Development of Ecosystem based Sediment Control Techniques & Design of Siltation Dam to Protect Phewa Lake

Harpan Khola Watershed Kaski

SUMMARY REPORT

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HARPAN KHOLA WATERSHED KASKI

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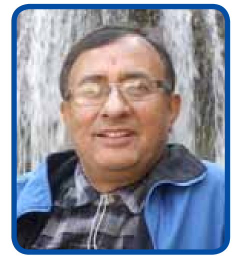
Foreword



Nepal's national economy and people's livelihoods largely depend on natural resources and ecosystem services. These resources and services are now being subjected to increasing threats of climate change. Of all the existing ecosystems in Nepal, the mountain ecosystems are highly susceptible to climate change and its impacts. This means that it is imperative for us to take necessary actions to withstand the impacts of the changing global climate. Adaptation, in this regard, is highly crucial for us and especially for the people living in mountain ecosystems. It is our responsibility to make these ecosystem resources resilient to the climate change impacts.

The Ecosystem Based Adaptation (EbA) in Mountain Ecosystems of Nepal is a pilot project implemented by the Department of Forests (DoF) in collaboration with many government line agencies and user groups in the Panchase Protected Forests located in the Western Development Region of Nepal. The EbA pilot project has been successful in contributing to the understanding of climate change adaptation at the ecosystem level. It has proven to be a comprehensive and effective initiative where 'ecosystem' is considered the most integral component to achieve livelihoods improvement, environmental integrity and sustainable development.

Besides piloting the necessary adaptation interventions, EbA project has also played a crucial role through action research of the study area which is of utmost need in today's context as it helps in addressing a prominent problem observed around Phewa Lake i.e. siltation which has already reduced the lake by 50 percent. The Phewa Lake has a long history of providing several important ecosystem services to the surrounding community including tourism related business opportunities. Due to various anthropogenic causes, the Lake is, now, at risk from increased sedimentation which is likely to be exacerbated due to climate variability in future unless proactive actions are planned and implemented.

In this connection, an extensive study was carried out by the team of experts under the supervision of the Western Regional Forest Directorate (WRFD). The study presents a detailed analysis of the current challenges the Lake is facing and concludes with recommendations to minimize the sedimentation problem. I believe, this study opens window of opportunity for collaborative effort between government, non-government and local actors in conservation of the Phewa Lake.

Resham Bahadur Dangi
Director General
Department of Forests

Foreword

It is important for people of developing countries' like Nepal to realize the current and future climate change impacts and gear up taking necessary steps to adapt. In this regard, improving the resilience of ecosystems and the human adaptive capacity is a foremost priority. I appreciate that UNDP has been working very closely with the Government of Nepal in addressing the challenges brought by climate change.

The Ecosystem based Adaptation in Mountain Ecosystems Project in Nepal,commonly known as EbA project, implemented by the Department of Forests under the Ministry of Forest and Soil Conservation (MoFSC), is piloting implementation of ecosystem based adaptation approaches in Panchase watershed, which is one of most vulnerable watersheds of Nepal. Panchase watershed supplies crucial ecosystems services to the surrounding population in the upstream and feeds water to the Phewa Lake located in the heart of Pokhara City in the downstream.

Over the years, the Phewa Lake has been experiencing growing threats from both climatic and non–climatic factors leading to shrinkage of lake area and poor quality of water. Numerous studies have identified siltation as a major threat to the Lake Ecosystem and services, including shrinking of the lake by more than 50% over the last five decades. There is an increasing trend of 'new island formation' around Phewa Lake due to siltation.

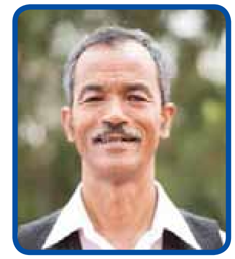
Over the years UNDP Nepal has, in partnership with government line agencies and relevant stakeholders, supported the building of an understanding about the siltation problem and creating a broader consensus towards addressing this. In this regard, the EbA Project collaborated with the Western Regional Forest Directorate (WRFD) Office to carry out a comprehensive study to determine the overall trend of siltation in the area and propose necessary recommendations to address them.

The report highlights the findings of the study: the issues related to siltation in Phewa Lake based on historical records and present day observations, and recommendations to address them. Since the study engaged the stakeholders from the beginning, the issues and recommendations captured in the report are locally owned.

I'm hopeful that the report will be useful for the government and partners towards finding a common and sustainable solution to the siltation problem in Phewa Lake.

Vijaya P. Singh
Assistant Country Director
UNDP Nepal

Foreword



Ecosystem based Adaption (EbA) in Mountain Ecosystems is a part of the Global Mountain EbA project that is being piloted in Nepal, Peru and Uganda. In Nepal, the project is implemented in the Panchase ecological region. It comprises of 17 Village Development Committees of the three districts, Kaski, Syangja and Parbat. As a pilot project, EbA has been working to build resilient ecosystems that reduce climate change impact vulnerabilities and enhance adaptive capacities of local communities through livelihood options.

Among the many ecosystems in Panchase, freshwater ecosystem is the most crucial. Phewa Lake and its feeder rivers are an important source of livelihood for local people living in and around the lake. The Lake is prized for its natural beauty and is a popular destination for both national and international tourists; Harpan River, the main feeder to the Lake, originates in Panchase. However, despite its significance, the lake suffers from immense siltation problem that has resulted in the reduction of the Lake's area and is hindering its provisioning services. Climate change and the resulting erratic rainfall in the region will result in extensive sedimentation thus further reducing the life of the lake.

Thus, in view of the increased threat to Phewa Lake and its ecosystem functions, an innovative approach was necessary to protect the Phewa Lake. In 2014, the Western Regional Forest Directorate (WRFD), with support from the EbA Nepal Project, partnered with Forum for Energy and Environment Development (FEED) P. Ltd to commence the detailed analysis of the Harpan Sub-watershed including its geology, geomorphology and rainfall patterns towards presenting a means to protect the lake and ensure sustainability of its ecosystem services. The study explored innovative approaches to protect the physical and biological environment of the Phewa Lake and analyzed the problem in a holistic manner, in consultation with the key stakeholders in Kaski district.

The EbA Project would like to extend our sincere appreciation to the team of experts lead by Er. Sanjay Devkota and Dr. Basanta Raj Adhikari from FEED P. Ltd for undertaking this rigorous and comprehensive study to identify factors responsible for siltation and providing recommendations to address the existing problems. We would also like to thank the former Regional Directors of WRFD, Dr. Rajan Pokhrel (Formerly Director General of DoF) and Dr. Akhileshwor Lal Karna (Regional Director of Central Regional Forest Directorate) and the incumbent Regional Forest Director, Mr. Shanta Muni Tamrakar, for their leadership and vision that has led to the successful completion of the study. We also like to thank the Activity Management Committee (AMC) members for their supervision, support and coordination role during the study. Also, we express our gratitude and appreciation to the Department of Soil Conservation and Watershed Management for their time and effort in technical input to this document.

Finally, this summary report captures the most crucial details and critical analysis of the detailed comprehensive study report and we are hopeful that this will be used by the government for any future conservation efforts of the Phewa Lake.

Gauri Shankar Timala
Deputy Director General/National Project Director
Department of Forests/EbA

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Acronyms

CAR	:	Catchment Area Ratio
CBDRMP	:	Community based Disaster Risks Management Programme
CBS	:	Central Bureau of Statistics
CFUG	:	Community Forest User Group
cum/m3	:	cubic meter
D/S	:	downstream
DEM	:	Digital Elevation Model
DFO	:	District Forest Office
DHM	:	Department of Hydrological and Meteorology
DSCO	:	District Soil Conservation Office
E	:	East
EbA	:	Ecosystem based Adaptation
GIS	:	Geographic Information System
HEC-HMS	:	Hydrologic Modeling System
HH	;	Households
IUCN	:	International Union for Conservation of Nature
JICA	:	Japan International Cooperation Agency
km	:	Kilometer
M/m	:	Meter
N	:	North
S	:	South
SMC	:	Sub-metropolitan City
Sq.m	:	Square meter
Sq.km/ km^2	:	Square kilometer
U/S	:	Upstream
UNDP	:	United Nations Development Programme
US	:	United States
VDC	:	Village Development Committee
W	;	West
WECS	:	Water and Energy Commission Secretariat
WRFD	:	Western Regional Forest Directorate
WWF	:	World Wide Fund

1 INTRODUCTION

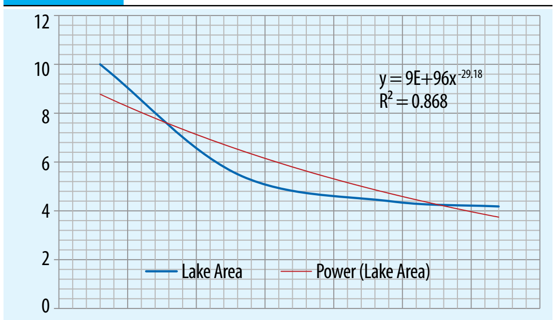
1.1 Background

The water level in Phewa Lake, located in the south-western corner of Pokhara valley, varies seasonally depending on the inflow and outflow. A dam has been built for power generation and irrigation purposes at the end of the Lake which, in general, regulates the water level. The lake extends about 4 km northwest to southeast and is approximately 2 km at its widest and 100 m at its narrowest section. The Phewa watershed has a complex geo-morphology and topography. The hilly terrain and valley bottoms stand out as distinct natural features in the landscape crisscrossed by a number of irregular ridges and spurs. The south facing slopes of watershed are comparatively gentle (around 30 to 50 percent) than the north facing slopes (above 50 percent). At 2,517 m, the Panchase peak is the highest point of the watershed.

Harpan Khola, the main feeder to the lake, meanders about 10 km and makes a sharp southeastern turn on meeting the western edge of the plain and joins Phurse Khola, a tributary of Seti River. A dam at the outlet of the lake has caused an increase in the storage capacity of the lake. In the north, Sarangkot and Kaskikot hills surround the lake and the sacred forest (called Rani Ban) in Chapakot and Pumdibhumdi VDC. There are some small torrents, mostly the seasonal, that also feed water and sediments into the lake. Phirke Khola carries sewerage and solid wastes from upstream areas of Pokhara Sub Metropolitan City (SMC).

Physical shape and size of Phewa Lake has been decreasing due to sedimentation and land encroachment along the lake shore. JICA in 1998 had carried out a time series map analysis and stated that the lake area decreased from 10 km2 (1956/57) to 5.5 km2 (1976) and, then, 4.4 km2 (1998). Within a time frame of 5 decades the area of the lake has reduced by more than 50% (JICA, 2002). In this study an effort was made to map the Lake's area, which was found to be 4.2 km2 in 2014. The figure below presents how the lake area has been reduced over the period.

FIGURE 1: TRENDS OF PHEWA LAKE AREA REDUCTION (1956-2014)



The major causes in the reduction of the lake area are the natural land forming processes and excessive human interventions. With the idea of keeping the conservation of Phewa Lake and its watershed in center, the Western Regional Forest Directorate Kaski, with support from Ecosystem based Adaptation (EbA) programme of UNDP undertook the study to implement a detailed study/design of ecosystem based mitigation measures to protect Phewa Lake and the Harpan Khola watershed.

1.2 Rationale

Some of the major issues of the lake includes extreme lake-area encroachment, accelerated eutrophication, invasive species, toxic contamination, un-managed fishing, water diversion, acidification, sedimentation, water pollution from Seti canal and hotels and the impacts of extreme weather events. The problems at the basin, however, are over-grazing, forest clearance, landslide and debris flow, unplanned development activities and excessive rural road construction, unattended terrace agricultural practices and excessive use of chemical fertilizers and pesticides. Some of the issues are described in more detail as they are relevant to the potential construction of the siltation dams and vital to the long-term sustainability of the Phewa Lake.

RECLAMATION AND ENCROACHMENT:

Growing urbanization along with undefined and officially non-demarcated shoreline, has led to a significant reduction in the Lake's morphometry. Such illustration can be observed in the lake-head which used to be completely submerged, but has now surfaced as alluvial plain, a result of heavy sediment load carried by Harpan Khola and its tributaries. Such alluvial plains were illegally encroached for agriculture and settlements; however, they were subsequently legalized by the cadastral survey of 1975. In addition, the shoreline of Phewa Lake along the eastern Baidam has been encroached where unplanned constructions such as rural roads and housing among others, are still in progress causing environmental degradation and also functioning as a source of sedimentation. Phirke Khola and the many sewer lines connected into the local drainage have been identified as the major sources of pollution. Hotels, but also government guest houses (e. g. Municipality Guest House), armed Police Offices and quarters and squatter settlements are the major polluters of the Lake.

SEDIMENTATION:

Sediments comprising silt, sand and gravel are transported into the lake by the Harpan Khola and its tributaries. Two of the tributaries, Andheri and Betini, are more vulnerable as a result of carrying excessive sediments. Mass movement, for example landslides and debris flows, are common in the up-stream basin of Andheri Khola – a major source of sediment.

Sediments in the form of urban garbage are also being transported in the lake by Seti Canal, Bulanudi and Phirke Khola. These also transport silt and sand in small quantities throughout the year, so the annual cumulative effect is huge. JICA (1998) carried out a time series map analysis that showed that the lake area has decreased from 10 sqkm (1956/57) to 5.5 sqkm (1976) to 4.4 sqkm (1998). More than 50% of the area has been reduced within a time frame of 5 decades. Natural land forming process along with the excessive intervention of human are the main causes for the reduction of the lake area.

THREATS TO BIODIVERSITY AND ECO-SYSTEMS:

Phewa is well recognized as a wetland of nationally and internationally significant aquatic biodiversity. Peripheral areas of this lake in Rani Ban and Pumdi Bhumdi forests are gifts for bird lovers and researchers. Panchase hill is popular due to its biodiversity richness, for example birds, orchids, wildlife and rare plant species of mid-mountain region of Nepal. However, existing threats posed by human activities and invasive species such as water hyacinth, and exotic carp fish species have led to a decrease in aquatic biodiversity, especially, native fish species. There is a laxity in managing and controlling the spread of the invasive species, for example, by utilizing it, and this, in turn, has adverse impacts on the health of the ecosystem.

There are several issues that need to be addressed to conserve Phewa Lake; however, this study has focused on investigating sediment generation processes and reducing the sedimentation into Phewa Lake while, at the same time, protecting the ecosystem.

ECOSYSTEM BASED SEDIMENT CONTROL TECHNIQUE:

This is the technique that makes use of local natural resources and knowledge in mitigating the effects of climate induced hazards such as debris flow, shallow landslides and soil erosion. Since landslides and soil erosion are the sources of sediments that ultimately fill out the low land (e.g. lake, river valley, wetland, etc). Soil bioengineering, a nature based solution is found to be suitable in stabilizing the unstable soil slopes leading to a reduced sediment generation process, while at the same time, local resources such as stone/boulders can be utilized combining civil-engineering principles to identify the sustainable way forward to protect the Phewa lake.

1.3 Objectives

The major objective of this study is to propose mitigation measures and design of siltation dam(s) in upstream Phewa Lake, i.e., Harpan Khola valley to trap the sediments flowing from the upper reaches of the hill. While conducting this assignment there are several other objectives to be completed during the study:

- Identify and map the landslide and debris flow hazard hot spots, their size, type, extent and causes in order to investigate the type of sediments and monthly/annual sediment volume generation from the basin and identify ecosystem based mitigation measures;
- Surface Geological Mapping of Harpan Khola watershed in general and landslide and debris flow areas in particular;
- Hydrological study of the Harpan Khola basin – monthly water inflow and out flow, drainage and river system, types of drainage;
- Investigate the volume of sediments deposited in the low land of Harpan Khola valley;
- Topographical survey of the of the proposed siltation dam area;
- Based on data and investigation, design an environment friendly, eco-system based and low cost Siltation at suitable location that allows clean water to enter into the lake. Alternative analysis of the dam shall also be carried out;

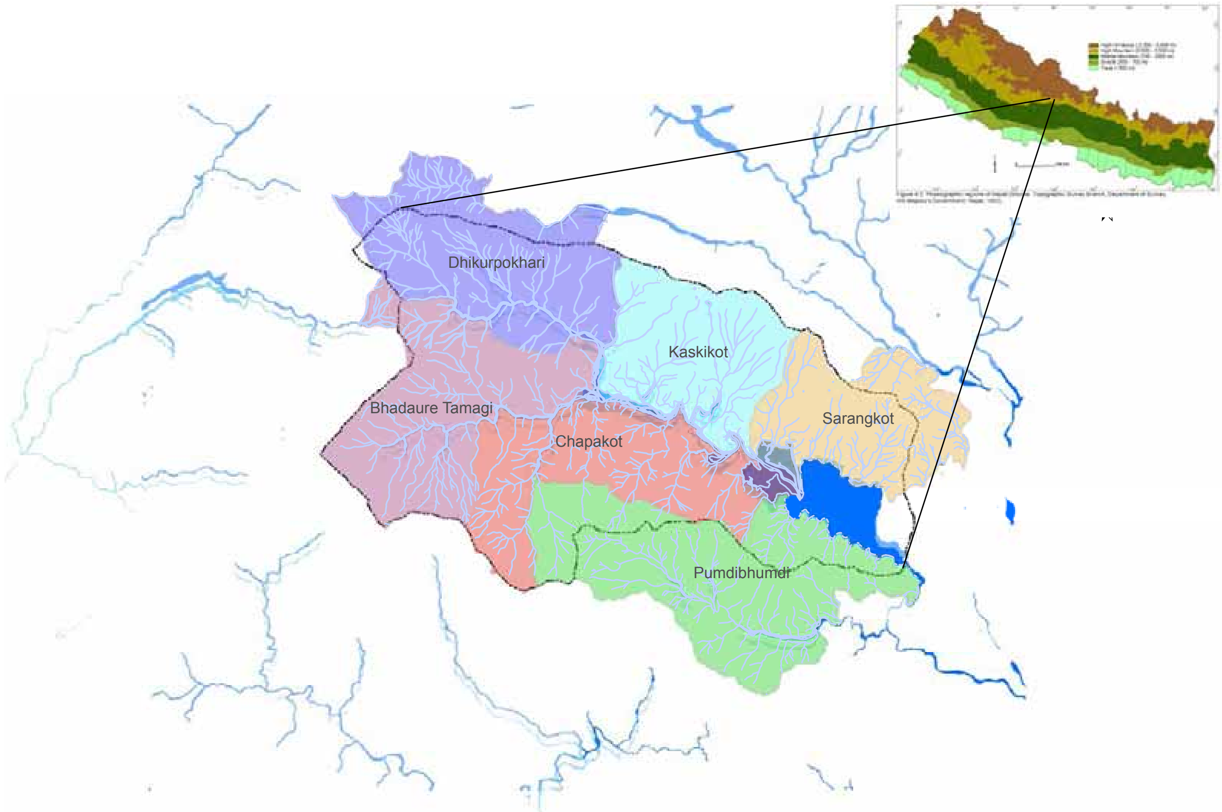
2 PHEWA WATERSHED

Phewa is a semi-natural freshwater lake in sub-tropical mountain climate lying at an altitude of 784m in Pokhara Valley (280 7'-280 12'N, 840 7'-840 19'E) that falls on relative subsidence zone in between the Greater Himalaya and the Mahabharat Range (Figure 1).

Administratively, Phewa Lake watershed is spread across six Village Development Committee (Sarangkot, Kaskikot, Dhikurpokhari, Bhadaure-Tamagi, Chapakot and Pumdi-Bhumdi) jurisdictions, fully or partially, as well as the south western part of the Pokhara Sub-Metropolitan City in the mid-western region of Nepal.

The watershed area forms a unique geographical entity and represents typical characteristics of the mountain environment with a temperate climate at the hill-top and humid sub-tropical climate in the conical unique valley landscape of mid-hill Pokhara. The total area of the watershed is about 123 sq.km (Oli, 1997). It is characterized by moderate temperatures that reach a maximum in July-August and minimum in January, heavy monsoon rainfalls and distinct seasonal variations.

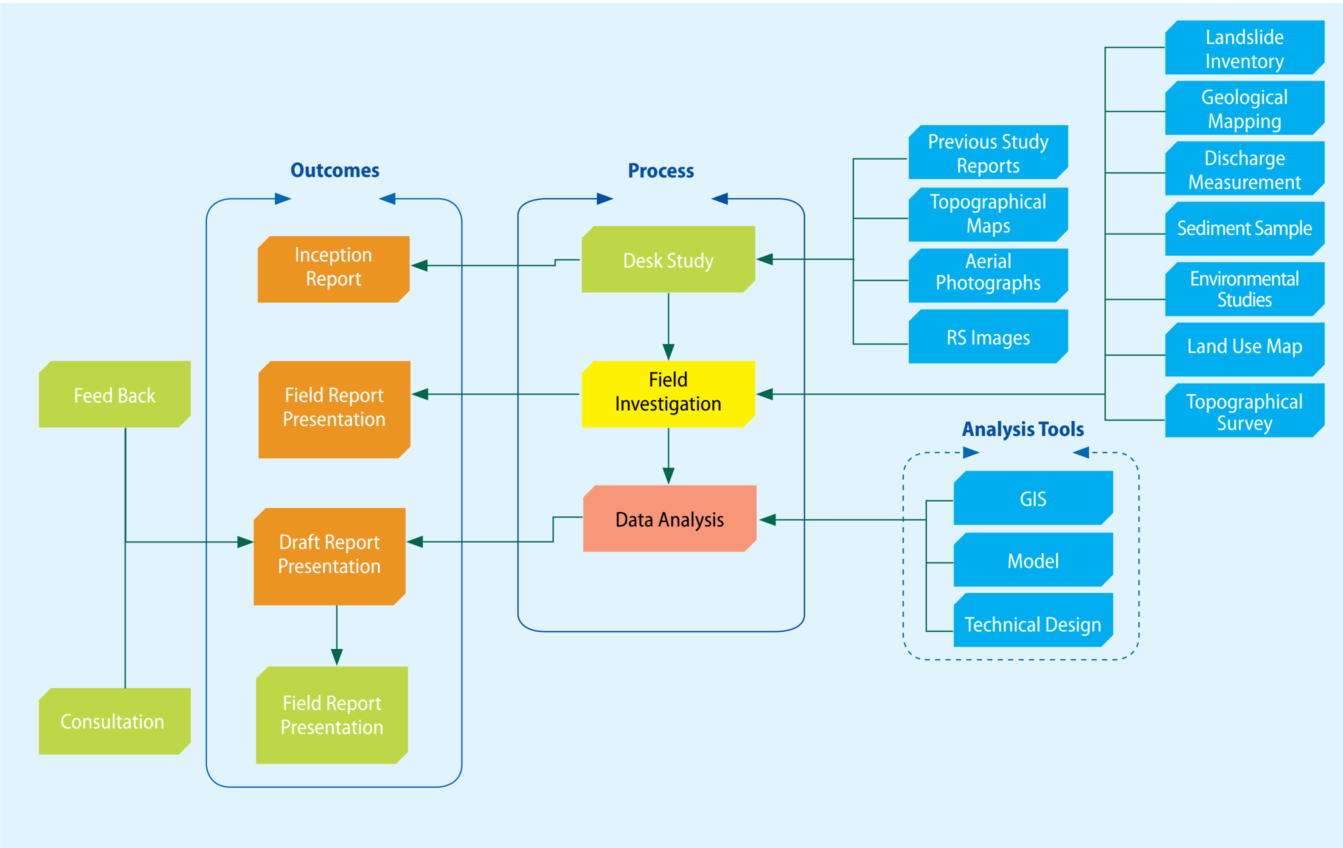
FIGURE 2: LOCATION MAP OF STUDY AREA



3 METHODOLOGY

The study was carried out by applying engineering norms, practices and scientific methods. The flow diagram below presents the general overview of the study method.

FIGURE 3: GENERAL OVERVIEW OF STUDY METHOD



The following approaches were used for the study:

1) Literature review
2) Field Assessment and consultation with the local population
3) Geological assessment
4) Hydrological Assessment and Discharge measurement
5) Landslide mapping
6) Environment and Ecosystem Assessment
7) Topographical Survey of the proposed Siltation Dam Area
8) Public Consultation

4 GENERAL FINDINGS

4.1 General Geology

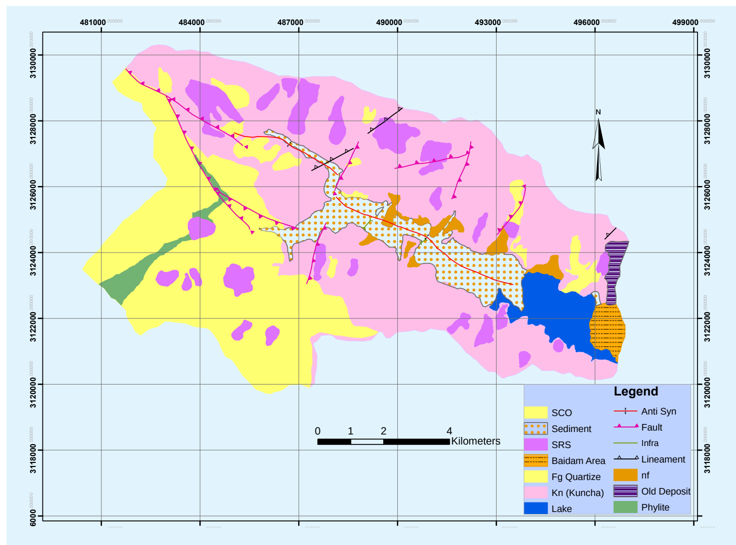
Geologically, the area is covered by rocks of two formations of Central Nepal Lesser Himalaya 1) Kuncha Formation and 2) Fagfog Formation (Figure 3).

Kuncha Formation (kn):

Geologically, most of the watershed area lies in the Kuncha Formation and occupies a total of 61.7 sq.km on both sides of the lake as seen in the figure (Figure 3) above. It is characterized by thin-to-medium beds of grey phyllites with intercalation of grey meta-sand stones. Gritty phyllites are more abundant than the pelitic ones. Thin-to-medium beds of grey-to-dark grey, thinly foliated, weathered phyllites (Figure 4) of Kuncha Formation are observed in the areas of Kaskikot, Manthali, Sarangkot, Dhikur Pokhari, Ghatichhina, Mulabari and Pumdi. The phyllites are deeply weathered around the top of the hill. Thick vegetation has increased weathering in the phyllites around World Peace Stupa, Pumdi and Mulabari.

The rocks in the northern slope of the watershed has a general orientation of E-W/40^0 S whereas, the southern slope has normal orientation of E-W/37^0 N

FIGURE 4: SURFACE GEOLOGICAL MAP OF PHEWA WATERSHED



forming an anticline structure. The core of the anticline is distinctly marked by the Harpan Khola within the watershed. The northern limb of the anticline is folded and the attitude ranges from the beds vary in attitudes from north dipping to south dipping and are almost horizontal at some places in the anticline around Khapaudi- Ghatichhina Road section.

FIGURE 5: PHYLLITES OF KUNCHA FORMATION AS SEEN IN KASKIKOT (LEFT) SARANGKOT AREA (RIGHT)

The top of the Manthali peak is marked sharply by the glacial till (Figure 5), which extends west towards the Sarangkot peak. The phyllites are usually deeply weathered, up to 2m. Gullies develop easily in weathered rocks. Mass wasting is common in both the limbs. The high hill slope, ranging from 37-60 degree could be a prime factor in mass wasting.

Fagfog Quartzite (fg):
Fagfog quartzite is represented by white, medium-to-thick beds with coarse-grained and fractured (three sets of joint prominent) quartzite (Figure 5). The quartzites of this formation are marked with massive beds and current ripples. The thinly joint, medium beds of quartzites of this formation are extensively observed around Bhadaure, Tamagi, Kudbidada, Damdame, Makawanpur, Himde, Philinghari, Tarebhir, Villages of Bhadaure Tamagi and Chapakot VDC's. The general attitude of the quartzite is N650W/ 400 SW. The quartzite forms the base of the anticline along with the Kuncha Formation in the watershed. Fracturing is a common feature of the quartzite resulting in deep weathering of the rocks in Tamagi and Makawanpur. The quartzite forms steep slopes at Bhadaure Tamagi. A small band of intercalating greenish-grey phyllites and quartzites form a syncline around Kudbidada and Tamagi Villages. The phyllite band is prominent in the south and pinches around Bhadaure in the north. The proportion of phyllite gradually increases in the upper reaches of the hill.

The hills are mainly made up of phyllite and quartzite. Sandy gravels are distributed in the hill slopes and unconsolidated sediments are found in the alluvial fan deposits. Surface geology of the watershed is generally fragile i.e., there are large scale thrust faults and many small faults and thus, the rocks have undergone intense deformation in many places in various ways.

4.1.1 SOIL EROSION AND LANDSLIDE

Landslide: Landslide describes the processes that results in the movement of sediment block, which has clear slide/slip surface. A landslide's dimension may be large or small, and the velocity may be fast or slow. The continuous movement is mainly affected by groundwater, land-use, geology under the surface and anthropogenic activity. Rotational, translational, debris flow, rock fall, rock topples and so on are different types of landslides which may be found in Phewa Watershed.

Debris flow: It is the process of movement of deposited or eroded sediments along the stream. It includes rapid movements including large volume of water through the stream.

The Phewa watershed receives very high intensity rainfall during monsoon. The high intensity of rainfall along with the high hill slopes of the area, mostly 45 degree, but increasing up to 58 degree, the soft lithology of phyllites and thinly fractured quartzite and the construction activities around the watershed are the major triggering factors of mass wasting. Thus, this area has already been marked severely with various mass wasting events in the past. Although the common mass wasting features at the present time is gully erosion and sheet erosion, occasional landslides and debris flow have been a major contributor to the mass wasting.

FIGURE 6: GLACIAL TILL OBSERVED ON THE PEAK OF MANTHALI VILLAGE (LEFT) EXPOSURE OF FAGFOG QUARTZITE IN GHATICHHINA-PANCHASE AREA (RIGHT)

4.1.2 SEDIMENT VOLUME

Analysis shows that the sediment deposited in Harpan Khola valley is found to be of different grading and reflects the types of earth materials in the upper reaches of the slope. The lithology is mostly shallow soil over highly weathered and fractured bed rock of Kuncha Formation in major portions of the watershed. The large Fagfog Quartzites in the south-western section of the watershed is heavily fractured and has led to several blocks in Ghatichhina area.

Several sub-watersheds of Beteni Khola valley contains maximum volume of sediments among other sub-watersheds, followed by those of Khahare Khola valley. The sediments analyzed at the outlet of the debris fan indicate that the upper reach consists of coarse materials, but the sediments are much finer in the downstream towards the lake inlet. This analysis also indicates that the stream energy is higher in the upper reaches and lower in the valley side. An attempt was made to estimate the sediment volume deposited in Harpan Khola Valley and sub-watershed. The assessment was visual inspection of the surface area and sediment profile.

TABLE 1: SUMMARY OF SEDIMENT VOLUME DEPOSITED IN HARPAN KHOLA VALLEY

S. N.	Name of sub-watershed/Debris Fan	Volume of Sediment (m^3)
1	Sedi Khola sub-watershed	245,000
2	Khapaudi Khola sub-watershed	270,000
3	Kanjare sub-watershed	166,250
4	Beteni khola sub-watershed	840,000
5	Lauruk Khola sub-watershed	20,000
6	Kahare (Andheri Khola) sub-watershed	238,000
7	Tora Khola sub-watershed at Bamdi	5,000
8	Harpan Khola Valley (Gatichinna to Lake inlet) Harpan Khola valley side	1,000,000
	Total	**2,784,250**

Sources: Field survey, January 2014

The total estimated volume of sediment deposited in Harpan Khola Valley, from the 8 sub-watersheds, is 2.784 million cubic meter.

4.2 Environment and Ecosystem

Streams, ponds, lakes and wetlands are the main sources of Phewa watershed. Tap stone spouts and spring water are the main source of traditional drinking water, however, the area has a very well developed public water supply system as the government has made significant effort in ensuring the availability of potable drinking water to the populations residing in the hilly area. These water sources are instrumental in fulfilling the water demands of the people, i.e., for drinking, bathing, cleaning utensils and clothes and feeding livestock.

TABLE 2: ACCESS TO DRINKING WATER SUPPLY IN THE VDCs

VDCs	Tap	Stone spout	Spring water	Total Population
Bhadaure Tamagi	862	31	2	3,257
Pumdibhumdi	1550	0	0	7,391
Chapakot	593	47	13	2,637
Kaskikot	1366	93	0	5,892
Sarangkot	1396	229	62	8,345
Dhikurpokhari	1863	81	26	7,318
Total	**7630**	**481**	**107**	**34,840**

Source: CBS, 2013

4.2.1 GENERAL ECOSYSTEM

Study area is a semi-agricultural watershed and a mid-hill mountain ecosystem. It can be broadly divided into three ecosystems: 1) aquatic 2) wetland and 3) terrestrial. The aquatic ecosystem in turn constitutes two distinct zones i.e., limentic (central zone with deep open water) and littoral swampland (peripheral/shoreline with shallow depth) zone of Phewa Lake. The wetland ecosystem consists of swamplands and marshlands located along the floodplains and inlet mouth portion of Harpan Khola and other inlets, for e.g. Phirke Khola, Sedi Khola and Seti Irrigation canal among others; however, most wetland sites have been converted into rice fields, while some are used as solid waste disposal area. The terrestrial ecosystem consists of different land use types; forest, grazing land and agricultural land. Urban and rural settlements are located along the lakeshore and hill slopes, respectively. Villagers are interspersed into agricultural land and slums have been developed by lakeshore (Figure 6).

The practice of community forestry in Kaski District was initiated in B.S. 2047/48 and since then the model has been moving forward progressively. The total forest area in the district is 93,649.08 ha, out of which 28,575.48 ha has been handed over to 475 Community Forest Users Groups (DFO, Kaski 2069). Most of the forest land in Phewa watershed has either been handed to the CFUGs (3269.25 ha) or is protected. The forest south of Phewa lake is also known as World Peace Forest and is a protected forest. It occupies 164.67 ha of land. Similarly, Panchase Protection Forest, which extends in three districts (Kaski, Syangja and Parbat) in the region, occupies 5776 ha, out of which 2298.24 ha falls in Kaski district. This protected forest is rich in bio-diversity and provides numerous ecosystem services. Further, CFUGs also protect the forest which has led to the improved ecosystem services.

4.2.2 FLORAL AND FAUNAL DIVERSITY

The study area has a substantial richness in floral and faunal species. The common tree species include *Shorea robusta, Schima wallichii, Castanopsis indica, Alnus nepalesnsis, Bombax ceiba, and Ficus spp* (Figure 7).

Notable economically important and commercially threatened species listed in the Catalogue of Life (Roskov et al, 2015) include *Swertia chirayta, Bergenia cillata, Choreospondias axillaris, Elaeocarpus sphaericus. Common species include Rotifers, Copepod and Cladocera.*

4.3 Socio-economy

The largest percentage of population is found in Dhikurpokhari (22.4%) and the smallest percentage is found in Chapakot (8.6%). Sarangkot and Kaskikot have similar proportion of population contributing to the watershed area. Only a small portion of the eastern belt of the Pumdibhumdi VDC represents the Phewa Lake watershed area from this region.

Based on the Census data (2011), the estimated population of Phewa watershed area covering six VDCs is 34,849 (Male: 15,755 and Female: 19,094) in 8,860 households (HH). Compared to the Census data of 2001 (Total: 36,092 Male: 16,989 and Female: 19,103), the total population has declined in the area by 1,143. However, the number of HHs in the VDCs

FIGURE 7: GENERAL VIEW OF RIVER VALLEY (LEFT) FOREST AREA IN UPPER PART OF HILLS SLOPE (RIGHT)

FIGURE 8: GENERAL VIEW OF THE STUDY AREA

has increased from 7,318 to 8,860. Similar results can be seen from disaggregated VDC-wise data except for Sarangkot VDC where the population has risen from 6,612 (2001) to 8,354 (2011). Simultaneously, the population in a few of the wards of Pokhara SMC has increased significantly (see table below). The table below presents the summary of HHs and the population in the VDCs.

TABLE 3: CHANGE IN POPULATION IN A DECADE

S. N.	VDCs	Census 2001				Census 2011			
		HHs	Male	Female	Total	HHs	Male	Female	Total
1	Bhadhaure Tamagi	762	1,810	2,021	3,831	875	1,468	1,789	3,257
2	Chapakot	638	1,395	1,686	3,081	680	1,151	1,486	2,637
3	Dhikurpokhari	1,687	3,741	4,340	8,081	1,880	3,288	4,030	7,318
4	Kaskikot	1,255	3,123	3,417	6,540	1,508	2,591	3,301	5,892
5	Pumdibhumdi	1,568	3,804	4,143	7,947	1,837	3,358	4,033	7,391
6	Sarangkot	1,408	3,116	3,496	6,612	2,080	3,899	4,455	8,345
7	Pokhara SMC2, 4-8				52,692				30,416
	Total of VDC only	**7,318**	**16,989**	**19,103**	**88,784**	**8,860**	**15,755**	**19,094**	**65,256**

Sources: CBS 2011 & Baseline study of Panchase Region of EbA (2013)

Caste and ethnic composition: Phewa watershed area comprised of 8218 households (HHs). The percentage of Brahmin/Chettri is 65% followed by Dalits (18%) and Janajatis (17%). Dhikurpokhari and Chapakot have the highest and lowest number of HHs with 24% and 8% respectively.

TABLE 4: CASTES AND ETHNIC COMPOSITION BY VDC (HHS)

VDC	Household	20% of total HHs	Dalit	Janajati	Others
Bhaudare Tamagi	899	180	301	310	288
Pumdibhumdi	1550	310	325	405	820
Chapakot	653	131	98	119	436
Kaskikot	1459	292	204	70	1185
Sarangkot	1687	337	168	383	1134
Dhikurpokhari	1970	394	419	138	1412
Total	**8218**	**1643**	**1515**	**1425**	**5275**
Percentage			**18**	**17**	**65**

Source: VDC Profile 2065

4.4 Land-use and Morphology

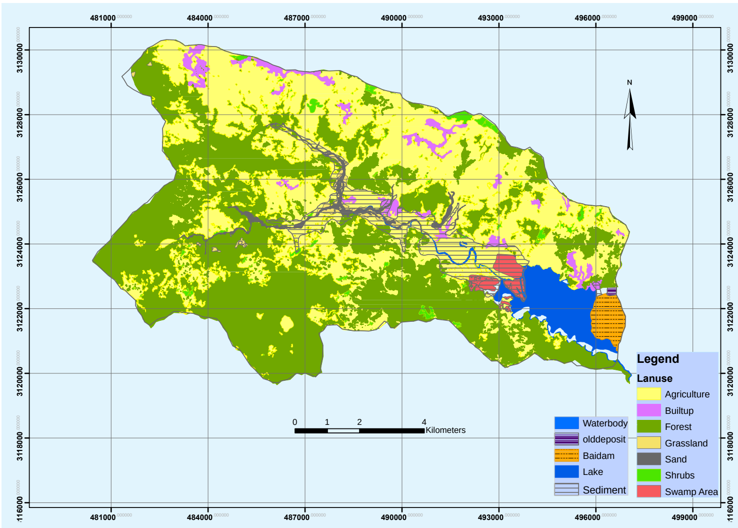
Land-use pattern of Phewa Lake watershed area discloses that the highest portion of the land i.e. 44.32% is covered by the forested area (Figure 8); total agricultural land coverage is less than 40%. Urban land constitutes about 5%, about 123 sq. km.

In addition, the waterbeds or lake and the rivers occupy about 6 percent of the entire watershed area (UNDP/CBDRMP, 2012).

Phewa lake watershed lies in the Mahabharat Range and is situated in the western part of Pokhara valley, Kaski district. The rugged topography comprises of several folds of steeping hills and tropical to temperate climate and vegetation.

Nine percent of the watershed area is too steep (above 60% slope) and needs perennial vegetation, while 55% of the area has slopes of 30-60% that need intensive care for human use. The average slope of Harpan Khola and its tributaries range from 5% in the valley to 35% in Marse Khola. Such natural conditions are a major cause of watershed degradation. The south facing slope of watershed are comparatively gentler (around 30-50%) than the north facing slope (>50%). The land-use change in the past decades indicates that the increase in forest area is due to successful practice of Community Forestry Program (Table 5).

FIGURE 9: **LAND-USE MAP OF PHEWA WATERSHED (SOURCES CBDRMP-UNDP)**



The slope and internal relief of the watershed varies at different locations; the river valley is flat with an average width of 0.75 kilometer and length of 9.8 kilometers, elongated east to west while the slope of the terrain increases at the upper part of the hill. The maximum slope of the hilly terrain is about 70 degree.

TABLE 5: LAND-USE TYPE AND CHANGE (1995-2010)

Land-use Type	1995		2010	
	Hectare	%	Hectare	%
Agricultural	5831.19	48.6	5339.08	44.5
Forest	4724.19	39.4	5279.4	44.0
Bush/Barren land	239.31	2	122.04	1
Water body	557.64	4.7	493.37	4.1
Wetland	13.29	1.1	87.12	0.7
Grassland	132.66	1.1	25.83	0.2
Sandy land	204.75	1.7	110.88	0.9
Built-up area	166.5	1.4	531.81	4.4
Total	**11989.53**	**100**	**11989.53**	**100**

Source: Hariyo Ban, 2013

5 HYDROLOGICAL ANALYSIS

The objective of the hydrological analysis was to understand the mean monthly flow of Harpan Khola and other streams directly related to yield sediment.

A regression equation popularly used for mean monthly flow estimation for un-gauged rivers of Nepal was used for further analysis. The regression equation developed by Water and Energy Commission Secretariat (WECS) was used to understand the mean monthly inflow and outflow of the lake.

Precipitation and hydrological data available from Department of Hydrology and Meteorology (DHM) was used for the hydrological analysis. There were no climatic and hydrological station established within the Phewa watershed and in the main stream feeding Phewa Lake within the course of the study.

5.1 Climate and General Hydrology

Pokhara valley experiences humid sub-tropical climate. Mean temperature ranges from 12°C in winter to 30°C in summer (CBDRMP/UNDP 2012). The rainfall pattern is monsoonal, with 85% of the total rainfall occurring during June to September. The average annual precipitation of Pokhara valley is 3,875 mm and altitude varies from the 827m at Pokhara airport to 2517m at the peak of the Panchase hill. The table below presents the minimum and maximum temperature and precipitation patterns observed in the valley.

Analysis of precipitation data shows an increase in the number of dry days and a corresponding decrease in the number of wet days; however, the annual average precipitation has remained the same. This means that the rainfall is more intensive within a shorter timeframe. Shorter duration storm rainfall usually increases surface runoff. The accumulated runoff over the steep and fragile lithology starts forming rills and gullies. Bank under-cutting and toe-cutting are some of the common phenomena observed in the field all resulting from a high surface runoff. This process will end only when the slope collapses completely, generating a significant amount of sediment flow towards the valley. The following figure (Figure 9) presents the general trend of mean monthly precipitation summarized from the daily records over the last 30 year period (1982-2012) at six stations that have been taken into consideration.

FIGURE 10: DAILY AVERAGE RAINFALL OF THE STATIONS SURROUNDING PHEWA WATERSHED

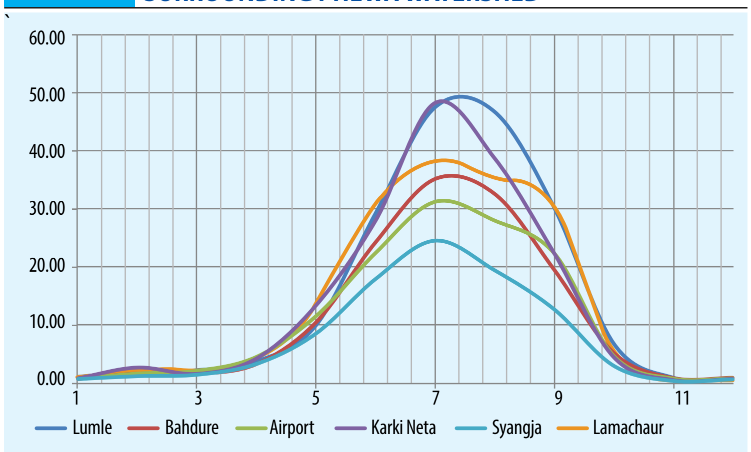


TABLE 6: CLIMATE PARAMETER OF THE WATERSHED

S. N.	Particulars		2006/7	2007/8	2008/9	2009/10	2010/11
1	Temperature (Celsius)	Max.	30.9 (June)	30.5 (June)	31.5 (June)	32 (June)	30.9 (June)
		Min.	7.1 (Jan)	7.6 (Jan)	8.5 (Jan)	7.6 (Jan)	5.6 (Jan)
2	Rainfall (mm)	Max.	616.1(June)	1186.2 (Sept)	1208.5 (Aug)	1026.2 (Aug)	NA
		Min.	NA	1.6 (Feb)	NA	NA	NA

Sources: UNDP/CBDRMP, 2012

The mean monthly precipitation was also analyzed to understand how the annual precipitation varies over time period. The maximum precipitation recorded in Pokhara Airport was 6,877 mm and in Lumle was 6,561.40 mm, whereas the minimum precipitation recorded in the same stations were 4,972.1 mm and 4,162.4 mm, respectively. The variation in maximum and minimum precipitation in Pokhara Airport is 28% and 37% at Lumle. Variation in the maximum and minimum precipitation is as high as 56% in Bhaudare Deurali station, suggesting that the rainfall pattern has been highly variable over the years. The figure below presents the generalized trend of precipitation over the last 30 years.

An attempt was made to understand the precipitation trend over the past 30 years, which indicates that the number of wet days have been decreasing over the period in all stations except Karki Neta, which shows the opposite trend.

Furthermore, to understand the rainfall-runoff-sediment, precipitation data were classified as 1) wet season rainy days and 2) dry season rainy days. For this purpose, five months of the year from June to October has been considered as wet months in which 85% of rainfall occurrs. Analysis of the data also indicates that the total number of wet days have also decreased, leaving the mean monthly precipitation about the same. The trend also gives a clear indication of storm precipitation over the short period of time. The figure above (Figure 9 & 10) represents the monsoonal trend of precipitation.

5.2 River System and Morphology

Several tributaries like Adhari Khola, Mahabir Khola, Betani Khola, Sidane Khola, Lauruk, and Bamdi Khola feed into the Harpan Khola which, in turn, feeds the Phewa Lake. The streams are dendritic (Figure 12) in nature and highly influenced by the tectonic activity such that the

FIGURE 11: ANNUAL PRECIPITATION TREND OVER PHEWA WATERSHED & SURROUNDINGS

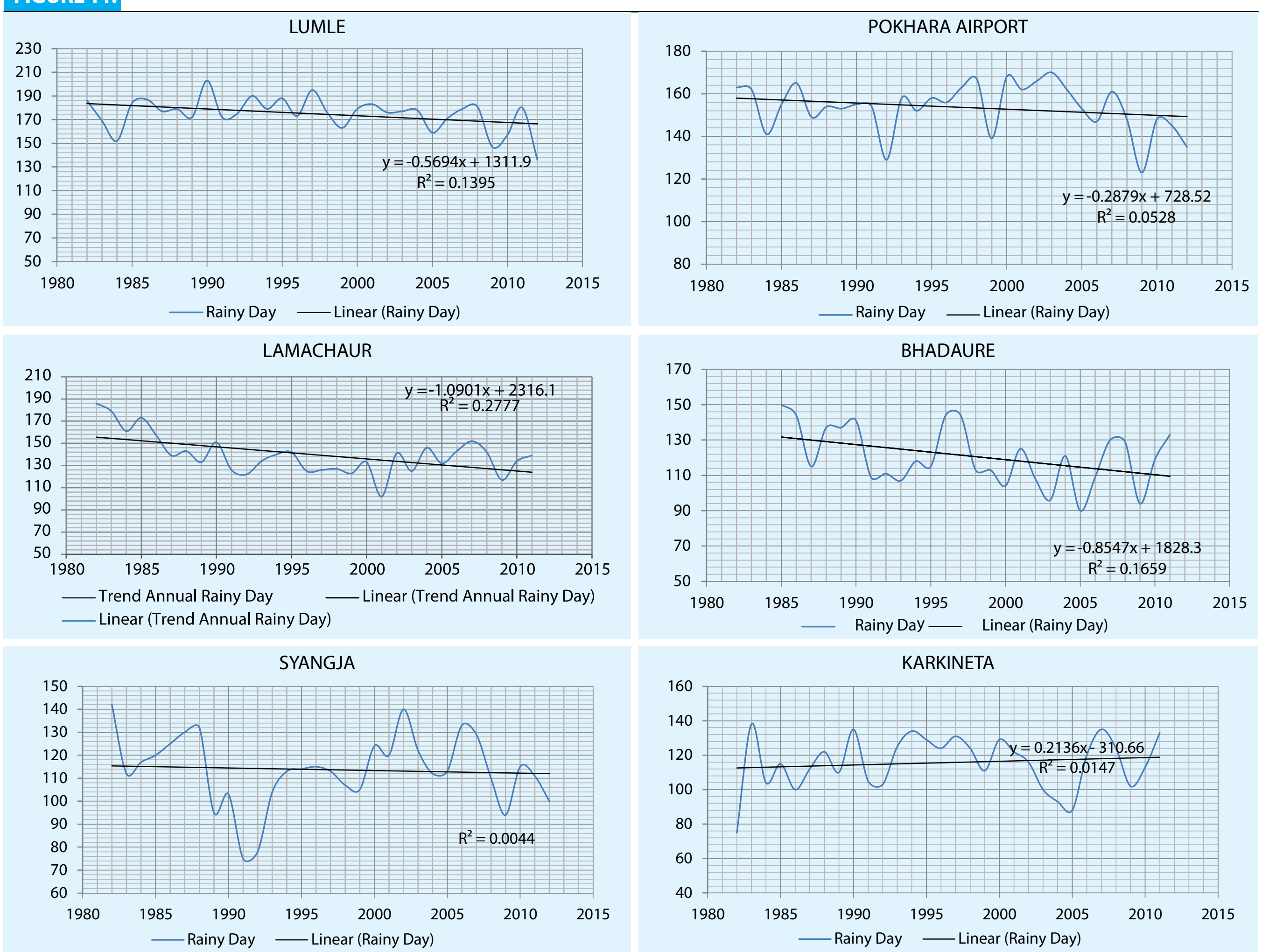
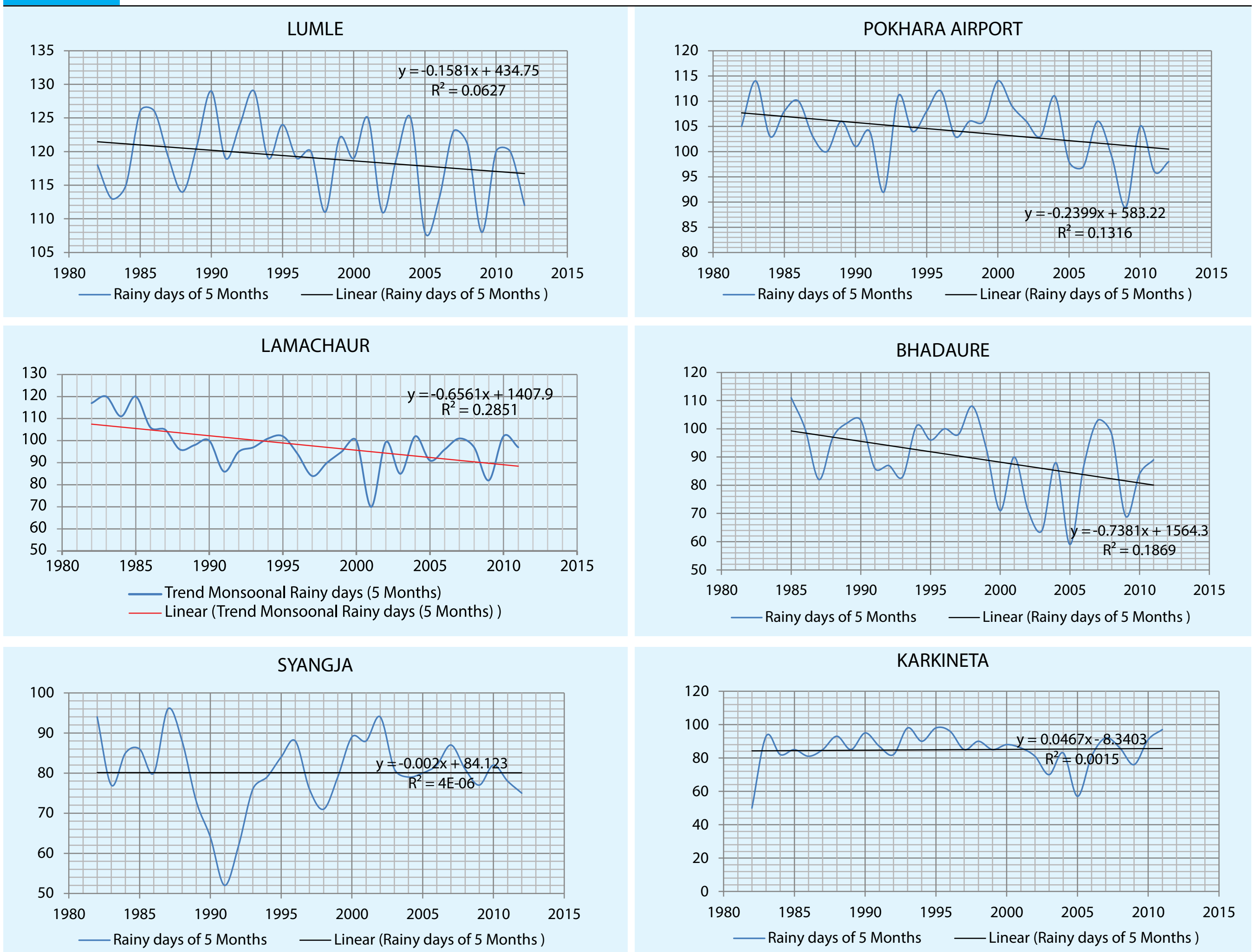


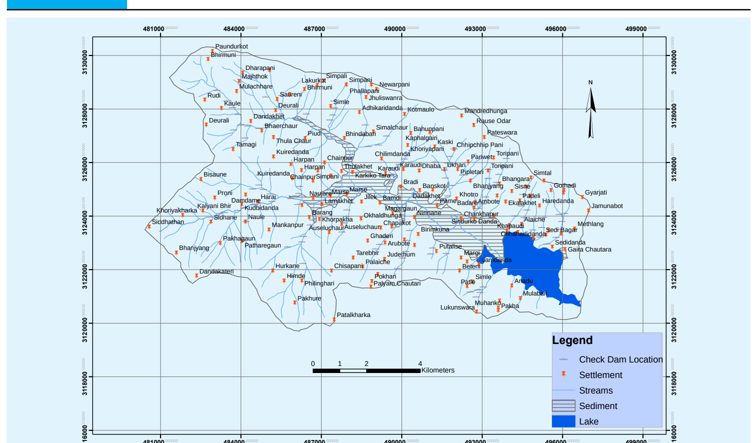
FIGURE 12: MONSOONAL TRENDS OF PRECIPITATION



drainage lines are incised forming deep gullies and gorges in the upper reaches of the watershed. The anticline, which runs through the lake and the Harpan Khola valley up to Ghatichhina, is clearly visible. Similarly, such anticline passes through Adheri, Sidhane, Lauruk and Beteni Khola as well. Harpan Khola valley is active in fluvial process as many of the fans are forming due to the sediments deposited under the fluvial process in the past and seems to be a continued part of the land forming process. The stream system was also analyzed in Geographic Information System (GIS) environment using the DEM generated by 20 meter contour lines and found that the stream order varies from 1 to 6 according to the Strahler (Strahler A.N. 1957).

The streams are highly energetic in the upper reaches of the hill slope where the gradient is

FIGURE 13: DRAINAGE SYSTEM(SOURCES CBDRMP-UNDP)



high (>70%) and these streams can carry anything on its course. The steep hill slope, consisting mostly of deposited colluviums, is highly fragile during intensive monsoonal rain. Soil depth in the watershed as observed over the road cut section and landslide area indicates that it varies from 0 to 10 m. The average depth of soil is 1.5 m.

Majority of the drainage is seasonal and dry almost 65% of the year. Average gradient of the streams were calculated in GIS environment using the DEM and found to be 10% counting from the origin to the inlet of the lake; however, this value is very conservative, especially if the streams are analyzed in different sectors. In the up-stream sector above the Harpan Khola Valley, the gradient of the streams are found to be >70% in some sections. The gradient decreases as Harpan Khola moves towards the lake. The average width of the river is 30m from the confluence of Harpan Khola at Ghatichhina to the lake inlet. The length and slope of the river are given in the table below.

TABLE 7: RIVER PROFILE DETAILS

SN	River	From	To	Gradient
1	Sidhane Khola	Panchase	Ghatichhina	30%
2	Mahabir Khola	Panchase	Ghatichhina	25%
3	Adheri Khola	Lumle	Khahare khola	16%
4	Harpan Khola	Ghatichhina	Phewa inlet	0.50%

5.3 Basin Hydrology

The source of the water for Phewa Lake is mostly surface water through the streams. There are two ways for the streams to feed into the Phewa Lake: 1) directly draining into the lake and 2) draining into the Harpan Khola then the lake. The Harpan Khola contributes to about 70% of the total inflow. The basin Harpan Khola at the point where it enters into the lake is about 83km2, about 67.4% of the total watershed. Phirke Khola, Chisapani Khola, Mulabari Khola and Sedi are mostly seasonal and feed directly into the lake. The major outflows from the lake occurs at Pardi Dam which diverts the water for irrigation purposes and the hydropower plant.

The nearest hydrological stations were used to develop a Thissen Polygon Model to understand the precipitation while the mean monthly flow of the major streams were derived accordingly. Meteorological data of those stations were collected from the Department of Hydrology and Meteorology (DHM) and analyzed. The stations closer to the Pardi dam showed a greater amounts of precipitation in the watershed. The data gives an idea of precipitation trends over a period of time and in different locations. The highest precipitation has been observed in Lumle (Index 814) of Kaski district, which is closest to the Phewa watershed. The altitude of Lumle gauging station is 1740 (amsl), and is located in the highest altitude that has major contribution in the Phewa watershed precipitation as seen in the Thession Model.

Thiessen Polygon Models have been developed for 1) the Harpan Khola basin at the point where it enters into the lake and 2) the whole watershed. The first option models the impacts of precipitation over the Harpan basin whereas the second model is used to understand the contribution of precipitation at each station. Six stations established before 1992 were taken into consideration for the modeling process as listed in the following table.

5.3.1 MEAN MONTHLY FLOW PREDICTION

The WECS model of mean monthly flow prediction demands 1) drainage areas below 5000 meter and 3000 meters and 2) Monsoonal Wetness Index. This model also considers snow contribution as it makes use of the altitude between 3000 and 5000 meters while predicting the mean monthly flow of a particular basin. The results of the hydrology of the streams under consideration are presented in the Annex- Hydrology. The drainage basin area and the monsoonal wetness index collected from the weather station at three locations are shown below:

FIGURE 14: METEOROLOGICAL STATIONS SURROUNDING PHEWA BASIN

S. N.	Station name	Index No.	Type of station	District	Elv. meter	Years of data	Starting From
1	Pokhara Airport	0804	Aeronatical	Kaski	827	31	1982
2	Lumle	0814	Agrometeorology	Kaski	1740	31	1982
3	Bhadaure Deurali	0813	Precipitation	Kaski	1600	27	1985
4	Lamachaur	0818	Precipitation	Kaski	1070	30	1982
5	Karkineta	0613	Precipitation	Parbat	1720	30	1982
6	Syangja	0805	Climatology	Syangia	868	31	1982
7	Kusma	0613	Climatology	Parbat	891	31	1982

1. Location: Ghatichhina of Harpan Khola
Drainage basin Area: 30.124 km^2
Basin Area Below 5000m: 30.124 km^2
Basin Area Below 3000m: 30.124 km^2
Monsoon Wetness Index at Basin Centroid: 2500

2. Location : Khahare Khola at Kerabari
Drainage basin Area: 21.283 km^2
Basin Area Below 5000m: 21.283 km^2
Basin Area Below 3000m: 21.283 km^2
Monsoon Wetness Index at Basin Centroid: 2500

3. Location: Harpan Khola at Downside of Pame bazaar
Drainage basin Area: 86.89 km^2
Basin Area Below 5000m: 86.89 km^2
Basin Area Below 3000m: 86.89 km^2
Monsoon Wetness Index at Basin Centroid: 2500

Computation of Stream flow for Sub Catchment
There is a temporary gauging station at the outlet of Harpan Khola, which has a catchment area of 86.89km^2. The available average monthly precipitation at the hydrological stations at the sub-basin and outlet of Harpan Khola, which observed the flow of the river, was computed. The flow at the sub-basin can be computed by using Catchment Area Method, because the climate impacts the drainage as both are occurring on the same basin.

Catchment Area Ratio Method (CAR)
The flow in the sub-basin has been established by catchment area ratio method with the same river flowing in the larger basin. The empirical model used for the analysis is as below:

$$Q_1 = \frac{P_1}{P_2} \times \frac{A_1}{A_2} \times Q_2 \quad , \quad \text{Where}$$

P=Average annual Precipitation (mm)
A= Basin Area (km^2)
Q= River Discharge (m^3/s)
CAR Factor= $(P_1/P_2) \times (A_1/A_2)$

The CAR factors were calculated on monthly basis by average monthly precipitation of the meteorological stations for each sub-basin based on the area covered by each station on the catchment as shown in the Table 8. The table below presents results of CAR analysis.

TABLE 8: CAR GENERATED MEAN MONTHLY FLOW OF HARPAN KHOLA AT GHATTICHINA

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AVE (m^3/s)	0.36	0.23	0.31	0.28	0.41	1.78	7.62	4.61	4.88	1.07	0.91	0.82

TABLE 9: CAR GENERATED MEAN MONTHLY FLOW FOR KHAHARE KHOLA AT KERABARI

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AVE (m^3/s)	0.25	0.17	0.22	0.19	0.29	1.26	5.39	3.26	3.45	0.75	0.64	0.58

Comparing the mean monthly flow predicted from WECS/DHM and observed data of 1983/84 of JICA at the outlet of Harpan Khola and correlating it with the desired location using Catchment Area Ration (CAR) method the hydrograph looks fairly comparable however CAR is unable to model sufficiently in the month of July and August.

The reason behind could be due the precipitation in the year 1983/84 was higher than the other years. Since, the basin is ungauged and discharge

FIGURE 15: COMPARISON OF FLOW AT HARPAN KHOLA AT OUTLET

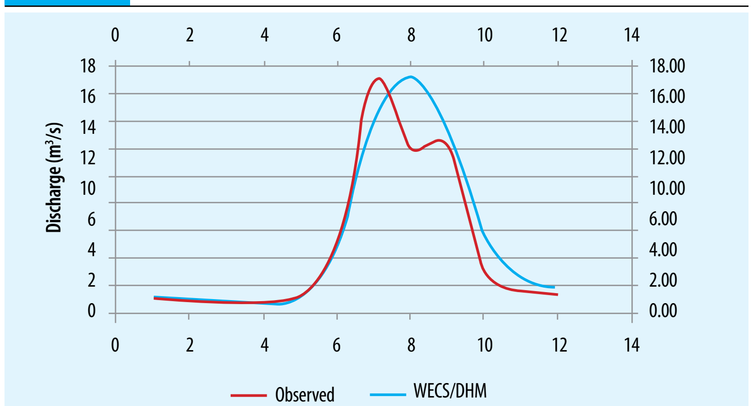


FIGURE 16: COMPARISON OF FLOW FOR HARPAN KHOLA AT GHATICHHINA

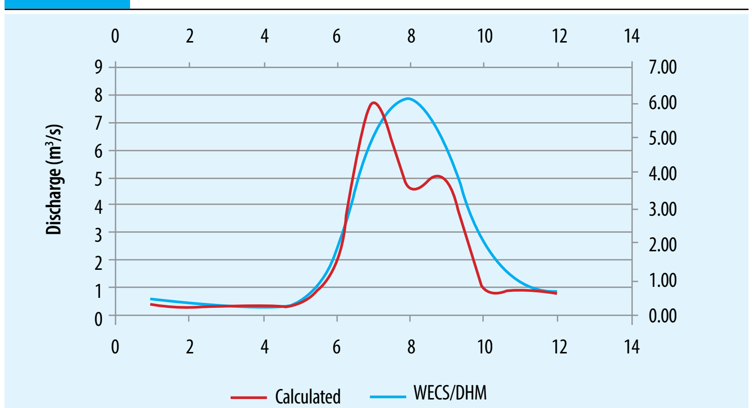
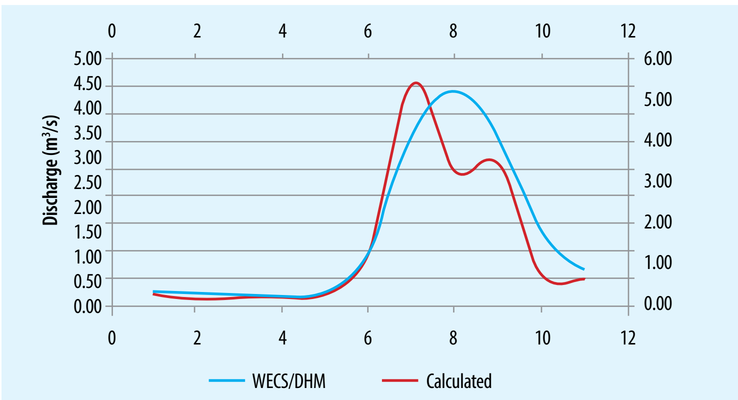


FIGURE 17: COMPARISON OF FLOW FOR KHAHARE KHOLA AT KERABARI



measurement at the outlet of the Harpan Khola is only for two years, there is not enough data to model the flow of the stream for long term time series data. Thus, WECS/DHM information was used to estimate the sediment accumulation at the watershed.

5.4 Sediment Accumulation Analysis

Sediment at the watershed is available in the form of suspended particles and bed load. Since the study period is short and there is no provision of direct sediment sampling from the river, formulas are used in determining the volume of sediment accumulated in each sub-basin at the dam location.

Meyer-Peter and Muller formula is widely used for sediment transport model for determining the bed load of the river with few basic input data. The basic formula for Meyer-Peter and Muller formula is:

$$q_{sb} = 8\sqrt{\Delta g D_m^3}\ \sqrt{(\mu\theta - 0.047)^3}$$

where, q_{st}= sediment transport per unit with of river

Δ = relative density of sediment

g= acceleration due to gravity

D_m= mean sediment diameter (m)

$$\mu = \sqrt{\left(\frac{C}{C_{90}}\right)^3} = \text{bed form factor}$$

$$\theta = \frac{u^2}{C^2 \Delta D_m} = \text{Shield parameter}$$

C= Chezy coefficient ($m^{1/2}/s$)

C_{90}= grain size related Chezy coefficient ($m^{1/2}/s$)

u = Normal flow velocity (m/s)

$$C_{90} = 18 log_{10} \frac{12h}{D_{90}}$$

h = normal depth of flow (m)

0.047 is the value of θ at initiation of motion according to M-P and M, if $\mu\theta\Delta < 0.047$, q_{st}=0

The following condition should be satisfied to validate M-P and M formula for sediment transport

$$\frac{\omega_s}{u_*} > 1$$

Where, ωs= fall velocity of sediment corresponding to Dm (m/s)

$$u_* = \frac{u \sqrt{g}}{C} \text{ X} = \text{shear velocity (m/s)}$$

Dm > 0.4mm

$\mu\theta\Delta < 0.2$

5.4.1 SEDIMENT BUDGET FOR HARPAN KHOLA AT GHATICHHINA

The total sediment budget for all the sub-watershed inside the Phewa basin were calculated from June to October when the flow in the stream was maximum (Figures 10-12). The basic input data for the sediment budget calculation from Meyer-Peter and Muller Formula are shown in the following table.

TABLE 10: DATA USED FOR SEDIMENT BUDGET CALCULATION - HARPAN AT GHATICHHINA

Items	Quantity	Unit
Flow	19.44	m^3/s
River width (B)	26	M
Mean Sediment Dia (D_m)	53	Mm
D90	100	Mm
Relative Density of Sediment (Δ)	1.7	
Overall Chezy Coefficient (C)	25	$m^{1/2}/s$
River Slope (i)	0.017	
Fall velocity of average sediment (ω_s)	1.1	m/s

The total sediment budget obtained for five months from June to October, as calculated from M-P and M, is 86,521.77 m^3.

5.4.2 SEDIMENT BUDGET FOR KHAHARE KHOLA AT KERABARI

The total sediment budget for Khahare Khola sub-watershed inside the Phewa basin was calculated from June to October when the flow is maximum. The basic input data for the sediment budget calculation from M-P and M are shown in the table below:

TABLE 11: DATA USED FOR SEDIMENT BUDGET CALCULATION - KHAHARE

Item	Quantity	Unit
Flow	13.92	m_3/s
River width (B)	45	m
Mean Sediment Dia (D_m)	7	mm
D_{90}	11	mm
Relative Density of Sediment (Δ)	1.7	
Overall Chezy Coefficient (C)	25	$m^{1/2}/s$
River Slope (i)	0.012	
Fall velocity of average sediment (ω_s)	0.51	m/s

The total sediment budget obtained for five months from June to October as calculated from M-P and M is 149,145.16 m^3.

5.4.3 SEDIMENT BUDGET FOR HARPAN KHOLA AT PAME

The total sediment budget for Harpan Khola watershed inside the Phewa basin is calculated from June to October when the flow in the river is maximum. The basic input data for the sediment budget calculation from M-P and M are as shown in the table.

TABLE 12: DATA USED FOR SEDIMENT BUDGET CALCULATION- HARPAN AT PAME

Item	Quantity	Unit
Flow	54.82	m^3/s
River width (B)	26	m
Mean Sediment Dia (D_m)	4.5	mm
D_{90}	11	mm
Relative Density of Sediment (Δ)	1.7	
Overall Chezy Coefficient (C)	40	$m^{1/2}/s$
River Slope (i)	0.00125	
Fall velocity of average sediment (ω_s)	0.56	m/s

The total sediment budget for five months from June to October, as calculated from M-P and M, is 73,999.70 m^3.

Observation of sediment budget and grain size analysis gives clear picture of sediment at Khahare, Kerabari and Harpan, Ghatichhina. Coarser sediments are found at Kerabari and Ghatichhina as compared to Harpan at Pame. As the streams flow towards the lake the river become less energetic and coarse sediment leaves behind and finer particles flow with the water. This is also proves that the study carried by Sthapit and Baila (1998) saying that accumulation of fine sediment is found in the lake bottom. The huge volume of coarse sediment that Kahare Khola brings down to the Kerabari area is deposited here as the stream gradient lowers and the stream become less energetic in the valley. Only finer particles move down-stream, over the valley, as seen in Harpan Khola at Pame, resulting in less total sediment volume.

6 OVERVIEW OF PHEWA WATERSHED

6. WATERSHED MANAGEMENT

In the last few decades it has been clear that degraded watersheds have caused serious problems in the environment and to people, both upstream and downstream (Mountain, 2002; Lal, 1998). Land degradation is, however, a global phenomenon and has affected more than 2 billion ha of land, putting more than 1 billion people at risk (Economic and Social Council UN, 2001).

The repeated pressure of grazing on grasslands in open public lands and shifting cultivation in the mountains beyond its carrying capacity leads to land degradation and damage in the ground vegetation and grassland ecosystems. The heavy grazing pressure in the mountain areas has sped up the process of soil erosion, leading to increased run-off and soil compaction (Figure 17). Cultivation on steep slopes without taking into account improved farming methods and decreased use of organic manures has contributed to increase in soil erosion resulting in high water turbidity. This has led to harmful impacts on aquatic flora and fauna including fish species. Furthermore, development activities such as construction of roads, buildings and dams have added the negative impacts. In Nepal, land and forest resources have been intensively used to meet the basic requirements of food, fuel-wood, fodder, and timber (Neupane and Thapa, 2001).

Phewa watershed ecosystems services have degraded due to significant geological and anthropogenic activities at the basin level. In 1956, the Lake extended up to 10 sq.km of area (WWF, 2013); however, by the end of 1998, the size had decreased dramatically to 4.4 sq.km (JICA, 2002). The study attempted to calculate the lake area using remote sensing imagery (LANDSAT ETM, 2012) and topographical map of 1995 and found that the lake area was 4.2 sq.km. Within a period of 20 years, from 1956 to 76, the size of the lake area was reduced by half. There was a further decrease in the lake area by 1.1 sq.km from 1976 to 1998. The data indicates that there were severe natural events in conjunction with excessive human interventions that caused lake area to shrink. The catastrophic event of 1974 was the cause of the Phewa dam failure (CBDRM/UNDP, 2012). Around the same time, numerous large to small size landslides were mapped by the Department of Mining and Geology, which also included the Bamdi landslide. The figure below (Figure 18) presents the view of Bamdi landslide. Various studies have revealed that the basin is highly exposed to the natural hazards such as landslide, debris flow and soil erosion on the hill slope and sedimentation in the valley bottom. The agriculture-dominated basin and the hilly areas under intensive monsoonal rain, yield excessive sediment from the streams and rivulets.

Fleming (1985) stated that the area of forest and shrub-lands in Phewa basin occupied 28% and 6% of the watershed, while terraced farm-land occupied 46%. The population residing within the watershed was 21,000. In 2006, the populations had increased to 37,000 and accordingly the use of natural resources had also increased, leading to degraded forest resources (Fleming, 2009); however the practices of open grazing was significantly reduced and people started stall-feeding their cattle.

The shift in land and forest management has helped end open grazing (FAO, 1987). By the end of 2004, the area of community managed forests increased to 60% of the total forest area in the basin (Fleming, 2009). Observations in the field, reinforced by satellite imagery, were that the forest and grazing land had not only recovered but improved markedly. The volume of soil loss from open grazing forested land was 8mt/ha/year, which was five to ten times greater than that from natural forest because of grazing activity and intensity of rainfall. The same study found that the soil loss from shrub-land was 15mt/ha/year. The most critical category was grazing land; although grazing land makes up only about 11%, it contributes to about 29% of the total soil loss (Fleming, 1983). The soil loss in grazing land was found to be critical

FIGURE 18: VIEW OF DEGRADED LAND (LEFT) AND SEDIMENTATION IN KAHARE VALLEY (RIGHT)

as it also occurs during landslides and debris flow and takes place in gullies, and sheet and rill erosion prone areas. Fleming (1985) identified soil losses from different land use areas in Phewa Watershed as shown in the table below.

TABLE 13: ESTIMATED ANNUAL SOIL EROSION RATES FROM LAND-USE CATEGORY IN THE PHEWA BASIN

Land-use	Area (ha)	Erosion Rate (mt/ha/year)	Annual soil Loss (t)
Forest	2,935	8	23,480
Shrub Land	1,070	15	23,480
Grazing Land	1,264	34.7	43,860
Terrace Land	5,410	10	54,100
Total	**10,679**		**129,490**

Sources: Fleming (1985)

Similarly, a study carried by the Kaski District Soil Conservation Office (DSCO) in 1994 has shown that the annual soil loss was 175,000 - 225,000 cum, which is 17 cum per hector while the study undertaken by Sthapit and Balla (1998) calculates the annual soil loss of the 94,000 cum (i.e. 12m^3 per hector) at the watershed. Soil loss is a process caused by extreme rainfall events mainly during monsoon season. Analysis of the last 30 years of precipitation data for the same five months of the year (June to October), shows that the period can be considered as the wet season and can cause measurable soil losses. Further, down-scaling the soil loss has meant that the watershed has been divided into three major sub-watersheds 1) Harpan Khola at Ghatichhina, 2) Khahare at Kerabari and 3) Harpan Khola at Pame to understand the volume of soil losses from the sub-watershed. Among the three, Khahare sub-watershed is yielding high sediment with annual yielding of 149,145 cum. The mean annual sediment budget is about 103,222 cum.

Present study has shown that the situation of the watershed has been changing significantly over the period. Forest area including shrub-lands has increased to 49%, 15% more than the forest area in 1985; while the present agriculture land coverage is 43% of the total watershed area (CBDRMP/UNDP, 2012). The increment in forest area means either agricultural land is shrinking or open grasslands that were used for grazing has been converted into forest land. The increased area of forest has positive impact in the physical and biological environment; however abandoned agricultural land in upper reaches of the hill, where maintenances of terraces is lacking, is leading to the formation of gullies.

As discussed earlier, populations in the watershed are found to have decreased, leaving much of the terrace farms abandoned. This has led to the failure of terrace farming and the formation of gullies in many places. Trees and vegetation are slowly growing in such places.

In recent years, it has become apparent that landslides present a far greater hazard, globally, than had been previously assumed, both in terms of economic losses and fatalities (Petley et al. 2005a; Petley, 2006). Landslides and debris flow are the major causes of sedimentation in the valley of Harpan Khola. The phenomenon has increased due to unplanned and un-engineered construction of rural roads around the watershed. Petley (2007) found that the causes for the increase in occurrence and impacts of landslides are poorly quantified, even though a wide range of hypotheses have been proposed, many of which are generally accepted even though there is little empirical evidence to support them. These include:

i. Population growth
ii. Land-use change
iii. Urbanization
iv. Linear infrastructure development and
v. Effect of climate change

The above mentioned hypothesis is not an exact fit for the Phewa basin as the population has decreased (CBS, 2011) and forest area has increased (CBDRMP/UNDP, 2012). The rate of deforestation in Nepal is as high as 1.35% of the forest resources per annum in

FIGURE 19: VIEW OF BAMDI LANDSLIDE 1974 (LEFT) BAMDI AT PRESENT (RIGHT)

FIGURE 20: VIEW OF PHYSICAL DEVELOPMENT (LEFT) HARPAN KHOLA VALLEY (RIGHT)

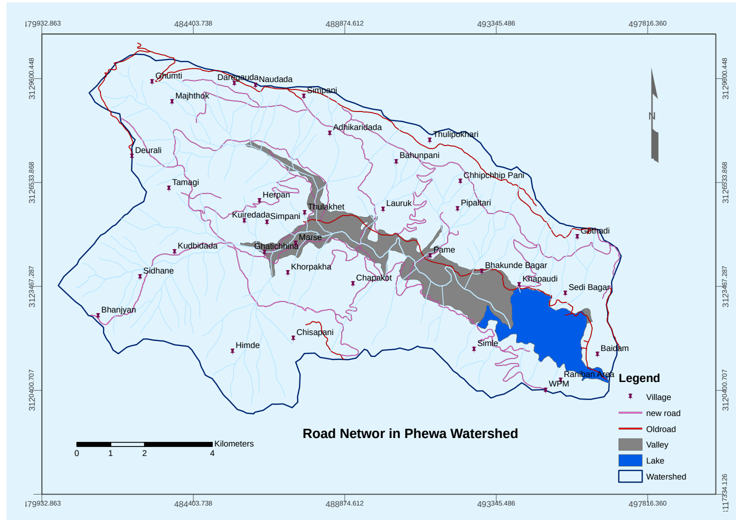
2005 (FAO, 2005); however the rate of deforestation peaked within the period of 1985-1990 and has declined since then in the Phewa basin. Data analysis in various studies concludes that the lake area was greatly influenced during the period when the deforestation was massive.

The effect of urbanization in sediment generation and landslides in Phewa basin is significant as most economic activities are concentrated in the valley. The case of Sarangkot VDC is an exception, where commercial activity is increasing, as the population has been increasing as well (CBS, 2011). Unplanned development of infrastructure such as access roads, commercial housing buildings and recreational centers over steep slope of Sarangkot and in the Harpan Khola valley has been taking place in the recent past. Building hard engineering structures, for example, metallic road surfaces and concrete structures increase the surface runoff down the hill slope. The accumulation of runoff starts forming gullies and could end up causing either landslides or debris flow.

The linear infrastructure which is the rural road has been increasing since 1990. Field study shows that the road construction in the basin after 1995 is about 150 kilometer and the road built before 1995 was 42 kilometer. Construction of many more kilometers of rural roads is still in progress.

Most of the new rural roads are earthen and poorly maintained without road side drainage systems, which leads to soil erosion, gully formation and landslides during the monsoonal climate (Petley, 2007). Unplanned and poorly engineered road construction has been resulting in extensive, large scale landslides along the alignment rather than in an undistrubed system. It would, thus, be a trigger it for failure and would probably result in a landslide in an event of large precipation or earthquake. Thus, it is likely that at least some of the roads constructed in the watershed has substiantial environmental degradation and increased level of risk for years to come. When land is disturbed at a construction site, the erosion rate accelerates dramatically. Since ground cover on an undisturbed site protects the surface, removal of that cover increases the

FIGURE 21: VIEW OF ROAD NETWORK IN PHEWA WATERSHED



site's susceptibility to erosion. Disturbed land may have an erosion rate 1,000 times greater than the pre-construction rate (WES, 2008). Even though construction requires that the land be disturbed and left bare for periods of time, proper planning and use of erosion prevention measures can reduce the impact of human-induced, accelerated erosion. The hypothesis of climate change impacts is connected to landslides and soil losses on the hill slope of Phewa basin where anthropogenic effect is very high. Analysis of the climatic data, mainly, the precipitation and temperature indicates that the number of rainy days has decreased despite the fact that the annual average precipitation remains the same. This means that the intensity of rainfall has increased for a short duration. Intensive rainfall of 25 mm per half an hour (short duration strom) is said to be erossive in tropical climates (Hudson, 1971). Fleming (1985) has confirmed the data from erosion plot measurement in Phewa watershed.

Slope and soil stability are generally considered two most important factors in identifying critical land-use areas (Hudson, 1971). Although many complicated schemes have been suggested for classifying land-use on the basis of various combinations of slope and stability variations, none is particularly suited for a country practicing intensive terrace agriculture and rural road construction on steep slope (Fleming, 1985; Petley, 2007).

FIGURE 22: LAND USE OVERLAID ON SLOPE MAP

Analysis of the slope map, land-use map and recent Remote Sensing Imagery followed by field verification indicates that the hill slope of the watershed varies with fairly high internal relief and narrow valleys. About 10% of the basin is flat to rolling (0-10% slope), 60% has slope of 20% to 60% (averag 40%) and 25% is very steep (60% to 100% slope). The rainfall pattern is monsoonal with 85% of annual total is falling between June and September, often in the form of brief, intense and erosive storms (Fleming, 1985). Analysis of daily rainfall pattern has shown that the rainfall has been decreasing with increased intensity which has caused slope failure and debris flow. The situation has become more pronounced due to poorly engineered rural roads.

7 PROPOSED SEDIMENT CONTROL TECHNIQUES

This study investigated alternative and ecosystem based sediment control techniques. The following three principles were taken into consideration:

i. River bank and gully protection
ii. Slope stabilization
iii. Siltation Dam to trap the sediment on the way to the lake

7.1 River Bank and Gully Protection

Gully and bank under cutting were identified from field surveys during which, its nature and extent were also observed. Land-use, lithology, stream power, precipitation and infrastructure were closely observed in order to understand the major causes for failure. In most cases, bank failure and under cutting are due to one or the combination of the following:

i. Excessive stream power
ii. Fragile lithology/geology
iii. Intense rainfall
iv. Poorly engineered rural road construction over the steep slope
v. No or less priority in protection
vi. Shift in settlement in the valley side
vii. Unmanaged terraces

Attempts have been made to identify the best fit, low-cost, and ecosystem-based mitigation and protection measures that reduces sediment generation from bank failure, shallow landslides and stream under cuttings. Soil bio-engineering together with the simple civil engineering methods are suitable and practical to protect the unstable slopes and banks. The following technique, which depends on the size and type of stream, flow gradient, the extent of bank and toe under cutting, has been recommended.

i. Soil bio-engineering work (e.g. vegetation, live fence, wattling, live check dam, bamboo fencing, etc)
ii. Simple civil engineering work (e. g. dry stone wall, boulder rip-rap, dry stone check dam, gabion check dam, etc.)

The figure below shows the location where slope stabilization is required to reduce the sedimentation process. Altogether 117 locations were identified (see Annex 1), where interventions were required to keep the watershed ecosystem safe.

Stabilization of stream bank and gullies involves the use of appropriate structural and vegetative measures in the head, floor and sides of the stream and gully. Once gullies have begun to form, they must be treated to minimize further damage and restore stability and there are a multitude of physical and biological techniques which can be applied for effective treatment. The combination of the two measures (biophysical approach) is the best solution for effective bank and gully control. The construction of physical structures will be followed by the establishment of biological measures also known as bio-engineering measures. The natural regeneration, which comes after the failure, are protected and enclosed and should also be considered in the overall rehabilitation scheme.

To obtain satisfactory results from physical and

FIGURE 23: PROPOSED LOCATIONS FOR CHECK DAMS, BANK AND LANDSLIDE PROTECTION WORKS.

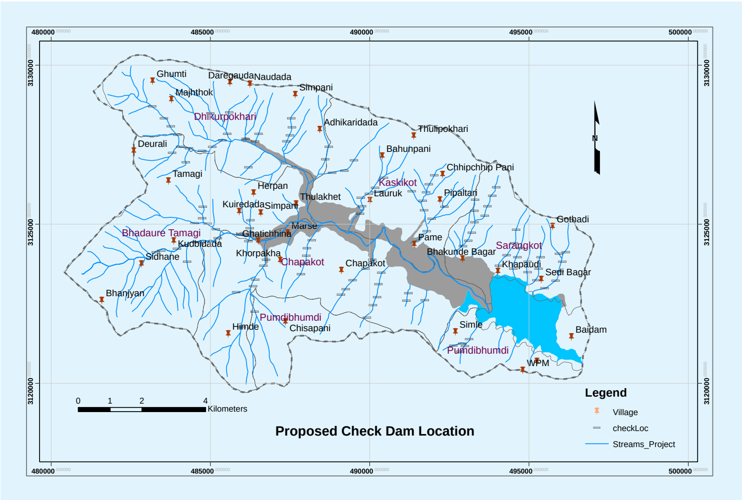
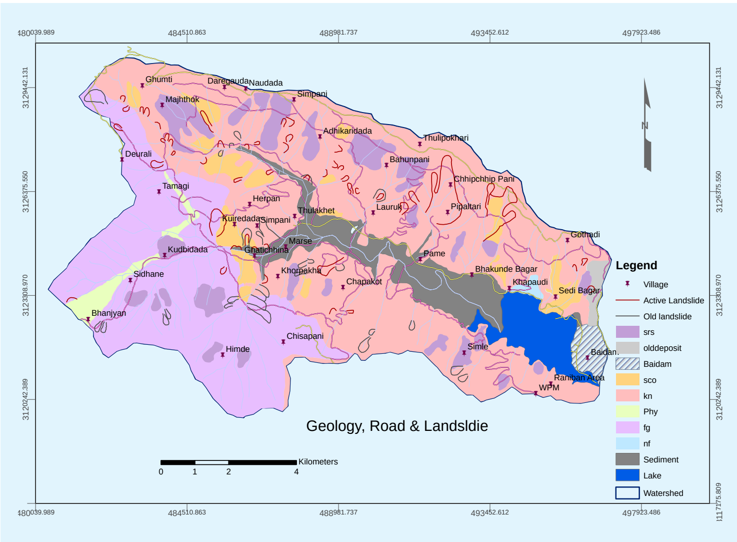


FIGURE 24: LANDSLIDE AND PROPOSED DAM LOCATION



biological measures, it is vital to understand the nature of the whole gully system/network and properly diagnose the different parts in the bank and gully section for example bed, gully sidewall and offset. Overall, stabilized watershed slopes are the best assurance for the continued functioning of the control structures. Therefore, attention must always be given to keep the catchment well vegetated. If this fails, the biophysical gully controls measures which will fail as well.

7.2 Landslide and Slope Protection

A landslide, also known as a landslip, is a geological phenomenon and a land forming process which includes a wide range of ground movements, such as rock falls, deep and shallow slope failure, and debris flow. Although gravity is the primary driving force for a landslide to occur, there are other contributing factors for example precipitation, human activities etc. that affect the original slope stability. Typically, pre-conditional factors build up specific sub-surface conditions that make the area or slope prone to failure, whereas the actual landslide often requires a triggering factor before being released.

The study has given ample information and identified active, dormant and passive landslides within the Phewa Watershed. Figure 24 presents the location of landslides observed during the field assessment (also see Annex 2). The nature of the slope failure in Phewa Watershed is highly influenced by geology, surface flow and land-use. In the recent years, it has been highly affected by anthropogenic activities such as rural road construction. History shows that the north facing slope (south of the lake) is more unstable as many old landslide scarp are noticed; however more active and frequent slope failures have been observed in south facing slope in the recent past.

Study has shown that majority of the slope failure can be mitigated applying simple civil engineering techniques for example 1) check dams, 2) toe wall and 3) drainage management, combined with the soil bio-engineering. However there are still some areas with complex landslides which need conventional engineering structures and detailed investigation of underlying causes for the landslides.

7.3 Eco-friendly Siltation Dam

Sedimentation is one of the major causes of Lake Ecosystem degradation and reduction in Phewa Lake's area. Ecosystem based approach has been followed in building siltation dam as discussed in the following section.

Rock fill dam has been proposed and designed to accumulate sediment entering into the valley and lake. Keeping the general requirement in view two locations, Harpan Khola at Ghatichhina and Khahare Khola at Kerabari, have been identified as sites for construction of siltation dams. The dam type is selected based on the availability of boulder material and its effect in the vicinity of the location. The dam proposed here is distinct from typical rock fill dam in the sense that no impermeable core is provided in the dam making the water in the upstream pass downstream without overtopping the crest of the dam. The size of boulders used for building the dam is between 0.6-1 meters in diameter.

The principal behind the design of such type of dam is to trap the sediment that is bigger than the small gaps between the rocks/boulders to allow finer sediment to pass through those gaps. The gaps, however, will be blocked after some time. The finer materials will be retained in the proposed downstream settling pool of the Harpan Khola near Pame.

The levee constructed needs to be the same height as the bank in order to accumulate sediments and control the flood water to prevent spillover. In time, gaps and voids inside the rock fill dam will be filled preventing seepages. The deposit in the dam i.e. rocks, sand, and gravel has to be removed annually (preferably after monsoon) to ensure maximum efficiency for next monsoon. The construction of levee shall use the local materials and excavated earth from the stream bed. The levee will be protected from scoring with the application of gabion mat and vegetation.

Based on the expert knowledge, empirical calculation and field observation following three location has been proposed for construction of the siltation dam as marked in figure below.

i. Harpan Khola at Ghatichhina
ii. Khahare Khola at Kerabari and
iii. Siltation pond at the straight reach near the suspension bridge at Pame

The purpose of the siltation dam is to collect the sediments from up-stream hill drainage and streams. While making the proposal for the siltation dam following factors have been taken into consideration:

i. River gradient
ii. Space availability
iii. Length of the dam axis (narrow width for shorter dam length)

7.3.1 SILTATION DAM AT HARPAN KHOLA NEAR GHATICHHINA

The location is fairly wide and flat in nature. The stream gradient is less than 1%, which is found to be suitable for the construction of siltation dam (Figure 24). The land occupied by the dam is mostly flood plain and public land.

The model used for siltation dam design is data driven and empirical. The table below presents the parameter used for the design of the siltation dam in Harpan Khola at the downside of Ghatichhina.

FIGURE 25: PROPOSED SILTATION DAM LOCATION

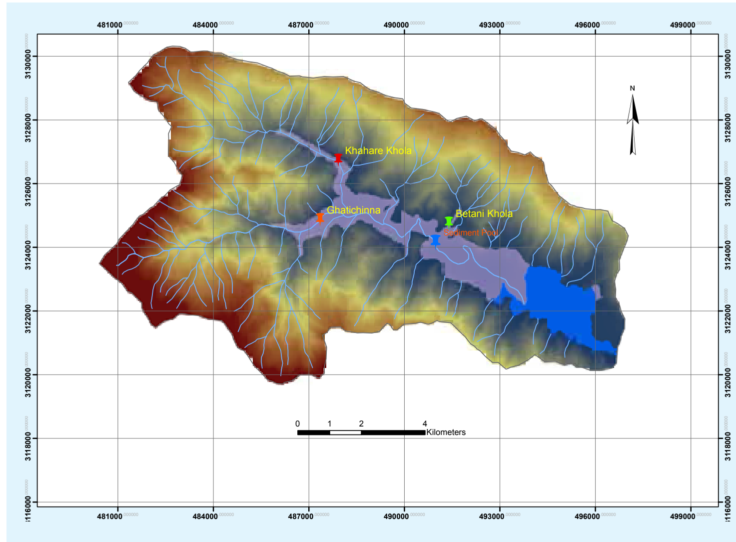


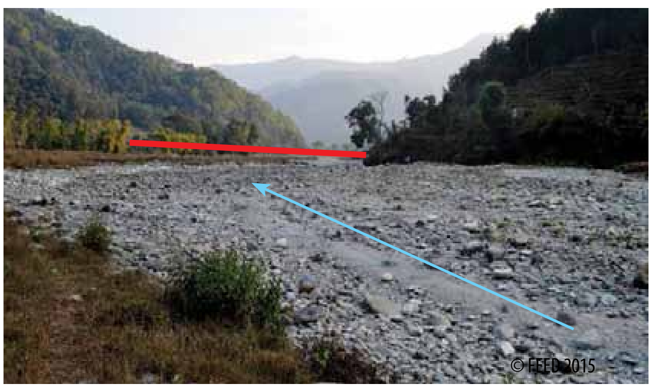
TABLE 14: DATA USED FOR SILTATION DAM IN HARPAN KHOLA AT D/S OF GHATICHHINA

Items	Amount	Unit
Top width(a)	0.5	m
Top Height (Ht)	0.5	m
Height of Dam above GL (H)	3.5	m
Bottom Width (B)	8.9	M
Depth of foundation (D)	0.5	M
U/S Slope (H:1)	1.2	
D/S Slope (H:1)	1.2	
Specific Gravity (Sc)	2.4	
unit weight of water	10	kN/m^3
Unit weight of Boulder	22	kN/m^3
Width of River (L crest)	60	M
Coefficient of Discharge (Cd)	1.7	
Flood (Q 100)	182	m^3/s
Height of water above crest (HCr)	1.47	m^3/s

Based on calculations, as shown in the table above, the safety factor was 2 and the dam is safe against sliding and overturning. The height of rock fill dam is 4m above ground level and 8.9m at base. The proposed location is fairly flat in morphology and the river gradient is less than 0.5%. The proposed siltation dam is of 7,787 sqm in area and can retain 24,140 cum of sediment.

FIGURE 26: PROPOSED SILTATION DAM LOCATION AT GHATICHHINA

FIGURE 27: PROPOSED SILTATION DAM LOCATION AT KHAHARE KHOLA OPTION 1 (LEFT) AND OPTION 2 (RIGHT)



7.3.2 SILTATION DAM AT KHAHARE KHOLA NEAR KERABARI

The chosen location is wide enough and full of sediments deposited in the past. There is negligible difference in elevation between the farm lands on either side of the streams which means that levees need to be constructed on either sides of the proposed dam axis. Two alternatives were identified and studied applying the basic parameters (c.f. Table 15). The dam is proposed to trap fairly coarse sediments.

The table below presents the data used for the dam design.

TABLE 15: DATA USED FOR SILTATION DAM DESIGN IN KHAHARE KHOLA AT KERABARI

Description of Structure	Amount	Unit
Top width(a)	0.5	M
Top Height (H_t)	0.5	M
Height of Dam above GL (H)	2.6	M
Bottom Width (B)	6.74	M
Depth of foundation (D)	0.5	M
U/S Slope (H:1)	1.2	
D/S Slope (H:1)	1.2	
Specific Gravity (S_c)	2.4	

Description of Structure	Amount	Unit
unit weight of water	10	KN/m³
Unit weight of Boulder	22	KN/m³
Width of River (L crest)	110	M
Coefficient of Discharge (C_d)	1.7	
Flood (Q 100)	142	m³/s
Height of water above crest (H_{Cr})	0.83	m³/s

Based on the calculation from the input data shown in the above table, the dam is safe against sliding and overturning as the safety factor were 2.51 and 2.24, respectively. The height of rock fill dam is 3.1m above ground and 6.74m at base. The recommended dam will be of 39,727 sqm in area and can retain 143,812 cum of the sediments. The dam should be cleared after every monsoon to trap the sediments in next year.

7.3.3 SETTLING POOL AT HARPAN KHOLA NEAR PAME

Sediment found at Harpan Khola near Pame is fine with average grain size of 4.5mm. Building a Siltation dam at this location is not feasible as it inundates a vast area of cultivated land because of its topography. A modest, practical and feasible method is to trap fine sediments in the Harpan Khola near Pame with construction of a settling basin (siltation pool) in the river course without disturbing the natural course of the stream (Figure 27).

This is a very important location to trap fine sediment in the Harpan Khola as the sediment filling up Phewa Lake is mostly clay and fine particles (Fleming 1985). About 300m section of Harpan Khola is widened to 60m and depth increased to 3m from the present level of the river bed to maintain the water level. Fine sediment passing through this stretch gets settled and is dredged periodically after monsoon.

FIGURE 28: PROPOSED LOCATION FOR SETTLING POOL AT HARPAN KHOLA

FIGURE 29: GENERAL VIEW OF BETENI KHOLA AND LOCATION OF CHECK DAMS

TABLE 16: DATA USED FOR SILTATION DAM DESIGN IN HARPAN KHOLA D/S OF PAME

Particulars	Quantity	Unit
Design discharge	54.82	m^3/s
Design capacity of basin	54.82	m^3/s
Discharge	54.82	m^3/s
Critical sediment grain size	0.70	mm
Density of sand	2.65	ton/m^3
Dynamic viscosity of fluid	1.307	$(N\ s/m^2) \times 10^{-3}$
Trap efficiency	90%	
Chosen width per basin	60.00	m

Based on the Vetters empirical model, the section of the siltation pool[2] that was 300m was trapping sediments with a 100% efficiency when the settling zone depth was 2.1m and sediment collection depth was 3m. The accumulated sediment that is trapped from June to September shall be removed soon after every monsoon is over. The proposed settling pool can retain mostly fine sediments of about 54,234 cum and will be of 18,078 sqm in surface area.

7.3.4 BETINI KHOLA CHECK DAMS

The stream has high gradient and is dry for almost 8 months of the year. During monsoon, the stream yields flash flood causing undercutting, bank failure and produce significant amount of sediments. The upper reaches of the hill slope contains shallow soil to bed rock. Field observations indicate that most of the regolith materials over the slope have moved down towards the toe-side of the hill slope. The deposited loose earth materials were reworked in the presence of water during monsoon season.

Four check dams have been proposed to protect the stream from under cutting and bank protection (left bank) work has been recommended to protect the bank failure during monsoon.

[2] Vetter, 1940

8 FIELD VERIFICATION & CONSULTATION

Natural and anthropogenic activities are the main causes of the slope failure in the watershed and thus, are the sources of sediments in the valley of Harpan Khola, leading to sedimentation in the lake. This study indicates that much of the old unstable slopes have either become stable or are in dormant position. However, many shallow type slope failures are found along newly constructed rural roads, for example formation of gully in the middle hill slope and alluvium fans in the valley sides, which are common phenomenon observed in the field. Analysis of climate data, mainly precipitation of the region, has given a clear picture of the decreasing trend of annual wet days while the mean annual precipitation remains the same. This means that the intensity of rainfall is increasing. Increased rainfall intensity is also a reason for shallow and road side slope failures.

Sediment sampling and grain size analysis of major sources were carried out to understand and verify the sediment volume. The analysis results differed from the results mentioned in the previous study carried out by DSCO Kaski. The annual sediment generation is decreasing. The probable reason behind this decrease is increased forest area and reduced open grazing. The transportation of sediment depends on the stream energy and grain size. The sediment analysis indicated that the coarse grain sediment is found in the upper reaches of the confluences of Harpan Khola and its tributaries; finer sediments are found in lower reaches i.e. closer to the Phewa Lake.

Some recent study reports discussed the increment in forest area which is due to the tree and vegetation growth in abandoned barren lands and the reduction in open grazing practices by the Community Forest Users Groups (CFUG).

The study team consulted with local communities to understand the past phenomena and the changes in land-use and livelihood as well as infrastructure development over the period. Three approaches were applied as a part of the consultation: 1) one on one interviews, 2) group discussions and 3) consultations among local communities and stakeholders. Their concerns and suggestions were documented. Local people also informed the study team about the possibility of a siltation dam construction and its benefit in order to protect Phewa Lake as well as the physical and biological environment of the watershed.

Participants in the interaction were optimistic about the mitigation measures and were ready to contribute to the watershed conservation mission. Population in the watershed reported that the monsoonal rain is more intensive but that the number of rainy days has decreased along with the surface flow of water, which was also observed in daily precipitation data analysis. According to the data and local populations, the monsoonal rain is more intensive and may cause flash floods in the valley and shallow slope failures in the upper reaches of the hills. The un-engineered rural road constructions further help in the accumulation surface flow of water leading to sheet, rill and gully erosion. Ultimately, the slopes become unstable and collapse. Unplanned construction and haphazard disposal of excavated earth materials can easily flow with the monsoonal rain to the valley and lake.

The Harpan Khola valley is under immense pressure as many construction activities, mainly housing, is ongoing. Excavation of hillock, filling of the low lands, plotting, etc were observed. Discussions with the local population show that they realized that unplanned developed activities would further harm the physical and biological environment of the area.

While various studies have shown that the forest area has increased in Phewa Watershed, many abandoned lands have also been observed leading to terrace failure, gully formation, and spread of invasive species. In some cases, too much vegetation

FIGURE 30: IMAGES OF PUBLIC CONSULTATION

has also led to slope failures. Large size trees growing on weak and highly weathered rock slope (e. g. phillite) promote the development of cracks and become unstable. In most cases, the terraces are not well maintained as out-migration of the youth continues to add to the number of abandoned agricultural lands. Rill forming process was also observed in many of the abandoned terraces.

Previously applied protection measures were not well maintained which led to an increase in the number of unstable slopes. Low cost and simple civil engineering structures together with bioengineering works will have greater impact in protecting the slope. During the consultation, local knowledge on bioengineering and vegetation was also identified, which is not in practice as most locals demand gabion cages.

Building houses over steep slopes without considering the safety measure were also noticed. Most dissatisfaction was found along the right shore of the Lake which could be due to the degradation of physical and biological environment of the watershed as well as the lake ecosystem.

9 CONCLUSION AND RECOMMENDATIONS

9.1 Conclusions

The field assessment has given a general picture of the basin - the causes of sedimentation and potential hazard area that has to be mitigated. The northern slope however seems more problematic but the southern slope is also important and needs protection. The streams draining directly into the lake from the southern slope should also be protected.

Landslides and slope instability are common in the middle hills – it is a natural land forming process; however, human activities have increased the frequency of slope failures. Geologically, the watershed is weak and fragile and requires a proper plan and engineering for any development work. Most of the development activities, especially rural road constructions, have not been well-planned and the road has been excavated without considering the potential hazards of slope failure and sedimentation in the downstream.

- Geologically, majority of the watershed area comprises of Kuncha Formation and Fagfog Quartzite of Central Nepal Lesser Himalaya. The northern hills slope (south facing slope) of Phewa Lake around Kaskikot, Sarangkot and Dhikurpokhari VDC is geologically fragile and phyllites of Kuncha Formation are most likely to fail during the monsoon, the main factor contributing to sedimentation in the lake. North facing slope seem stable compared to the south facing slope, however, there were also many shallow and deep sheeted landslides and slope failure events even in the North facing slope, for example, Bamdi landslide.
- The southern section of Phewa Lake, Raniban and Panchase area seem relatively stable, however, increased human activities in the area may have severe effects on slope stability.
- Increasing population in the Harpan Khola valley (census 2001 and 2011) is contributing to the sediment generation by excavation of hillock, access roads and use of local resources. The estimated length of the mostly unplanned road is more than 200km with road density of 1.63 km/sq.km. The unplanned road construction with unprotected slopes along the road is creating more problems for sediment generation.
- The relatively short span of the drainage channel is about 12 km long. The intense rainfall that the area receives is the major factor behind an alarming rate of sedimentation in the area. Visual observations of sediment profile over debris fan and measurement of surface area shows that the estimated sediment deposited in Harpan Khola Valley is about 2.78 million cubic meters.
- Trend analysis of daily precipitation over the last 30 years in six stations indicate that the number of rainy days are decreasing but that the annual precipitation remains the same which means that precipitation intensity has increased over the period. This has significant impact over the slope instability, gully formation, toe under cutting due to excessive surface runoff.
- Sediment budget has been estimated based on two assumptions 1) grain size at the particular location analyzed from the sample collected during the field assessment and 2) monsoonal season of five months (June – October). Applying Meyer-Peter and Muller model for sediment transport the estimated sediment at Harpan Khola at Ghatichhina and 2) Kerabari at Khahare is 86,521.77 cum and 149,145.16 cum respectively. Sediment in Harpan Khola, at Pame Bazaar, is found to be much finer compared to the sediments in Khahare at Kerabari and Harpan at Ghatichhina. Due to this the volume is less at about 73,999.7 cum. The soft lithology, high hill slopes and high internal relief, stream energy and human activities are the prime causes of slope failure, sedimentation and natural hazards in the watershed.

- All together 117 locations have been identified for gully and bank protection and 46 locations for slope protection. Retaining wall, check dams, bio-engineering, vegetation, siltation dams and settling pools have been recommended as interventions to protect the slope and the stream banks. These protection works will ultimately reduce the sedimentation in the Harpan Khola valley and the Phewa Lake.
- Rock fill type gravity siltation dams has been proposed for 1) Harpan Khola at Ghatichhina, and 2) Khahare Khola at Kerabari whereas settling pool is recommended for Harpan Khola at Pame bazaar. These structures are ecosystem friendly, simple in construction and low cost. Gabion Check Dams are found to be better alternative for Beteni Khola.
- Implementation of proposed conservation approaches of bioengineering in combination of simple civil engineering structures will significantly reduce sediment load in the downstream, i.e. the Harpan Khola Valley and, ultimately, the Phewa Lake. Construction of siltation dams and settling pools are immediate measures to be carried out to enhance the lake ecosystem, whereas, the overall watershed conservation is the approach that helps protect the lake, infrastructures and the watershed ecosystem. Bamdi landslide in Chapakot is an example of ecosystem based protection measures that has to be reflected in other part of the watershed.

9.2 Recommendations

- Construction and human activities in the northern hill around Sarangkot, Kaskikot and Dhikurpokhari should be checked and proper plans have to be made to stabilize the hill slopes. There is more road construction in the south facing slope than the north facing slope. Mandatory provision of roadside bio-engineering and drainage system has to be developed and implemented to protect the slope from failure, resulting in sedimentation in the valley.
- Reduction in the run off time of the water in the stream and provision of energy dissipater is necessary. The best way to increase the elapsed time is to obstruct the natural flow by means of artificial check dams, retaining structures, and vegetation and siltation dams. Potential location for check dams have been identified and recommended for further investigation. So far ideal siltation dams' locations were identified at 1) Harpan Khola in Ghatichhina, 2) Kerabari in Kahhare Khola and 3) Harpan Khola just downstream of Pame. The dams are proposed based on the sediment budget and it is expected that the dams will retain 90% of total sediment. The dams will also need to be cleared after monsoon each year to ensure maximum efficiency in next monsoon.
- Gabion check dams are proposed for Beteni Khola in order to stop the reworking of debris mass deposited over the period in the valley side. The gabion check dams should be further reinforced by vegetation (e. g. bamboo, vetivar, etc).
- There were some limitations observed during the study; limited or no data of the stream discharge has affected the study significantly. Keeping the limitations in view, it is recommended that a hydrological station be established to measure and record the Harpan Khola discharge in regular hourly basis. The simple method of Pizometer with computer added software can record real time discharge data of the stream. Furthermore, sediment carrying capacity of the streams and how the sediment generation is reducing after implementing the mitigation measures has to be investigated regularly in order to estimate the life of the lake and to understand the ecosystem of the watershed.
- The watershed is about 123 sq.km in area and very popular because of Phewa Lake; however, there is not a single precipitation gauging station inside the watershed. The data used for discharge analysis are from outside the watershed. From the available data, Lumle station influenced majority area which might not be the case as it is in a different part of the slope (Modi Khola watershed). The data from the Deurali precipitation station on top of the Deurali hill is not well maintained. Looking at the possibility of influencing the analysis from the precipitation station location, it is recommended that a few more stations be established inside the watershed that can record real time precipitation data.
- The problem of toe under cutting and bank failure are to be protected by building check dams (stone, gabion or live fence) and applying soil bioengineering method. The proposed check dam location aims to protect from excessive toe cutting and slope failure which need to be investigated in detail before implementation.

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ANNEX

Annex 1: Location for gully and river bank protection

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
1	Dhikurpokharai-8	83	49.7121	28	16.5516	Live Fence, wattling and vegitation
2	Dhikurpokharai-8	83	49.9347	28	16.34358	Live Fence, wattling and vegetation
3	Dhikurpokharai-8	83	50.06568	28	16.2048	boulder riprap, toe protection
4	Dhikurpokharai-8	83	50.1966	28	16.06608	boulder rip rap, tor protection
5	Dhikurpokharai-8	83	50.24922	28	15.85782	Dry stone check dam
6	Bhadaure Tamaghi-3	83	50.0925	28	15.75348	Dry stone check dam
7	Bhadaure Tamaghi-4	83	50.35422	28	15.59172	Small low heigh gabion check dam
8	Dhikurpokharai-8	83	50.4192	28	15.83484	Small/low height gabion check dam
9	Dhikurpokharai-8	83	50.66766	28	15.78888	Low heigh gabion check dam
10	Dhikurpokharai-9	83	50.86368	28	15.85854	dry stone and gabion check dam
11	Dhikurpokharai-9	83	51.05958	28	15.97446	Gabion and dry stone check dam
12	Dhikurpokharai-9	83	51.15096	28	16.07874	Gabion check dam and drainage managment
13	Dhikurpokharai-9	83	51.18966	28	16.44918	Gabin check dam with vegetation on eitehr side of the stream
14	Dhikurpokharai-3	83	50.82366	28	16.4256	Gabion check dam with vegetation on eitehr side of the stream bank
15	Dhikurpokharai-3	83	51.50406	28	15.9981	Gabion check dam with fast growing vegetation
16	Dhikurpokharai-3	83	51.75234	28	16.0794	Gabion check dam with fast grawing vegetation
17	Dhikurpokharai-3	83	51.68718	28	15.95202	Gabion check dam with bamboo plantation
18	Dhikurpokharai-2	83	51.55698	28	15.51204	boulder rip rap

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
19	Dhikurpokharai-2	83	52.2885	28	15.95256	Boulder riprap with vegetation
20	Dhikurpokharai-2	83	52.35378	28	16.05678	boulder riprap with vegetation
21	Dhikurpokharai-2	83	52.39284	28	16.19574	gabion check dam with bomboo plantation
22	Kaskikot-1	83	52.37958	28	16.34616	dry stone wall with fast grawing vegetation
23	Kaskikot-1	83	53.03406	28	15.65232	gabion check dam with the bamboo plantation
24	Kaskikot-1	83	53.09916	28	15.8607	Gabion check dam with the bamboo plantation
25	Kaskikot-3	83	53.16498	28	15.42096	Boulder riprap with fast grawing plant species
26	Kaskikot-2	83	53.4003	28	15.45588	Gabion check dam with bamboo plantation
27	Kaskikot-4	83	53.58312	28	15.62964	Gabion check dam with bamboo plantation
28	Kaskikot-4	83	54.15858	28	15.34068	Gabion check dam with the bamboo plantation
29	Kaskikot-4	83	53.98878	28	15.16698	Gabion check dam, drainage managment and bamboo plantation
30	Kaskikot-4	83	54.08034	28	15.09756	Gabion check dam, drainage managment with bamboo plantation
31	Kaskikot-4	83	53.87124	28	15.0627	Gabion check dam, bamboo plantation and drainagement managment
32	Kaskikot-9	83	53.71446	28	14.99316	restainment of exisitng gabion check dam and bamboo plantation
33	Kaskikot-7/8	83	53.74074	28	14.85426	Fairly large gabion check dam w, open stream channel
34	Kaskikot-7/8	83	53.70168	28	14.72694	fairly large gabion check dam, open stream channel
35	Kaskikot-7/8	83	54.69474	28	15.10956	Live fence, wattling, vegetation
36	Kaskikot-7/8	83	55.1259	28	15.37602	Live fence, wattling, vegetation
37	Kaskikot-7/8	83	55.02144	28	15.22554	Live fence, wattling, vegetation
38	Kaskikot-7/8	83	54.96924	28	15.08658	Clear stream channel, Gabion check dam and bamboo plantation

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
39	Kaskikot-7/8	83	54.90402	28	14.94768	Clear stream channel, gabion check dam and bamboo plantation
40	Kaskikot-7/8	83	54.9303	28	14.78562	Clear stream channel, Gabion check dam and embankment
41	Kaskikot-6	83	55.07418	28	14.63526	Clear stream channel, Gabion check dam, embankment
42	Kaskikot-6	83	54.98286	28	14.42688	Clear stream channel, Gabion check dam and embankment
43	Sarangkot- 5	83	55.32234	28	14.84376	Clear stream channle, Gabion check dam and embankment
44	Sarangkot- 5	83	55.91046	28	14.9598	Boulder riprap, drainage managment and Vegetation
45	Sarangkot- 5	83	55.89756	28	14.77458	boulder riprap, drainage management, vegetation
46	Sarangkot- 5	83	55.89768	28	14.57784	small gabion check dam, embankment
47	Sarangkot- 4	83	55.84548	28	14.4042	Small gabion check dam, embankment
48	Sarangkot- 4	83	55.7802	28	14.2653	Gabion check dam and clear the channel, bamboo plantation
49	Sarangkot- 4/5	83	55.67574	28	14.17266	Clear channel, boulder riprap and bamboo plantation
50	Sarangkot- 4/5	83	56.31558	28	15.17988	Bamboo fence, wattling, vegetation
51	Sarangkot- 4/5	83	56.23722	28	15.0294	Bamboo fence, wattling, vegetation
52	Sarangkot- 4/6	83	56.14584	28	14.85576	boulder riprap, bamboo fence, vegetation
53	Sarangkot- 2	83	56.09364	28	14.6937	boulder riprap, bamboo fence and vegetation
54	Sarangkot- 2	83	56.69502	28	14.45088	partial boulder riprap and gabion check dam, bamboo plantation
55	Sarangkot- 2	83	56.65596	28	14.2194	make space for flood flow, gabion check dam, bamboo plantation
56	Sarangkot- 2	83	56.51226	28	14.02254	make space for flood flow, gabion check dam and bamboo plantation

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
57	Sarangkot- 2	83	56.36862	28	13.83732	make space for flood flow, gabion check dam, embankment, bamboo plantation
58	Sarangkot- 2	83	56.7867	28	14.1384	make space for flood flow, boulder riprap, bamboo plantation
59	Sarangkot- 2	83	56.72142	28	13.98792	make space for flood flow, gabion check dam, embankment and bamboo
60	Sarangkot- 1	83	56.64312	28	13.79112	make speace for flood flow, boulder riprap, bamboo plantation
61	Sarangkot- 1	83	56.9175	28	13.90698	make space for flood flow, boulder riprap and bamboo plantation
62	Sarangkot- 1	83	56.91756	28	13.7334	make speace for flood flow, embankment and plantation
63	Sarangkot- 1	83	57.16578	28	13.9881	make space for flood flow, embankment and plantation
64	Sarangkot- 7	83	57.12666	28	13.7913	make space for flood flow, embankment, boulder riprap and plantation
65	Sarangkot- 7	83	57.08754	28	13.59456	make space for flood flow, embankment and plantation
66	Sarangkot- 7	83	57.51864	28	14.04606	boulder riprap, clear channel, plantation
67	Sarangkot- 7	83	57.64932	28	14.06928	bouldr riprap, clear channel, and plantation
68	Sarangkot- 7	83	57.58404	28	13.90722	Gabion chekc dam, embankment, bamboo plantation
69	Sarangkot- 7	83	57.53178	28	13.74516	Gabion check dam, embankment and bamboo plantation
70	Sarangkot- 7	83	57.45348	28	13.5831	Gabion check dam, embankment and plantation
71	Bhadaure Tamaghi-8	83	57.24444	28	13.45572	Gabion check dam, embankment and plantation
72	Bhadaure Tamaghi-7	83	49.78146	28	14.06322	Boulder riprap

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
73	Bhadaure Tamaghi-7	83	49.88598	28	14.0865	Boulder riprap
74	Bhadaure Tamaghi-8	83	50.18652	28	14.1216	boulder riprap
75	Bhadaure Tamaghi-9	83	50.33016	28	14.17968	boulder riprap
76	Bhadaure Tamaghi-6	83	50.3829	28	13.90194	Gabion check dam
77	Bhadaure Tamaghi-6	83	50.57844	28	14.23782	Gabion check dam
78	Bhadaure Tamaghi-3	83	50.5257	28	14.56182	Gabion check dam, bamboo plantation
79	Bhadaure Tamaghi-3	83	50.68212	28	14.8398	Gabion check dam, bamboo plantation
80	Bhadaure Tamaghi-3	83	50.66934	28	14.643	Gabion check dam, bamboo plantation
81	Bhadaure Tamaghi-3	83	50.77404	28	14.55054	Gabion check dam, bamboo plantation
82	Bhadaure Tamaghi-3	83	50.931	28	14.45814	Gabion check dam, bamboo plantation
83	Bhadaure Tamaghi-3	83	50.97042	28	14.30772	Gabion check dam, bamboo plantation
84	Bhadaure Tamaghi-3	83	51.40164	28	14.36604	Gabion check dam, bamboo plantation
85	Bhadaure Tamaghi-3	83	51.55866	28	14.25048	Clear drainage line, gabion check dam
86	Bhadaure Tamaghi-3	83	51.58452	28	14.47038	Clear drainage line, gabion check dam
87	Chapakot-8	83	51.59742	28	14.60928	Boulder riprap, bamboo plantation
88	Chapakot-8	83	51.32454	28	13.38216	boulde riprap
89	Pumdibhumdi-8	83	51.4299	28	12.79194	gabion check dam
90	Chapakot-9/7	83	51.67782	28	13.0584	gabion check dam
91	Chapakot-9/7	83	51.65112	28	13.48662	Gabion check dam
92	Chapakot-9/7	83	51.69018	28	13.60242	Gabion check dam
93	Chapakot-9/7	83	51.84672	28	13.83408	Gabion check dam, bamboo plantation
94	Chapakot-8	83	51.89886	28	13.9383	Gabion check dam, bamboo plantation
95	Chapakot-7	83	52.5657	28	13.69584	boulder riprap, dry ston wall

Id	Location	Latitude		Longitude		Measures
		Degree	Minute	Degree	Minute	
96	Chapakot-7/6	83	52.61778	28	13.86954	boulder riprap, dry stone wall
97	Chapakot-7/7	83	52.66986	28	14.00844	bloulder riprap, dry stone wall, plantation
98	Chapakot-6	83	52.68282	28	14.13576	boulder riprap, dry stone wall,plantation
99	Chapakot-5/6	83	52.77414	28	14.27478	Gabion check dam, bamboo plantation
100	Chapakot-7	83	53.33712	28	13.34928	Boulder riprap, dry stone wall for top protection
101	Chapakot-5/3	83	53.4285	28	13.44198	boulder riprap, dry stone wall for top protection
102	Chapakot-3	83	53.559	28	13.59252	Gabion check dam
103	Chapakot-3	83	53.8071	28	13.7895	Gabion check dam
104	Chapakot-3	83	53.93766	28	13.94004	Gabion check dam, bamboo plantation
105	Chapakot-3	83	53.83404	28	12.95616	boulder riprap,
106	Chapakot-3	83	53.95146	28	13.1646	boulder riprap
107	Chapakot-3	83	54.02976	28	13.30356	gabion check dam, dry stone wall for top protection
108	Chapakot-3	83	54.05568	28	13.52346	gabion check dam, dry stone wall for top protection
109	Chapakot-2	83	54.10776	28	13.72026	gabion check dam, drystone wall for toe protection, bamboo plantation
110	Chapakot-2	83	54.59172	28	13.24608	gabion check dam
111	Chapakot-1/2	83	54.63084	28	13.3734	gabion chake dam
112	Pumdibhumdi-5/3	83	54.94452	28	13.25784	gabion chekc dam and vegetation
113	Pumdibhumdi-5/3	83	55.49394	28	12.4827	live fence, with boulder packing
114	Pumdibhumdi-5/3	83	55.62468	28	12.3786	live fence with the boulder packing
115	Pumdibhumdi-5/3	83	55.71606	28	12.47124	LIve fence with boulder packing
116	Pumdibhumdi-5/3	83	55.6638	28	12.5175	live fence with boulder packing
117	Pumdibhumdi-5/3	83	55.79442	28	12.58704	gabion check dam, dry stone wall for top protection

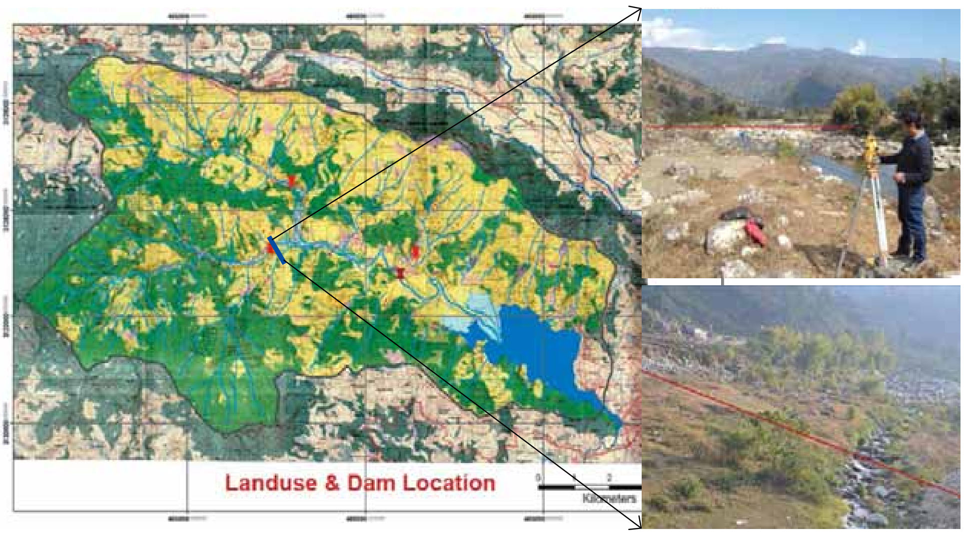
Annex 2: Landslides and slope failure location

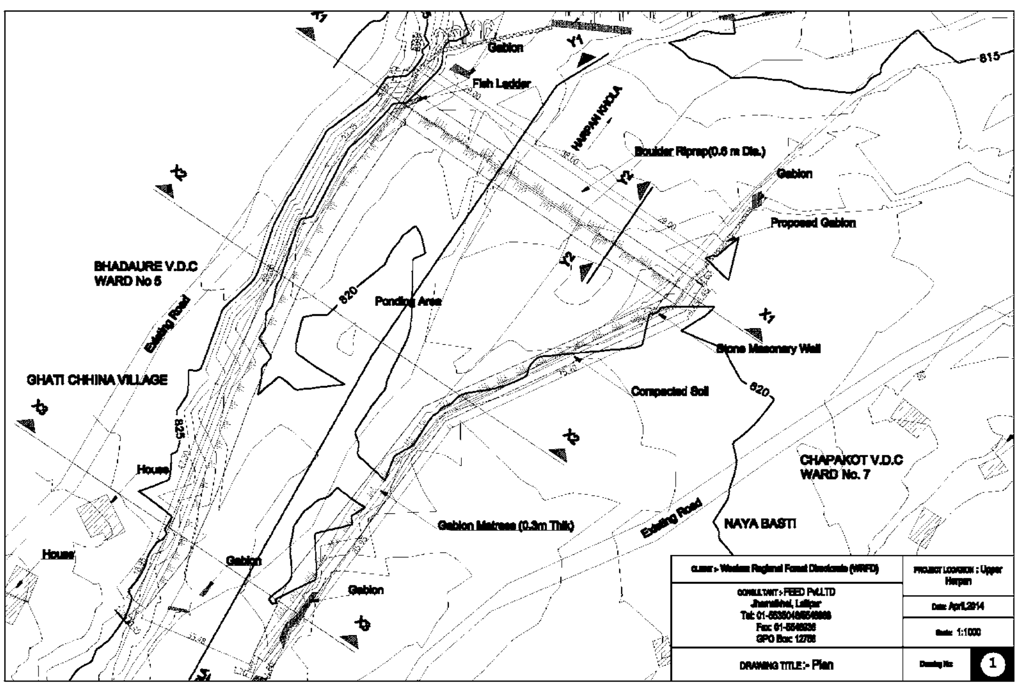
S. No	Landslide	VDC	Northing	Easting	Status	Remarks
1	Menthli Landslide	Sarangkot	496360.64	3123295.695	Active and likely	Soil creeping of the old cllluvium mass
2	Sedibagar	Sarangkot	495712.939	3123467.146	old and Probale	Old scarp, rock slide
3	Haredada	Sarangkot	495744.689	3124291.377	old and passive	Old scarp, rock slide
4	Padeli	Sarangkot/ kaskikot	494582.637	3124469.178	old and passive	Old scarp, rock slide
5	Khapaudi	Kaskikot	494258.786	3123796.076	old and passive	Old scarp, rock slide
6	Badare	Kaskikot	492997.495	3124424.815	old and passive	Old scarp, rock slide
7	Chipchippani	Kaskiot	492121.897	3126226.044	old and passive	Old scarp, rock slide
8	Dadakhet	Kaskiot	491346.368	3124775.054	old and passive	Old scarp, rock slide
9	Lausidhunga	Kaskiot	489063.143	3127633.672	Active	New slide induced by road develop-ment
10	TotneKhola	Dhikurpokhari	488437.716	3127041.601	old and passive	Old scarp, rock slide
11	Bhirmuni	Dhikurpokhari	486484.716	3128048.955	old and Probale	Small old landslide, mud flow
12	Sera	Dhikurpokhari	485183.828	3127615.326	old and Probale	Small old landslide, mud flow from old colluvium mass
13	Thulachaur	Bhadaure-Tamagi	486117.799	3127248.409	old and Probale	Small soil slide induced by river toe cuting
14	Majhthok	Dhikurpokhari	483624.431	3128424.211	old and Probale	Small soil slide induced by river toe cuting
15	Kaule	Dhikurpokhari	48332.599	3128007.26	old and Probale	Small rock slide induced by river toe cuting
16	Adherikhola (A)	Dhikurpokhari	482677.117	3128676.05	old and Probale	Small rock slide induced by river toe cuting

S. No	Landslide	VDC	Northing	Easting	Status	Remarks
17	Adherikhola (B)	Dhikurpokhari	482201.793	3128901.204	old and Probale	Small rock slide induced by river toe cuting
18	Adherikhola (C)	Dhikurpokhari	482168.437	3128467.574	old and Probale	Small rock slide induced by river toe cuting
19	Tamagi	Bhadaure-Tamagi	485020.383	3124791.732	old and passive	Old scarp, rock slide, induced by toe cutting of Mahabhir Khola
20	Simpani	Bhadaure-Tamagi	486538.086	3124958.513	new and probable	A few year old slide , mud slide
21	Hurkane	Chapakot	485345.605	3122491.829	new and probable	Massive Rockslide
22	Philinghari	Chapakot	486287.915	3121516.163	new and probable	Massive Rockslide
23	Kupre Khola	Chapakot	486604.798	3122258.336	new and probable	Massive Rockslide
24	Auseluchaur	Chapakot	487338.632	3123242.341	old and passive	Massive old scarp, the Khorpakha village sits on the colluvium
25	Chapakot	Chapakot	489519.288	3123180.632	old and passive	Small old slide induced probably by toe cutting
26	Bhedikharka	Chapakot	490585.849	3122747.003	old and Probale	Slide probably by deep toe cutting of Birim Khola
27	Bhirpani	Pumdi Bhumdi	492872.41	3120733.962	old and Probale	Slide probably by deep toe cutting of Bhirpani Khola
28	Simle	Pumdi Bhumdi	493214.31	3121359.389	old and Probale	Slide probably by deep toe cutting of Bhirpani Khola
29	Mulabari	Pumdi Bhumdi	494356.756	3120900.743	old and Probale	Slide probably by deep toe cutting of stream

Annex 3: Proposal for Eco-friendly Siltation dam

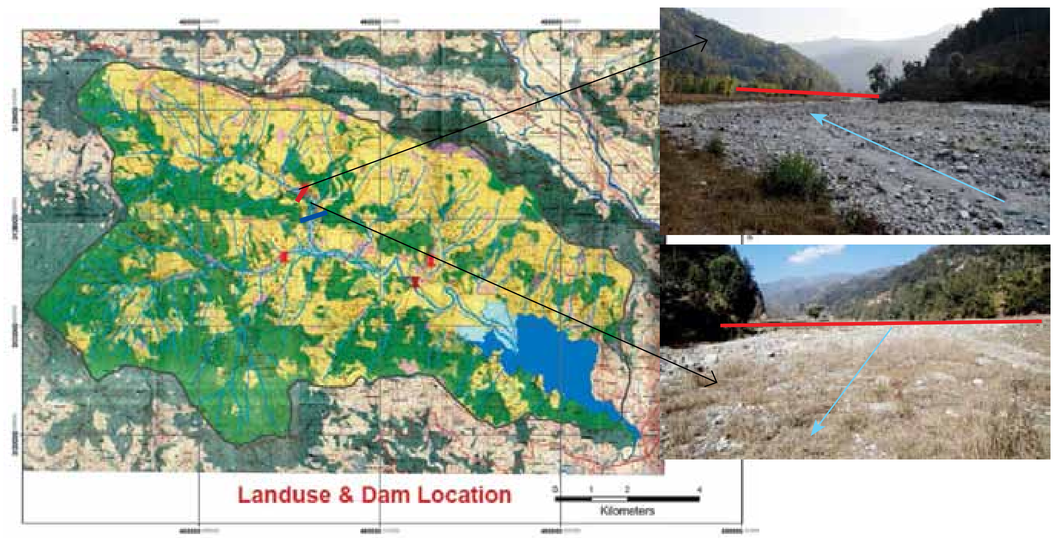
3.1 Ghatichhina land use and dam location with proposed dam sketch



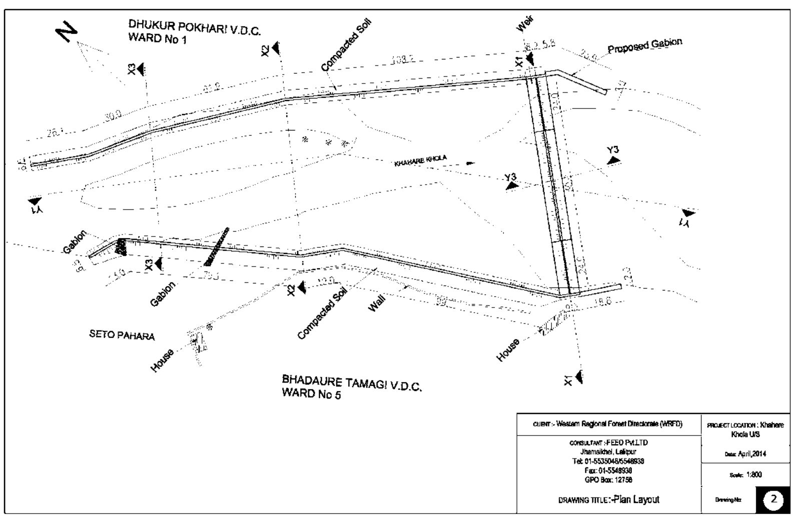


- Earth fill embankment
- Dam Height – 4 meter
- Surface area - 7,787 sq m
- Volume – 24,140 cum
- Rock fill dam – 96 m long

3.2 Khahare land use and dam location with proposed dam sketch

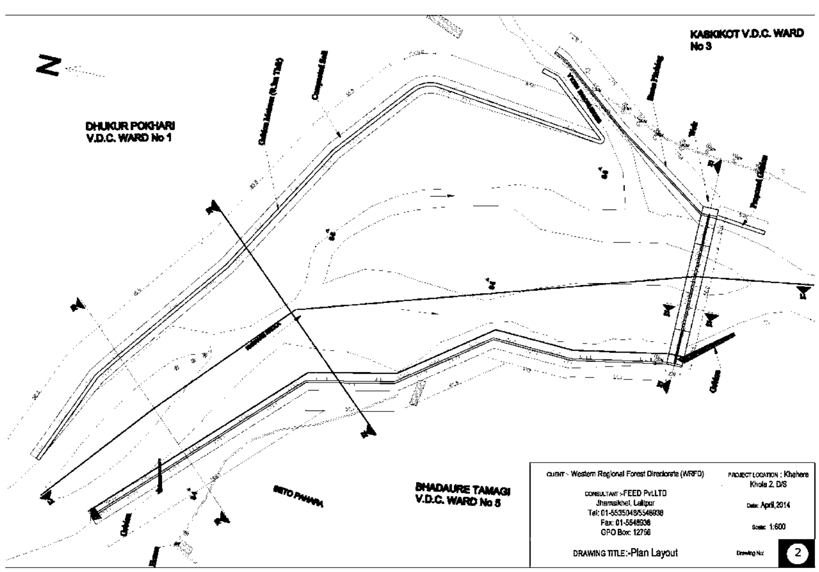


Option 1



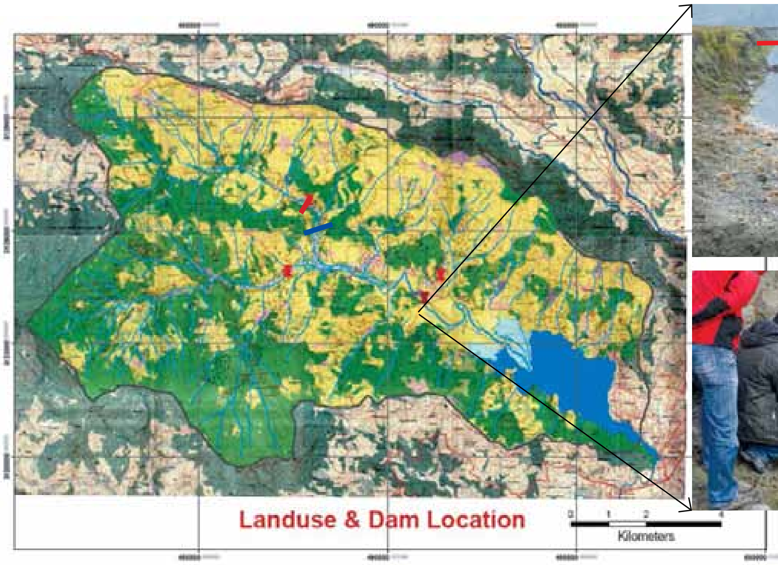
- Earth fill embankment
- Dam Height – 3 meter
- Surface area - 5,580 sq m
- Volume – 33,140 cum
- Rock fill Dam -96 m

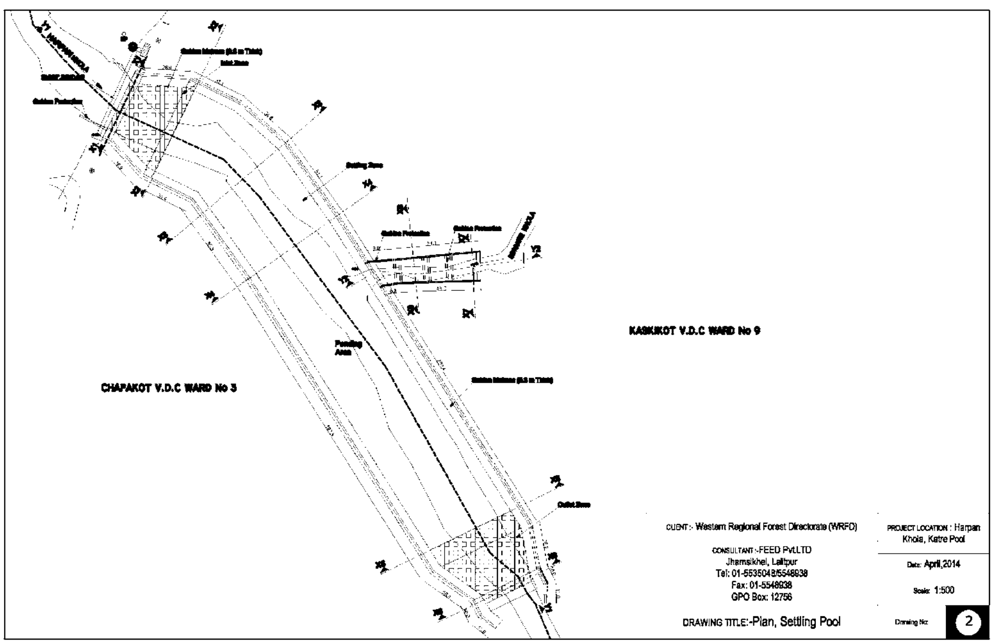
Option 2



- Earth fill embankment
- Dam Height – 3 meter
- Surface area – 39,727 sq m
- Volume – 143,812 cum
- Rock fill Dam – 103 long

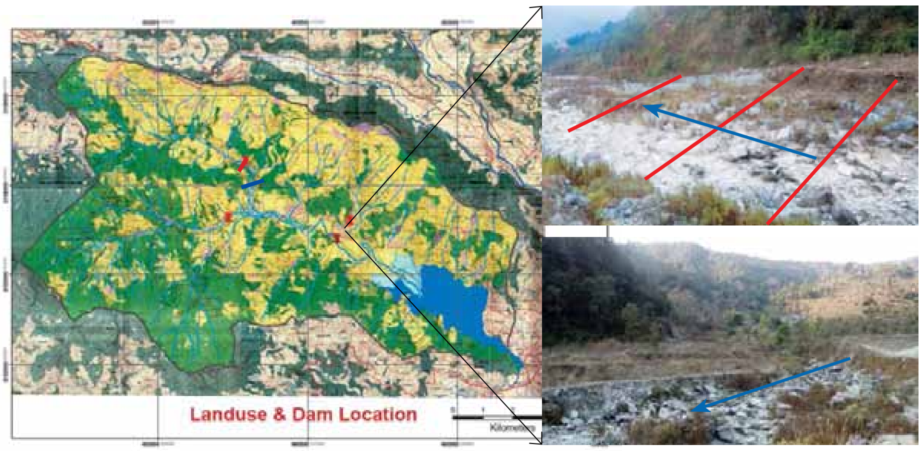
3.3 Harpan (Kavre) land use and dam location with proposed dam sketch

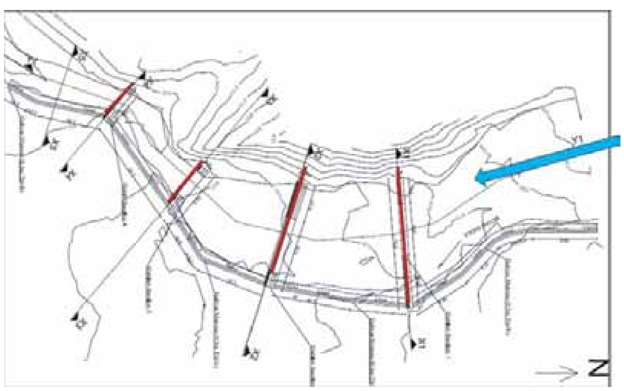




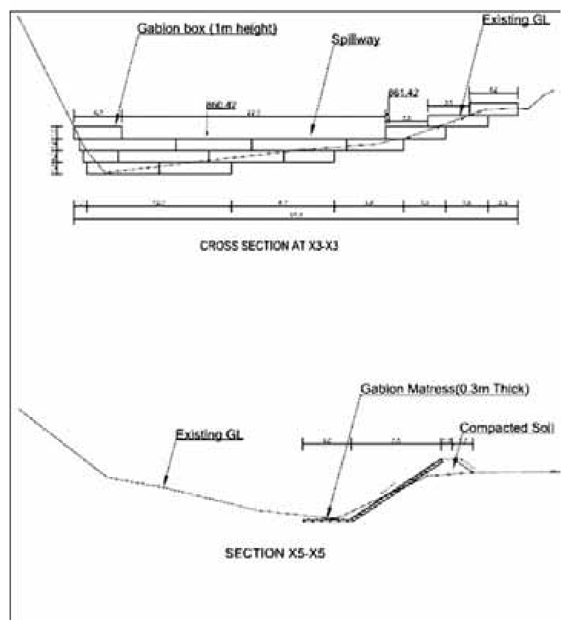
- Earth fill embankment
- Dam Height – 3 meter
- Surface area – 18078 sq m
- Volume – 54243 cum
- Stone masonry anchor – 30 long
- Depth of pool – 3 meter
- Width of Pool – 60 m

3.4 Beteni Khola land use and dam location with proposed dam sketch





- Earth fill with gabion mat embankment
- River gradient – 30%
- Numbers of check dams – 4
- Length is varies (22-75 m)
- Height – Varies (3- 5 m)



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