment are in transit from the source to the reservoir. Sediment monitoring is essential for the necessary counter-measures to be taken in time to protect the reservoir from sedimentation. Every effort should be made to lengthen the life of the reservoir, and this includes watershed management, construction of sediment traps, structures, and management of the sediment within the reservoir and watershed.

The observed annual sediment delivery rate from the Kulekhani watershed is much more than the anticipated rate of about 7 m^3 per hectare. The current rates diminish the economic benefit of the Kulekhani Hydro-power Project dramatically. Also, if the dead volume is silted up as quickly as projected from the survey, this will affect the whole country's energy scenario and hydro-power economy. Therefore, realizing the risk and dramatic effects of monsoon storms, future hydro-power generation projects need to be designed to account for unusual events and very high sedimentation rates. Lack of sufficient long term information on rainfall and sedimentation rates have been the bottleneck for designing such hydro-power projects in Nepal.

2.1 Methods of determining sediment inflow:

Most methods for predicting sediment yields are either directly or indirectly based on the results of measurements. Direct measurements of sediment yields are considered the most reliable method for determination of sediment yields. This is accomplished by either surveying of reservoirs or sampling the sediment load of a river. Other methods for predicting sediment yields depend on measurements to derive empirical relationships or utilize empirically checked procedures such as the sediment yield rate weighting factors or the Universal Soil-loss equation (Wischmeier and Smith, 1965).

a. Sediment yield rate factors

The factors which determine the sediment yield of a watershed can be summarized as follows:

1. Rainfall amount and intensity
2. Soil type and geologic formation
3. Ground cover
4. Land use
5. Topography
6. Upland erosion (nature of drainage size, and alinement of channels)
7. Runoff network-density, slope, shape,
8. Sediment characteristics - grain size, mineralogy, etc.
9. Channel hydraulic characteristics

Table 1: Rating chart of factors affecting sediment yield

Factors	Sediment yield level High	Moderate	Low
1. Rainfall amount and intensity	10	5	0
2. Soil type and geological information	20	10	0
3. Ground cover	10	0	-10
4. Land use	10	0	-10
5. Topography	20	10	0
6. Upland erosion	25	10	0
7. Runoff	10	5	0
8. Sediment characteristics) 9. Channel hydraulics)	25	10	0

Note: An example of the techniques for weighting of the nine factors which is not identical but similar to those used in the report (Pacific Southwest Interagency Committee, 1968)

b. Reservoir resurvey data

Surveys of existing reservoirs for determining loss of storage space and distribution of sediment deposits within the reservoir provide data on sediment yield rates as well as for operations purposes. The main purpose of a reservoir survey is to determine the storage capacity at the time of the survey which when compared to an earlier survey (usually the original survey) gives the sediment accumulation.

c. Sediment sampling data

Sampling is the surest method of obtaining an accurate determination of the suspended sediment load being carried by a stream at a particular location. Suspended sediment sampling in combination with total load computations is the preferred method used for planning studies in determining the sediment inflow to a proposed reservoir. The objective of a sediment-sampling program on a river is to collect sufficient samples of sediment carried both as suspended load and as bed load to define the total sediment being transported. For suspended sediment, sampling it is essential to measure the water discharge, Qw in ft^3/ (m^3/s) which is combined with suspended sediment concentration, C, in mg/L to give the suspended sediment load Qs in tons/day by the equation:

Qs = 0.0027 C Qw (inch-pound units)

or Qs = 0.0864 C Qw (metric units)……..equation (1)

Suspended sediment sampling equipment and techniques for collecting can vary considerably depending on program objectives and field conditions. The objective of any suspended sediment sampling program is to develop a correlation between water discharge and sediment load commonly called a suspended sediment rating curve. This rating curve is normally a plot on logarithmic paper of water discharge Qw in ft^3/s (m^3/s), versus sediment load, Qs in tons/day from equation 1.

d. Unmeasured sediment load

Bed material - The sediment mixture of which the streambed is composed.

Bed load - Sediment that moves by rolling or sliding on or near the streambed.

Bed material load - That part of the sediment load, which consists of grain sizes, represented in the bed.

Wash load - That part of the sediment load, which consists of grain sizes finer than those of the bed.

Suspended load - Particles moving outside the bed layer.

Unsampled zone - The 3 or 4 inches (7.62 to 10.2 cm) from the streambed up to the lowest point of the sampling vertical. Most suspended sediment samplers cannot sample within this zone.

e. Adjustment to dam-site

Any direct measurement of sediment yield either from reservoir surveys or sediment sampling requires an adjustment in the yield rate from a specific location to that at the dam site. In many cases the sediment yields in acre-feet or tons per square mile (cubic meters or tons per square kilometer) derived from the reservoir survey or at the gaging station can be applied directly to the drainage area above the dam site. If the yield rates are not directly applicable to the drainage area above a dam site, the nine factors shown in table 1 can be used in a calibration technique for adjustment to the dam site.

2.2 Reservoir sediment deposition:

A schematic diagram of anticipated sediment deposition (***Figure 1***) shows the effect of sediment on storage. In operational studies of a reservoir for determining the available water supply to satisfy projected water demands over an economic life, an average (50 years for a 100-year economic analysis) can be used of the sediment accumulation during the economic life period. However, the total sediment deposition is used for design purposes to set the sediment elevation at the dam to determine loss of storage due to sediment in any assigned storage space and to be used in determining total storage requirements.

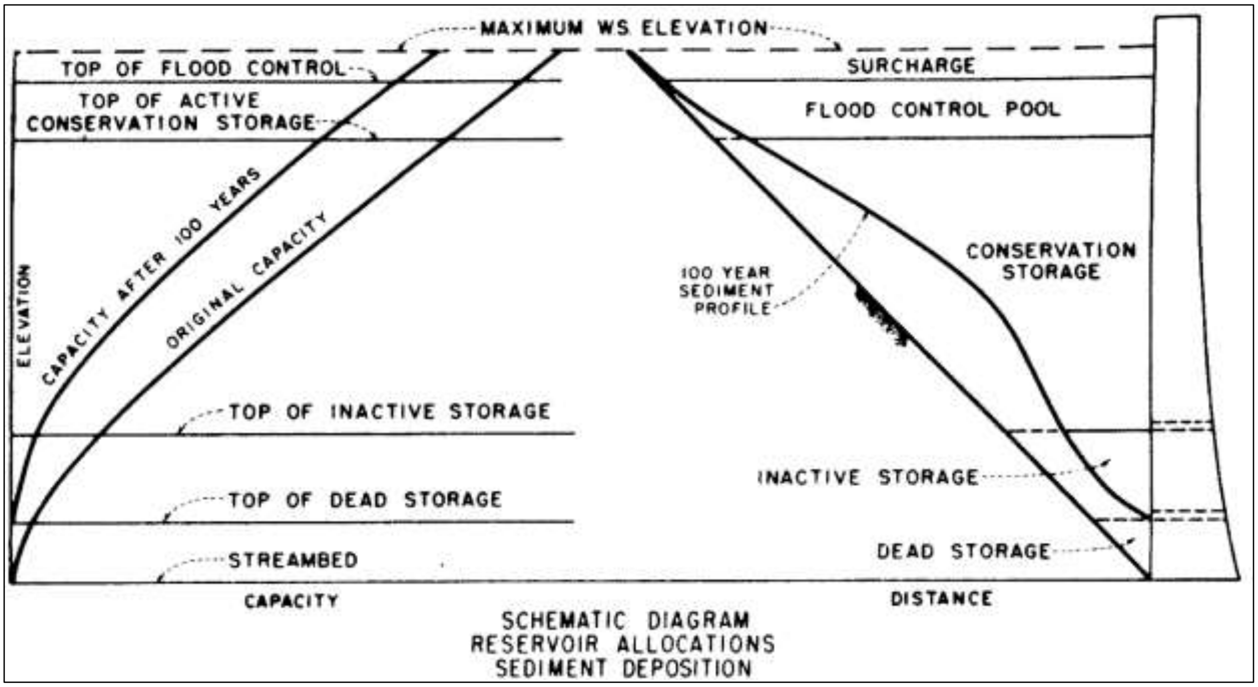


Figure 1: Schematic diagram, reservoir allocations, sediment deposition

a. Trap efficiency

The trap efficiency of a reservoir is defined as the ratio of the quantity of deposited sediment to the total sediment inflow and is dependent primarily upon the sediment particle fall velocity and the rate of flow through the reservoir. Particle fall velocity may be influenced by size and shape of the particle, viscosity of the water, and chemical composition of the water. The volume of inflow with respect to available storage and the rate of outflow determine the rate of flow through the reservoir.

b. Density of deposited sediment

The density of deposited material in terms of dry mass per unit volume is used to convert total sediment inflow to a reservoir from a mass to a volume. Basic factors influencing density of sediment deposits in a reservoir are: (1) the manner in which the reservoir is operated, (2) the texture and size of deposited sediment particles, and (3) the compaction or consolidation rate of deposited sediments. The classification of sediment according to size as proposed by the American Geophysical Union is as follows:

Sediment type	Size range in millimeters
Clay	Less than 0.004
Silt	0.004 to 0.062
Sand	0.062 to 2.0

The accumulation of new sediment deposits, on top of previously deposited sediments, changes the density of earlier deposits. The influence of reservoir operation is most significant because of the amount of consolidation or drying out that can occur in the clay fraction of the deposited material when a reservoir is subjected to considerable drawdown. The size of sediment particles entering the reservoir will also have an effect on density as shown by the variation in initial masses.

c. Sediment distribution within a reservoir

Sediment accumulations in a reservoir are usually distributed below the top of the conservation pool or normal water surface. However, if the reservoir has a flood control pool and it is anticipated that the water surface will be held within this pool for significant periods of time, a portion of the sediment accumulation may be deposited within this pool.

d. Delta deposits

The major consequence of these delta deposits is the raising of the backwater elevations in the channel upstream from a reservoir. Therefore, the delta may cause a flood potential that would not be anticipated from pre-project channel conditions and proposed reservoir operating water surfaces. Predicting the delta development within a reservoir is a complex problem because of the variables such as operation of the reservoir, sizes of sediment, and hydraulics (in particular, the width of the upper reaches of the reservoir). Sediments deposited in the delta are continually being reworked into the downstream storage area at times of low reservoir stage and during extreme flood discharges.

CHAPTER 3: METHODOLOGY

3.1 Description of study area:

Kulekhani Reservoir of the Kulekhani Watershed area was selected for the present study which is located in the Makawanpur district of Bagmati Province. The reservoir is also known as Indrasarbar synonymously known as Kulekhani Hydropower. The total area of the watershed is 124.67 km^2. Geographically it is extended from 27^0 34' 54" N to $27^0$40' 59" N and 85^0 01' 21" E to 85^0 12' 20" E.

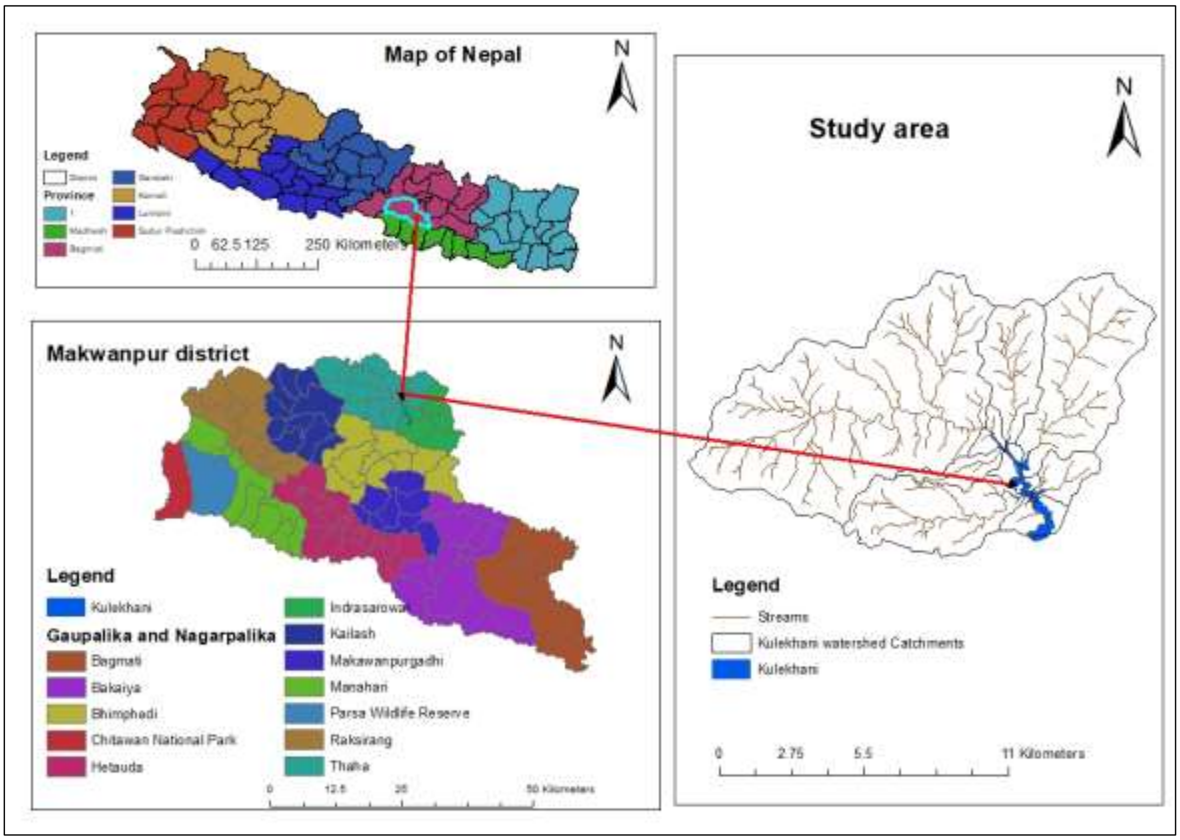


Figure 2: Study area map

Topography and drainage

The topography of the Kulekhani watershed area is steep and rugged. The lowest altitude within the watershed is about 1500 masl at the dam site area whereas the highest altitude is about 2621 masl at the southwestern ridge of the watershed. The slopes around Chitlang, Bisinkhel, Palung, Markhu are relatively in gentler slope.

The major sources of water to Kulekhani watershed area are from Palung Khola which originates from the southwestern ridge of the watershed, the Kiteni Khola begins at Daman and flows northwards, whereas the Bisinkhel Khola flows from Bisinkhel in the southward direction and joins the Palung Khola near the reservoir. The Chitlang Khola and Thado Khola flows in to the reservoir from the north of Chitlang and the south of Daman, respectively. The Palung Khola and its major tributaries are mainly rain-fed and perennial, whereas the minor gullies and streams are ephemeral but can be highly destructive during the summer monsoon (June to September), when more than 80% of the total annual rain falls.

Rocks

The rocks of the Kulekhani area belong to the Bhimphedi Group and the Phulchauki Group of the Kathmandu Complex (Stöcklin 1980). The Bhimphedi Group is represented by the Chisapani Quartzite (finegrained quartzite), the Kulikhani Formation (alternating quartzite and schist), and the Markhu Formation (alternating marble and schist). The overlying Phulchauki Group is represented by the Tistung Formation (slate and phyllite), the Sopyang Formation (slate and limestone), and the Chandragiri Limestone. There are from three to five sets of joints in the rock. In the study area, the Palung Granite is intruded in the Kathmandu Complex and crops out on the right bank of the Palung *Khola* in the southern part of the watershed. Generally, the granite is highly weathered and changed into yellow-brown soil. As a result, a large amount (more than 60%) of sand and gravel in the Kulekhani reservoir was derived from the Palung Granite.

The steep rocky cliffs and gentle soil terraces indicate the control of lithology in the development of landforms. The Chandragiri Limestone and the Palung Granite form high peaks whereas the soft rocks (i.e. slate and phyllite) constitute moderate slopes.

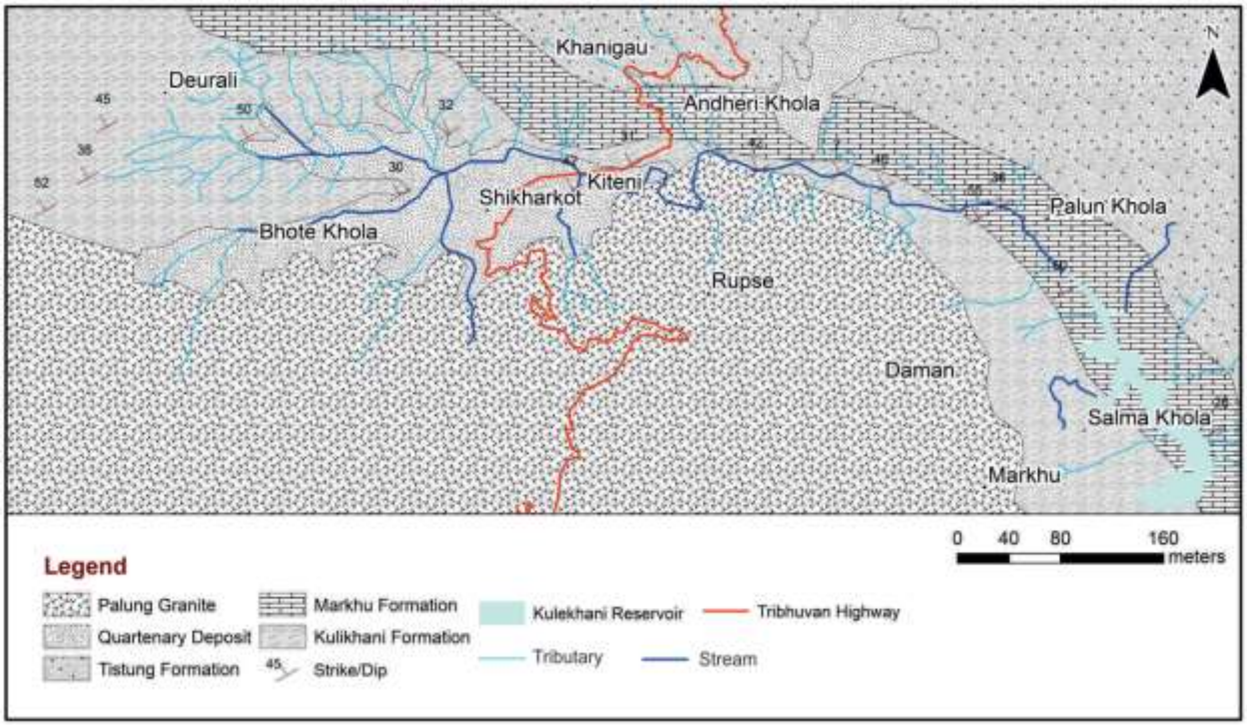


Figure 3: Geological map of the study area (modified after Stöcklin and Bhattarai, 1977; Stöcklin, 1980)

Soils

Soils cover about 3/4 of the watershed area (Table 1) and are exposed along the roads and riverbanks. Alluvial terraces are developed mainly along the Palung *Khola*, Chuliprang *Khola*, Tistung *Khola*, Bisingkhel *Khola* and Chitlang *Khola*. The dominant soil colour is yellowish brown and the depth of soil varies from 1 to >6 m. In the Kulekhani watershed, several alluvial and debris fans exist, and the major ones are located at the mouths of the Palung *Khola*, Kiteni *Khola*, Bisingkhel *Khola*, and the Thado *Khola*.

The residual soils are commonly developed on gentle hillslopes. They are found on hilltops, spurs, and ridges, generally at an altitude of more than 1600 masl. The residual soil over granite occupies the southern part of the watershed and its thickness varies from 1 to 6 m.

The colluvial soils are present on the valley slopes. The colluvial soils, deposited by landslides, are mainly on the foothills. An extensive area (about 6000 m^2) covered by coarse colluvial soil occurs along the right bank of the Palung *Khola*, near Tasar. At Phedigaun, colluvial soil is frequently observed at an altitude of 1900 to 2500 masl.

Table 1: Main geological and geomorphic characteristics of Kulekhani watershed

Attribute	Subcategory	Distribution, % of total watershed area
Slope angle (q)	0–15 15–25 25–35 >35	30 23 16 31
Soil type	Residual Colluvial Alluvial	26 34 17
Soil depth (m)	1–3 3–6 >6	18 40 17
Bare rock slope	Slate/phyllite Schist/quartzite/marble Granite	7 9 7
Land use	Cultivation/settlement Forest/bush Others (Kulekhani reservoir, road, etc)	44 54 2

Source: Dhital et al. (1993)

Table 2: Major debris flow and landslide events in the Kulekhani watershed

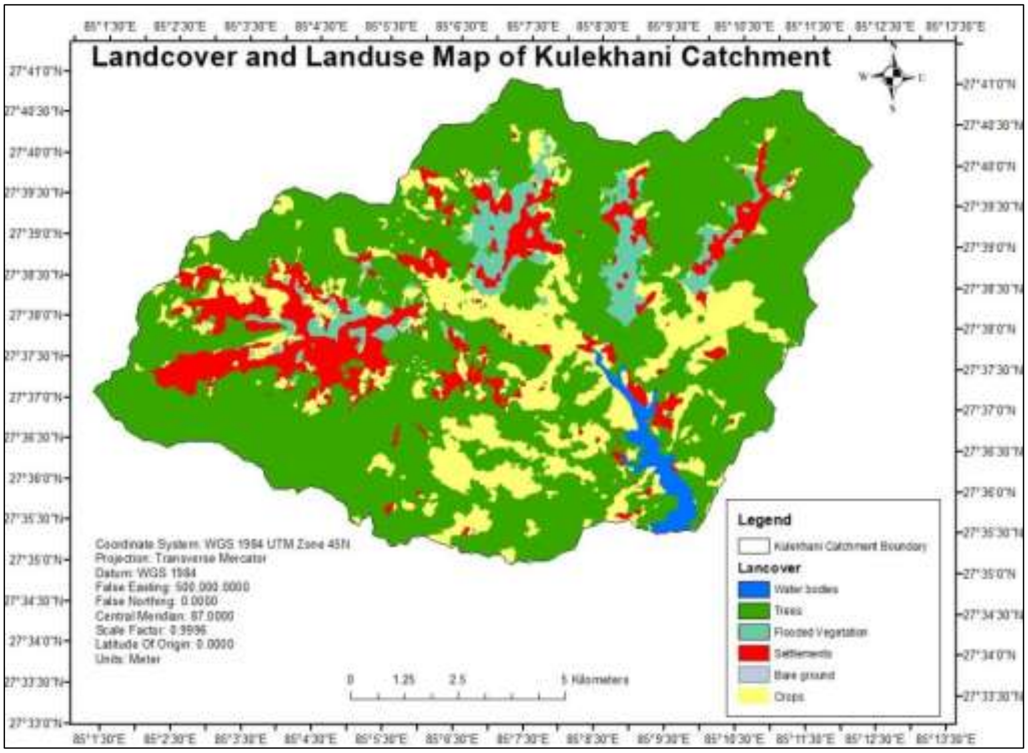
Location	Year of major events
Daman–Palung	1915,1954,1979, and 1993
Phedigaun	1954,1970, 1971, 1974, 1985, and 1993

Source: Dhital et al. (1993)

Table 3: Distribution of landslides in the Kulekhani watershed

Attribute	Subcategory	Landslide distribution, % of total subcategory area	Landslide distribution,% of total category area
Slope angle (q)	0–15	0.04	1.31
	15–25	1.38	
	25–35	2.80	
	>35	1.73	
Soil type	Residual	0.46	0.88
	Colluvial	1.60	
	Alluvial	0.05	
Land use	Cultivation/settlement	1.44	1.45
	Forest/bush	1.45	
	Others (Kulekhani Reservoir, road, etc	0.02	

Source: Dhital et al. (1993)



Source: ICIMOD, 2020

Figure 4: Landuse map of Kulekhani Reservoir

Table 4: Landuse area of Kulekhani Catchment area

S.N	Landuse	Area (ha)
1	Water bodies	197.68
2	Trees	8047.25
3	Flooded vegetation	704.61
4	Settlements	1322.74
5	Bare ground	1.31
6	Crops	2121.31

3.2 Data collection technique

3.2.1 Primary data collection

The methodology of the study comprises several steps such as; desk study, literature review, collection of available secondary data, review of published and unpublished research works and followed by the field works. A walk over survey was conducted for the measurement of flood plain area (deposits). It includes the measurement of sediment thickness along the riverbanks and measurement of length of flood plain across from the riverbed. The stream discharge was measured and calculated using formula. Here, cross sectional area was calculated by the product of width of each individual section and the depth of water. The velocity of the stream was calculated using the distance travelled by object per unit time period. Hence, the discharge was calculated by the product of sectional area of stream and velocity of stream flow. It was measured in cubic meters per second (cu.m./sec). Six pits were excavated for examining the sediment composition and the depth of sediment. Pits were excavated by observing the sites where the data are necessary. It was a random selection based on field condition as per need based. An assessment of landslides and erosion activities were conducted around the periphery of the Kulekhani reservoir. Basically, stream section areas which contributed sediments to reservoir area were selected for the study. Finally, field data were plotted and analyzed for the presentation and report writing. It also involves active discussion between the study team and the stakeholders. And the final reports were submitted after incorporating all the comments by the experts and reviewers.

Hence, the study was conducted on the basis of field measurements along the Kulekhani reservoir area. It covers the section from the confluence of Chitlang Khola to Chalkhu Khola. It is about 900 meters long sections along the both banks of Kulekhani watershed. Field level survey was conducted with six pits excavation for examining the sediment composition and the depth of sediment.

3.2.2 Secondary data collection

Literature reviews of published and unpublished documents were used to collect the information regarding the sedimentation in the Kulekhani reservoir area. Relevant information from the research works are presented in literature review section.

3.2.3 Data management

The collected data sets were plotted in the graphs for the calculation of the volume of sediment. Both banks data sets were tabulated and calcuated to estimate the volume of sediment along the flood plain of Kulekhani reservoir area.

3.2.4 Data analysis

The plotted data were further analyzed to estimate the sediment volume. Sediment depth were measured and tabulated in annex II and representative photographs during the study were presented in annex I. Excavated pits were examined to understand the sediment composition and the particle size by field measurement method. Details of analyzed and plotted data are tabulated in annex II and annex III.

CHAPTER 4: RESULTS

Field observation and findings

Dominant variation in sediment transport and deposition were found to be dependent on geology of the surroundings, slope, landuse and rainfall/precipitation. In addition to this, anthropogenic activities have initiated erosion and landslide activities within the periphery of the watershed and reservoir area of Kulekhani.

Sources of major suspended sediment concentration- 5 major tributaries. Particle size varies from fine to coarser- sand to boulder size materials of different rock unit were found. Stream flow characteristics- medium to high gradient flow of streams. Measurement of discharges from the contributing streams are presented in table below:

Table 5: Discharge measurement in the streams contributing to Kulekhani reservoir

Date	Time	Location	discharge (section area*velocity) cu.m/s	discharge cu.ft/s
22 June 2022	9:30 AM	Chitlang Khola	288.75	10197.11
22 June 2022	1:30 PM	Thado Khola	235.95	8332.5
23 June 2022	9:30 AM	Chalkhu Khola	27.258	962.68
23 June 2022	10:00 AM	Dhasku Khola	26.25	927.01
23 June 2022	11:05 AM	Palung Khola	631.8	22311.81

The comparison between the current discharge measurement presented on table and field observation of sediment at flood plain reflects that major contribution of sediment were from Palung Khola, Chitlang Khola and and Thado Khola. Dhasku Khola sediment comprises fine sediment compared to all the tributaries.

Sedimentation process in a reservoir are quite complex because of the wide variation in the many influencing factors;

- Hydrological fluctuations in water and sediment inflow
- Sediment particle size variation

- Reservoir operation fluctuations
- Physical control on size and shape of the reservoir

Additional sources of sediment from vegetation growth in upper reaches, turbulence or density currents and erosional activities observed during the study area. It was also noted that anthropogenic activities (figure are adding up the sediment in the reservoir or watershed area. Brief information collection during the field visits are presented specific to observe sites below;

Wpt: 2463 (E05-15-166 N30-55-025, Altitude: 1525 m)

It lies on the left bank of the reservoir, 200 m downstream from the confluence of Chitlang Khola and Kulekhani reservoir. There is an exposure of highly fractured, jointed bedrock of Marble oriented due east with an inclination of 39 degrees. It is one of the potential sources of the sediment as shown in figure 5. The measurement of joints were; joint 1: 128/42, Joint 2: 328/70, Joint 3: 179/75 (metasandstone/phyllite /marble) wedge formation.

Figure 5: Moderately weathered and highly fractured bedrock on the left bank of Kulekhani reservoir (Wpt: 2463)

Wpt: 2464 (E05-15-104 N30-55-144, Altitude: 1499 m)

This section represents the huge accumulation of sand particles and active erosion works by the stream and major river flow as shown in figure 6.

Figure 6: Recent undercutting by the flowing water courses

Wpt: 2466 (E05-15-031 N30-55-476, Altitude: 1503 m)

This site is located at the confluence of Chitlang Khola and Kulekhani reservoir. Muddy water was flowing durig the study period which suggests that there is an active erosion works happening on the upstream of Chitlang Khola. The figure 6 represents the deposit along flood plain of Chitlang Khola. It is actively eroding unconsolidated sediment on the both bank of Chitlang Khola. The discharge of Chitlang Khola was measured to be 10197.11 cu.ft./sec. Sediment deposit was 2.5-3 m depth along the river bed composed of mixed soil/clay/sand and silt.

Figure 7: Active erosion of recent deposits along the channel of Chitlang Khola

The sediment along the Thado Khola looks very recently flooded. Different layers of deposits forming terraces can be observed in figure 7 & 8. The sediment depth was 2.5 m (2 events-Jestha and Asar 2079 B.S.). The sediment comprises boulders of Palung Granite, Metsandstone and Quartzite. Layerrs, Terrace T_1 was 1.95 m depth and Terrace T_2- 1.3 m depth.

Figure 8: The sediment deposited on the left bank of Thado Khola

Figure 9: Very recently flooded debris collected at the bank of Thado Khola

Wpt: 2471 (E05-14-947 N30-54-300, Altitude: 1530 m)

There is a landslide on the northeast facing slope 200 m south west of waypoint 2471. It lies on the right side slope meeting at Thado Khola. Erosional failure occurred due to undercut by the flowing debris and unmanaged slope. The accumulation of debris fan on the right bank of Thado Khola is being continuously eroded by Thado Khola as shown in figure 10. Small scale erosional slides occurred due to the debris flow and its influences along the flow path.

Figure 10: A debris flow occurred due to unmanaged slope after excavation and lack of control measures prior to the failure

The Chalkhu Khola area comprises rock strata of Quartzite, Phyllite and Marble (interbedded). Rock beds are moderately weathered, highly jointed and fractured. The attitude of rock: S135E/44 NE and joint orientations were measured as J1-300/70, J2-210/85 and J3-160/37. Recent rainfall and the runoff through the stream contributed huge amount of sediment into the reservoir near the end section of Khulekhani reservoir. The discharge of Chalkhu Khola was measured to be 962.68 cu.ft./sec. Thickness of sediment was 2 m and actively eroded along the stream flow path and at its bank.

Figure 11: A debris flow occurred due to unmanaged slope after excavation and lack of control measures prior to the failure

Bisingkhel Khola meets at Dhaskhu Khola which lies at E05-14-504 N30-56-201 Alt: 1508 m. Recent active erosion on the upstream is carrying out sediment can be observed during the visit. Muddy water water flow during the field visit is shown in figure 12.

Gabion wall structure constructed across the Dhasku Khola was partially damaged by the stream flow. Sediment thickness was about 0.2m along the side of river bed. Basic soil types of collected sediments are silt/clay dominant. This stream has less number of boulders. The bedrocks around the stream area are; Quartzite, Marble, Phyllite and Metasandstone which are oriented northeast with inclination from 38-44 degrees.

Figure 12: Muddy water flow due to active erosion on the upstream of Dhasku Khola

***Wpt: 2475 (*E05-13-586 N30-56-970, Alt: 1539 m)**

Palung Khola is one of the major streams contributing sediment into the Kulekhani reservoir. The sediment along the river section is mostly of boulder size materials of Granite, Metasandstone and Quartzite. The discharge of Palung Khola was measured to be 22311.81 cu.ft./sec. The end part of reservoir and the Palung Khola joining the reservoir is shown in figure 13.

Figure 13: Embankment across the Palung Khola constructed at end section of the Kulekhani reservoir.

Small streams contributing to the major streams were also observed during the field visit. Streams meeting at Palung Khola (1993 flood event area) consists of boulders size materials that are present along the river bed plain. Chuliparang Khola/Bajrabarahi Khola adds up to Palung Khola in the downstream. It has gravel size materials at the river bed section. There is absence of boulders as observed around the Bajrabarahi Bajar.

Figure 14*:* The stream flowing below the bridge section of Saraswoti Bajar

Road-cut failure of about 100 meters was observed at the Sarbang area along the main road to Bajrabarahi Bajar. Groundwater seepage was also observed during the study. Residual soil and ancient alluvial terrace deposit was the composition of landform. The rock type was Phyllite which is moderate-highly weathered and highly fractured. The bedrock orients NE/45 degrees.

The two types of failure modes; Wedge and plane failure was observed. Active gully erosion and dry debris fall is still active. This adds up the sediment down to Dhasku Khola meeting at the reservoir. The failures are shown in figure 15.

Figure 15: Road-cut failure observed at Sarbang area

Wpt: 2483 **(Dam site area)**

There is an active debris flow at E05-15-218 N30-52-986, Altitude: 1533 masl. It was activated in 2078 B.S monsoon period. The settlement on the upslope of failure is Dharampani Village. The sediment comprises Phyllite and Quartzite materials. There is still active erosional failure from the upper slope. Currently, control measures such as gabion works were under construction as shown in figure 16.

Figure 16: Lanslide observed at dam site area

There was active erosion near a portal site at E05-15-545 N30-53-049 alt: 1538 m. Gabion wall construction work was undergoing to control the sediment transport to the reservoir as shown in figure 17.

Figure 17: Gabion works undergoing in an active erosional failure on loose sediment slope

The results of field measurement data for the sediment study is presented in annex II and III.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The sediment transportation from the watershed areas were observed to be very active after observing the sediment deposition layers at the tributaries of Thado Khola, Chalkhu Khola, Dhasku Khola and Palung Khola.

Total volume of sediment along the flood plain was calculated by field measurement was found to be 46,627.1 cubic meter, where right bank shares 30526.25 cu. m. and left bank shares 16100.85 cu. m. The discharge measurement in contributing streams shows the maximum sediment transport from Palung Khola and Chiltang Khola. This study shows that Thado Khola also contributes huge amount of sediment into the reservoir.

The study suggests that the slope failures and stream-bank cutting contribute tremendously to the sediments in the reservoir. Hence, it is very important to stabilize these activities for reducing sediment deposition. Special emphasis should be given to the prevention and reclamation of landslides and gullies. Stream bank protection and the construction of sediment traps are needed to protect the hydro-power capacity of the reservoir. Implementation of such activities needs to be borne by projects (such as hydro-power) which are directly affected by the sedimentation. For the significant impact of conservation on reservoir sedimentation, long term conservation programs should also be an integral part of all the nationally important hydro-power programs.

CHAPTER 6: REFERENCES

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Appendix

Appendix 1: Photos

Figure 1: Sediment deposit along the reservoir beds (sand dominant); wpt: 2464

Figure 2: Unstable, wedge formation on the rock beds and potential sediment source site (wpt-2463)

Figure 3: Sand deposit along the banks of Kulekhani reservoir, fissures formed due to undercutting by the water flow

Figure 4: Erosion of the deposited sediments by a small stream meeting at Kulekhani reservoir (wpt:2465)

Figure 5: Sand bar deposit on the right bank of Kulekhani reservoir opposite of Chitlang Khola which meets at reservoir

Figure 6: Decreased water level at the confluence of Kulekhani reservoir and Chitlang Khola (June 2022) It shows that there is an active sediment transportation during a heavy rainfall (rise of water level)

Figure 7: Measurement of deposition on the bank of rivers using tape meter

Figure 8: Measurement of slope cutting

Figure 9: Measurement of deposition from the bed level of river

Figure 10: Measurement of old deposition by digging a pit

Figure 11: Alignment of rocks along the bank of reservoir

Figure 12: Excavation of deposited materials from the rivers

Figure 13: Landslides along the road

Figure 14: Overview of Kulekhani Reservoir

Appendix 2: Field measurement / data collection sheet

Right bank of Kulekhani Reservoir						
S.N	**Front Bearing (degrees)**	**Distance (m)**	**Terrace height (m)**	**flood plain (across length)**	**hill slope angle (degrees)**	**Additional remarks**
1	270	50	2.5	99		colluvial deposit
2	278	10.5	2.5	21.7		colluvial deposit
3	310	41	3.3	1	40	colluvial deposit, bedrock
4	335	50	4.2	1	35	bedrock (Marble, Phyllite)
5	345	15.9	4.1	1	45	bedrock (Marble, Phyllite) dipping NE/45
6	330	50	4	1		bedrock (Marble, Phyllite) dipping NE/45
7	335	50	4	2	40	vertical beds
8	358	50	4	2	35	vertical beds
9	358	45	2	18.5	40	highly fractured rocks, alluvial deposit overlying
10	350	50	1.8	43		flood plain, colluvial deposit
11	335	30.4	2	47		flood plain
12	308	13.6	1.2	42		flood plain
13	330	37.4	0.6	54	42	flood plain, colluvial deposit, fractured rocks
14	340	45	0.8	73.5	40	flood plain, colluvial deposit, fractured rocks
15	316	39.5	2	50	35	flood plain, colluvial deposit, fractured rocks

16	297	50	1	44.8		flood plain, boulder reach region
17	297	41	1	34		flood plain
18	295	29	0.5	20.6		Suspension bridge section
19	276	22	0.5	1.8	36	bedrock
20	310	21	0.5	1	34	calcareous rocks
21	330	26	0.7	10	55	calcareous rocks
22	332	58	0.6	16		flood plain, bedrock
23	305	32	1	14	45	bedrock
24	295	46	0.5	4	45	flood plain, opposite to the confluence of Dhasku Khola and Palung Khola
25	305	23.6	0.4	7	42	flood plain
26	23	21.5	0.4	30.4	42	flood plain
27	357	15	0.2	45		flood plain
28	304	46	0.2	52	45	shallow depth , river bed meets , bed Rock dipping NE/45
29	308	50	0.1	60	43	shallow depth, confluence of Chalkhu Khola and Palung Khola

Left Bank of Kulekhani Reservoir						
S.N	**Front Bearing (degrees)**	**Distance (m)**	**Terrace height (m)**	**Flood plain (across length)**	**Hill slope angle (degrees)**	**Additional remarks**
1	303	86	0.5	1.5		colluvial deposit, bedrock
2	6	50	0.3	45.7	70	45.7/bedrock quartzite, phyllite dipping NE
3	309	50	1	50		50/bed rock quartzite, phyllite
4	317	50	0.8	54.4		54.4/ bed rock Orients 020/55 degrees, calcareous quartzite (wpt 2502)
5	308	50	1	55		55/bedrock (stream-1.5m wide)
6	300	17	1	47.5	60	47.5/bedrock calc qtzite /metasandstone
7	300	35	1	42		42/bedrock highly weathered
8	285	25	0.9	20.7	55	20.7/bedrock fractured
9	292	41.1	0.95	0	65	bedrock, river width 17 m
10	330	50	2.8	0	50	bedrock
11	325	19.8	2.8	0		bedrock
12	310	49	2.8	0	55	bedrock
13	340	47.8	2.8	1		bedrock, Granite boulders
14	303	37	2.6	24	55	flood plain

15	35	13.8	1.9	35	60	flood plain
16	8	25	2.2	50	60	meandering part, excessive bank erosion
17	32	39	1.7	57.8	60	flood plain, bedrock dipping NE/30, highly weathered
18	290	14.7	1	92	30	flood plain, bedrock dipping NE/30, highly weathered
19	285	49	0.5	88	30	flood plain, bedrock dipping NE/30, highly weathered
20	235	50	1	50	25	flood plain

Appendix 3: Calculation of sediment volume along the flood plain (900 m section from the confluence of Chitlang Khola to the confluence of Chalkhu Khola)

Right bank of Kulekhani Reservoir			
Length (m)	**Breadth (m)**	**Depth (m)**	**Volume (cu. m)**
60	50	2.5	7500
11.5	11	3.3	417.45
1	40	4.2	168
1	50	4.1	205
1	17	4	68
1	50	4	200
2	50	4	400

10	5	2	100
30.7	40	1.8	2210.4
45	48	2	4320
44.5	28	1.2	1495.2
48	13	0.6	374.4
64	36	0.8	1843.2
62	38	2	4712
47.5	37	1	1757.5
39	48	1	1872
27	40	0.5	540
11	20	0.5	110
1	20	0.5	10
9	20	0.7	126
13	27	0.6	210.6
15	53	1	795
9	28	0.5	126
5.5	45	0.4	99
19	25	0.4	190
37.5	25	0.2	187.5
48	42	0.2	403.2
33	26	0.1	85.8
			30526.25
Left Bank of Kulekhani Reservoir			
Length (m)	**Breadth (m)**	**Depth (m)**	**Volume (cu. m)**
80	5	0.5	200

25	47.5	0.3	356.25
50	47.5	1	2375
50	54.5	1	2725
52	54	1	2808
50	15	1	750
42	30	1	1260
31	17	0.9	474.3
12	55	2.8	1848
18.5	33	2.6	1587.3
42.5	10	1	425
38	68	0.5	1292
			16100.85

Note: measurements are done manually and plotted in graphs for the further calculation (these data are based on graph plot from the field data)