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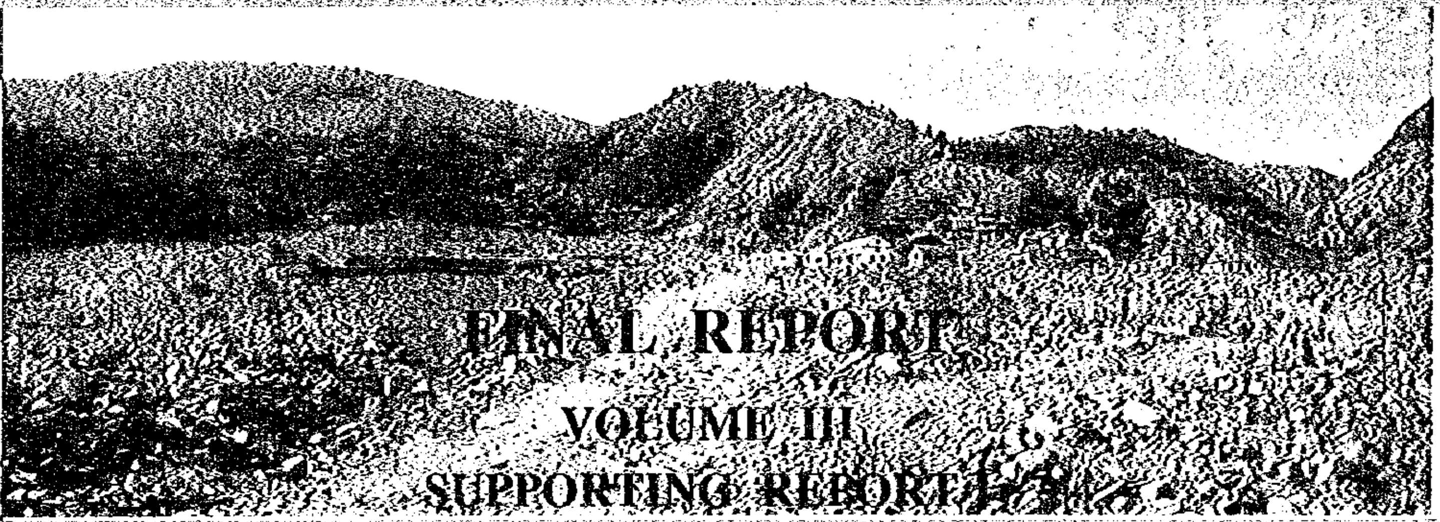
JAPAN INTERNATIONAL COOPERATION AGENCY

DEPARTMENT OF SOIL CONSERVATION
MINISTRY OF FOREST AND SOIL CONSERVATION
HIS MAJESTY'S GOVERNMENT OF NEPAL

THE STUDY ON THE DISASTER PREVENTION PLAN FOR SEVERELY AFFECTED AREAS BY 1993 DISASTER IN THE CENTRAL DEVELOPMENT REGION OF NEPAL



FINAL REPORT

VOLUME III

SUPPORTING REPORT 1/3

ANNEX-1 : DISASTER ANALYSIS
ANNEX-2 : DISASTER PREVENTION PLAN
ANNEX-3 : HYDROLOGY

MARCH 1997

NIPPON KOEI CO., LTD., TOKYO, JAPAN
INA CORPORATION, TOKYO, JAPAN

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The Study on The Disaster Prevention Plan for Severely Affected Areas by 1993 Disaster in The Central Development Region of Nepal

Composition of Reports

Exchange Rate

The exchange rates used in this Study are:

NRs.55.75 = US$1.00 = ¥109.1
as of June, 1996

ANNEX - 1

DISASTER ANALYSIS

The Study
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Annex-1 : Disaster Analysis

1. DISASTER ANALYSIS FOR COMMUNITIES

1.1 Procedures to Disaster Analysis for Communities

Figure 1.1.1 shows the procedures for disaster analysis which was taken in the Study. The details for respective process is explained as follows:

(1) Data collection

Prior to the detailed field investigation, data collection will be required. For the disaster analysis of the mountainous area, the following data shall be collected:

a) Topographic map,
b) Geological map,
c) Aerophotographs,
d) Vegetation map,
e) Landuse map,
f) Rainfall data,
g) Previous disaster information in and around the project site,
h) Research papers and reports related to the mountain disasters in Nepal.

In Nepal, topographic map with a scale of 1:25,000 is being developed for the eastern part of Nepal by Topographic department which was developed based on the aero-photographs taken in 1992. For all the project areas of the Study, the map is available and was collected at the beginning of the Study.

However, for the detailed assessment of disaster aspects for the community, the topographic map with 1:25,000 is too small to use, and it is required to prepare the detailed map with the scale of about 1:5,000 to reflect the detailed disaster phenomena in the community. For geology, vegetation and landuse conditions, it is required to prepare by the Study Team themselves based on the field investigation on the prepared topographic map, so that the existing geological, vegetation and landuse maps are also too small for the detail assessment. Accordingly, topographic mapping with about 1:5,000 scale is the essential activities prior to the field investigation works.

For the rainfall data, it is generally not available in the area and it will be required to look for the existing data nearby the project area. The important rainfall information is the storm duration and intensity by the automatic rainfall stations, which is known as high correlation with disaster occurrence. In case that there is no automatic rainfall station nearby, it is recommended to install the raingauge station at the sites for the further data collection as well as collecting the daily armful data in and around the site.

For the research papers and report regarding the disasters in Nepal, both of the ICIMOD and the DPTC would be highly available in Nepal. The both agencies are put force the incentive researches for disaster mechanism and prevention works in Nepal. The research papers provided by the both institutes were almost collected by the Study Team.

(2) Basic Investigation

Basic investigation shall be carried out after the preparation of the detailed topographic map, which would be essentially necessary to record the geology, vegetation, land use and location of the various disaster phenomena in the area. All such information shall be filled up in the maps and it will be highly available for the further assessment of disaster mechanism as well as the disaster prevention plan formulation.

(3) Aerial Photographs Investigation

Aerial photographs after the disaster are highly available to analyse the disaster mechanism in the area. In case of the project area they are available with the scale of 1:20,000, which were taken by the DPTC immediate after the disasters. In case that no aerophotographs are available, it is strongly recommended to take them at the beginning stage of the Study.

In this Study, the aerophotographs taken before the disaster were also available so that the topographic mapping project were executed by the topographic department under the technical assistance from the FINNISH government. The scale of aerophotographs were 1:42,000. By comparison of the both photographs before and after the disasters, the full analysis for disaster mechanism made possible for respective priority areas in the Study. For aero-photo investigation, however, it is generally required to prepare the large scale of photographs for detail disaster analysis.

The following aspects shall be assessed based on the aerial photographs investigations:

- condition of gullies,
- gradation distribution of riverbed material,
- topographic condition of river bank,
- location and scale of debris cones,
- list up landslide topography,
- location of major cracks, and so on

The above survey works would be useful not only to analysis the disaster mechanism but also to estimate disaster potential.

After the field survey, review of aero-photographs shall be carried out, by which the detailed analysis of disaster mechanism will be proceeded.

A key issue on aerial photographs investigation is not only to compare the photographs before and after the disaster but to grasp the trend of area condition by comparison of periodical series of photographs. Based on the trend analysis, the following items are revealed:

- trend of landuse and vegetation condition,
- change of knick lines, and the foundation of slopes
- change of watershed boundary,
- development condition of cracks, landslides and slope failures, and so on.

The finding on the above shall be marked on the same map to identify the trend of the aerial conditions.

(4) Field Survey

Field survey was intensively carried out by the specialists team which is composed of topographist, geologist, landslide expert and sabo planner. More or less one week to stay at respective site and all the required information at site were collected and record on the topographic map.

(5) Disaster Mapping

Disaster map shows the major hazardous phenomena in the community such as landslide, failure, cracks, bank erosion, water veins, knick lines, exposure rock, weathered condition of rock, colluvium, old debris flow deposit, flood inundation area, debris prone area and so on. In addition, hearing survey from the villagers will be carried out to identify the severely damaged areas in the view of human lives as well as rural infrastructures. The prepared disaster map would be based on the hazard map as well as the plan formulation of disaster prevention activities.

(6) Hazard Mapping

Hazard map indicates that the current hazard potential of the area, which will be quite important for the disaster prevention planning as well as consideration of landuse plan and evacuation plan for the community. This would be the final output of the disaster analysis.

1.2 Disaster Mapping

The procedures for disaster mapping are mentioned as follows:

Prior to disaster mapping, aerophotographs investigation will be carried out using the aerophotographs taken before and after the disasters. By comparison of the both photographs, it is clearly understood the location of landslide, river erosion, slope failures, sediment deposition and transportation and so on.

All the information collected by aerophoto investigation shall be recorded on the detailed topographic map with the scale of more or less 1:5,000. It is noted that the information put on the map shall not only the disaster conditions but also the relative topographical factors such as gully networks, location of knick lines, sediment boulders prone area, rock exposures, weathered condition of rock, and so on. Such relative topographic information are one of the major factors for judgement of hazard level.

In the course of disaster mapping works, the major disaster types of the community will be selected. In this Study, the following disaster phenomena were selected and contained in the disaster map.

(1) Landslide

All the landslides located in the community are identified in the disaster map and they are divided into the following seven categories:

a) Landslide area which had already slided by sudden mass movement and no unstable material remained on the slope (mainly plane slide)
b) Landslide area which is still active during rainstorm such as
   - the slope which slided at 1993 disaster and many crack remains (mainly plane slide)
   - the slope which is re-sliding on the old landslide area (mainly slump slide)
c) Landslide area which is so far not active but it was previously slided. (mainly slump slide)

(2) Cracks

The cracks observed at site of which are assumed to be occurred or developed by the 1993 disaster were indicated on the disaster map.

(3) Gully erosion

The gully is generally defined as the small gutter which is eroded on the slope by rainfall and drain water. By the 1993 disaster many gullies are developed by the flush flows to erode the river banks. In the disaster maps, all the gullies which are developed by the 1993 disaster are marked. Many of them were the sources of debris flow.

(4) Water vein networks

Water veins are defined as the water path in concave cross sections on the slope, which is not scoured as gullies but may be developed as gully by erosion due to water flow. All the water veins of which have possibility to be gullies in future are put in the disaster map.

(5) Knick line

Knick line or knick point means the point at which the slope degree changes on the slope. Knick line is generally defined as the boundary of erosion landslide. In the case of Chisapani, for example, the upper area from the knick line are found less disaster but the lower was quite severely damaged by the landslide, gully erosion and slope failures. To identify the knick line is the key issues to assess the slope stability in the mountain areas.

(6) Exposure rock

The area in which rock foundation is exposed on the slope or river bank, is generally stable compared with the other area. In such areas, it may be defined as not critical areas to the further disaster even some disaster phenomena such as landslide and collapses are observed on the place. In the disaster map, all the location in which fresh rock foundation are seen, they are marked.

(7) Old debris deposit

The land which is formed by the old debris materials is identified. Most of such areas are generally stable. In the disaster map, this aspect is selected to mark on the disaster map.

(8) Debris prone area

Debris prone areas are identified in the disaster map as the most severely damaged area due to the 1993 disaster.

(9) Flood prone area

Flood prone area is identified in which sediment material such as sand and silt are spread by the flood due to the 1993 disaster.

(10) River bank erosion

The area which was lost by bank erosion were assumed based on the comparison of aerophotographs before and after the flood, and indicated on the disaster map.

(11) Collapse and slope failure

Collapse and slope failures are generally observed on the most upper area of the slope, from where the deep gullies are developed. Such collapses and slope failures are the source of severe disasters such as debris flows which is occurred by the collapses or the slope failures and flowing down on the gully with severe erosion of the bed and the banks and the amount of the volume are enlarged to flowing to the downstream. In the disaster map, all the collapses and slope failures are identified as the important factors for analysing disaster mechanism.

1.3 Procedures to Hazard Mapping

1.3.1 Disaster Type and Viewpoint of Hazard Assessment

Hazard map generally indicates the location of hazard zones against a certain disaster phenomenon. In the Study, there are various types of natural disaster phenomena such as landslide, slope failure, gully erosion, debris flow, flood and so on. The hazard map for the communities in the Study shall be prepared to identify the hazard zones by all considerable disaster phenomena. The considered disaster phenomena for hazard mapping in the Study are as follows:

Disaster type	Viewpoint for hazard mapping
Landslide	Hazardous area and degree of hazardous
Failure	Hazardous area and degree of hazardous
Gully erosion	Possibility of the further gully devastation
Debris flow	Possibility of debris flow occurrence and the affected area
Flood	Range of mud and sediment flow to be spread by the flood
River bank erosion	Range of hazardous area and the depth of erosion
Gully bank failure and landslide	Alarming phenomena of the disaster, and range of the hazardous area.

The detailed procedures of hazard assessment for the respective disaster type is described in the following:

(1) Landslide

There are two types of landslide phenomena in the Study area, plane slide and slump slide as shown in Figure 1.3.1. The major view points for hazard assessment of landslide are as follows:

a) For the area in which the landslide have occurred
   1) The time after the occurrence of the landslide
      Generally the newer landslides tend to be more unstable than the older one.
   2) Degree of surface deformation
      The more remarkable surface deformation such as cracks and settling down indicate the more unstable of the slided materials.
   3) Condition of the toe portion of slide
      In case that the toe portion of the slide is affected by the river flow, the slided slope tends to be less stable.

b) For the area in which the landslide doesn't occur yet
   1) Geological condition
      In case that the direction of the geological layers in the slope is forming the dip slopes the possibility of new landslide is higher than the back slope formation.
   2) Topographical condition
      The slided area of which the toe portion is affected by the river flow, the slope stability may be seriously affected that there are high possibility that the slided materials at toe portion is washed out by the river flow.

(2) Failure

Failure is defined that the surface of the weathered slope are collapsed without clear sliding surface. This disaster phenomenon sometimes affects to the residents directly. For the hazard assessment the following viewpoints are considered:

   1) Topographical conditions
      The slope which is steeper than 30 degree and forming concave section have high hazardous against the failures.
   2) Geological conditions
      The thicker weathered rock surface has the higher hazardous against the failures.
   3) Vegetative conditions
      The less density of the crown cover and surface cover of the slope have the higher hazardous against the failures.

(3) Gully erosion

The possibility of gully development mainly depends on the geological condition and the tractive force of the water flow. The gullies which has rather weathered banks have higher possibility of the devastating.

(4) Debris flow

Figure 1.3.2 shows the typical mechanism of debris flow. Debris flow is generally occurred by the consisted activities of several disaster phenomena such as failures on the upper most area of the slope, landslide and gully erosion on the middle part and so on. By accumulated the debris materials by the yielding activities, the debris flow occurs and flows to the downstream. For assessment of the hazardous of the debris, it is necessary to consider all the related hazard potential of respective disaster phenomena. The important viewpoints for the assessment are to estimate the correlation between the rainfall pattern and the occurrence of the debris flow and the range of the debris to reach to the downstream. The details are as follows:

a) Rainfall pattern
It is known that rainfall pattern, the intensity and the duration, is one of the main factors of debris flow occurrence, however, it is not possible to define the criteria of rainfall to forecast the debris flow only by the data obtained in 1993. It is important to accumulate the rainfall data and observe the co-relation between debris flow occurrence and rainfall pattern.

b) The range of debris flow to reach
The major factors to assume the range to reach debris flow is the amount of debris material and the topographic condition on the downstream. The debris flow discharge generally depends on the yield amount on the slope and debris transportation capacity of the flood. Accordingly, the debris flow which has bigger volume of the material tends to reach the further to the downstream. At the downstream area, the slope is generally becoming gentle and the tractive force of debris flow is increasing. The velocity of debris flow is gradually decreased and finally trapped somewhere. Based on the previous experience and analysis in Japan the critical degree of the slope of which debris flow is observed is more than about 3 degree as shown in Figure 1.3.2. In case of the 1993 disaster at Phedigaon, the downstream end of debris deposited area has more or less 3 degree of the slope, which is almost same as the Japanese examples.

(5) Flood

Damages by the flood generally occurs at the downstream area of which the slope is gentle. The hazardous degree mainly depends on the capacity of the river channel, and the elevation of the surrounded area.

(6) River bank erosion

a) <u>River condition</u>
Hazard assessment against the river bank erosion generally depends on relationship between the bank location and the flow direction. The bank

which is directly attacked by the flood or outside of river course has higher possibility of bank erosion by the stronger tractive force of the flood.

b) Geological condition
The bank material is also the major factors of the hazard assessment of the bank erosion. The material which is rather weathered or the bank formed by the river terrace has high possibility of the erosion.

c) Topographical condition
The river bank in which some cracks or surface deformation exist has generally higher possibly of the erosion. In such cases, the small erosion may trigger the bigger scale of bank erosion by losing the stability.

(7) Gully bank failure and landslide

a) Degree of surface deformation of the bank
The surface deformation on the gully bank of which the gully erosion occurred, is the major factors of the occurrence of gully bank failure or landslides.

b) Topographical condition
The degree of the slope of the gully bank is another major factor of the high hazardous possibility against the gully bank erosion or landslide. Generally, it is said that the maximum slope of the bank with 45 degree is the critical point for the higher hazard potential. It is noted that the critical slope with 45 degree is rather steep than the critical slope with 30 degree for the surface failure explained in (2) above. The difference of the critical slopes are that the slope of gully bank is generally formed by the gully erosion and no unstable material are usually remained on the slope. Therefore the criteria for judging the hazard degree for failure of gully bank slope is set at higher than the slope failure in (2).

1.3.2 Hazard Zoning

Based on the viewpoints of the hazard assessment for respective disaster phenomenon, the hazard zoning are carried out. The zoning procedures are explained as follows for the respective disaster phenomena:

(1) Landslide

a) Topographic condition
The area in which the slump slide occurred is generally observed the remarkable land deformation such as scarp. The whole area including such the area observed surface deformation is defined as the landslide zone.

b) Geological condition
The landslide occurred mainly on the dip slope portion in the Study area, all the slopes formed by the dip slope are defined as the potential hazard zone.

c) Range of recognised surface deformation
The area on the slope in which some alarming phenomena against landslide such as cracks, mass slips and so on are defined as the potential zone for re-sliding.

(2) Failure

a) Topographic condition
Figure 1.3.3 shows the Typical Zoning for failure. The unit zone for failure is divided by the knick lines, ridge, gully watershed, cross sectional formation in concave, plane or convex, and so on.

b) Geological conditions
For each unit zone divided in the topographical viewpoint, the thickness of the surface material of the slope is assessed and classified based on the surface thickness.

c) Vegetative conditions
For each unit zone divided in the topographical viewpoint, the crown cover condition is assessed and classified depended on the density of the crown cover degree.

d) Range of recognised surface deformation
All the areas in which failure occurred is defined as failure zone since there is high possibility to expand the failure to the surrounded zone.

e) Reaching range of the failure material
The area to which the failure material rolls down are defined as the failure zone as shown in Figure 1.3.3.

(3) Gully erosion

a) Scale of the existing gully
The assumed range of further gully enlargement will be zoned within the gully erosion as shown in Figure 1.3.3.

b) Range of exposed hard rocks
In case that fresh rock exposed on the gully bank, the gully would not enlarged. Therefore, this condition will be considered to determine the hazard degree.

(4) Debris flow

The zoning for debris flow are made by the same degree of rainstorm as the 1993 disaster. The debris zone is defined based on the aero photo investigation results. The whole alluvium corn area which was formed by the 1993 debris flow is defined as the debris flow zone.

(5) Flood

The zoning for the flash flood are made by the same degree of rainstorm as the 1993 disaster. The flood zone is defined based on the aero photo investigation results. The whole inundated areas by the flood are defined as the flood zone.

(6) River bank erosion

All the portion which was eroded by the 1993 disaster are defined as the river bank erosion zone. In addition, the area formed by the river terrace or severely weathered are defined as the river bank erosion zone.

(7) Gully bank failure and landslide

The both sides of the gully slopes for all the gullies are defined as the zone. In addition, all the area in which surface deformation are observed on the top of the bank along the gully are defined as the zone for the gully bank failure and landslide.

1.3.3 Hazard Level

Mainly three hazard levels are defined for preparation of hazard map, which are "A", "B" and "C". Hazard level "A" is defined as high hazard, "B" is defined as medium hazard and "C" is low hazard. The criteria for determination of hazard level are explained for the respective disaster type as below:

(1) Landslide

a) Hazard level "A"
Hazard level "A" for landslide zones are defined for the area in which:
- many new cracks are observed,
- severe erosion at the toe portion are observed, or
- potential mass sliding zone.

The schematic explanation for Hazard Level "A" is shown in Figure 1.4.1. In the case of Chisapani area, there area quite many places defined as level "A" of the landslide zones. In such case, sub classification "A1" and "A2" was made in the viewpoint of the urgency of the countermeasures. "A1" is the most serious and the "A2" follows to "A1".

b) Hazard level "B"
Hazard level "B" for landslide zones are defined for the area in which severe erosion at the toe portion are not observed though the some new cracks or deformation are observed which is shown in Figure 1.4.1, and the area which is upper than knick line but there is less possibility of sudden mass sliding.

c) Hazard level "C"
Hazard level "C" for landslide zones are defined for the area in which no new cracks and deformation are observed though the clear landslide formation are observed.

(2) Failure

Figure 1.4.2 shows the procedures for hazard level determination for failure zone.

a) Hazard level "A"
Hazard level "A" for failure zones defined for the area which is severely affected by development of the neighbouring failures and the remarkable

surface deformation are observed, and there are high possibility of failure even by the normal rainfall.

b) Hazard level "B"
Hazard level "B" for failure zones are defined for the area in which some possibility for failures are assumed by the heavy rainstorm. Also the zones of failure in which noting or pasture are vegetated on the surface and the slope formed in concave and the drainage water tend to be concentrated during the rainstorm.

c) Hazard level "C"
Hazard level "C" for failure zones are defined for the area in which some possibility for failures are assumed by the extreme heavy rainstorm. Also the zones of failure in which nothing or pasture on the surface of the convex slope or bushes or trees on the surface on the concave slopes are defined as hazard level "C".

(3) Gully erosion

There is no classification of hazard level for the zones of gully erosion. All the selected gully zones are defined as the hazardous area. The gullies of which the cracks are observed on the upper part and assumed high potential of collapse by heavy rain are defined as hazard level "A".

(4) Debris flow

There is no classification of hazard level for the zone of debris flow. All the selected debris zones are defined as the hazardous area level "A".

(5) Flood

There is no classification of the hazard level for the zone of flash flood. All the selected flood zones are defined as the hazardous area.

(6) River bank erosion

a) Hazard level "A"
Hazard level "A" for river bank erosion defined for the area in which the bank would be affected by the normal stream flow.

b) Hazard level "B"
Hazard level "B" for river bank erosion defined for the area in which the bank would be affected by the heavy flood.

c) Hazard level "C"
Hazard level "C" for river bank erosion defined for the area in which the bank would be affected by the extreme heavy flood such as 1993 disaster.

(7) Gully bank failure and landslide (mainly for Chisapani)

a) Hazard level "A"
Hazard level "A" for failure and landslide on the gully bank is defined for the area in which cracks or surface deformation are clearly observed on the gully bank slope. Among them, the area in which the abnormal surface deformation are observed are defined as "A1" as the most critical area, and the other areas are defined as "A2".

b) Hazard level "B"
Hazard level "B" for failure and landslide on the gully bank defined for the area in which the slope degree is more or less 45 degree and so far no surface deformation are observed though there is some possibility to occur the surface deformation by developing further gully erosion.

c) Hazard level "C"
Hazard level "C" for failure and landslide on the gully bank defined for the area in which the slope degree is less than 45 degree and no surface deformation are observed.

1.3.4 Hazard Mapping

Based on the procedures mentioned in sub sections 1.3.1 to 1.3.3 above, hazard map is prepared for respective community. The hazard map is the final output of the disaster analysis, and the plan formulation for community disaster prevention plan consisted of the disaster prevention, mitigation and evacuation measures are carried out based on the hazard map. The detailed explanation about the prepared hazard map are mentioned in Sections 2.4 for Phedigaon, 2.5 for Namtar and 2.6 for Chisapani respectively.

2. DISASTER ANALYSIS AT PHEDIGAON/PHATBAZAR

2.1 Natural Conditions and Background of Disaster

2.1.1 Topography and Geology

Phedigaon/Phatbazar area is located near the upstream of Palung Khola, the confluence with three rivers; Palung Khola, Garti Khola and Bhangkhoriya Khola. The main tributaries in the study area are Dhungakate, Ghatte and Bhottekhoria Khola (refer to Figure 2.1.1). The river characteristics of the Study Area are shown below:

River Characteristics of The Study Area

Basin name	*Catchment area (km^2)*	*Maximum altitude (m)*	*Minimum altitude (m)*	*Relief energy (m)*
Dhungakate	1.20	2,510	1,794	716
Ghatte	0.97	2,500	1,802	698
Bhotekoria	1.40	2,300	1,802	498
residual basin	2.33	-	-	-
total study area	5.94	2,510	1,770	740

The alluvial cone having length of 350 m and width of 100 m is formed from the outfall of Dhungakate Khola and Ghatte Khola to the confluence with the main tributaries as shown in Photo 1. in the front page (e.g., Dhungakate and Bhottekhoria). In the 1993 disaster, debris flow inundated almost all over the alluvial cone and gave large damages. Many landslides and gullies are distributed in the hill slopes and the banks of these tributaries. It looks very devastating.

The profile of Phedigaon torrents is shown in Figure 2.1.2. The riverbed gradient in the cone portion of Dhungakate and Ghatte Khola is from 1/13 to 1/15 in average. The relative height difference between tributaries at outfall is about 4 m. The riverbed gradient of Bhottekhoria Khola is about 1/21, more gentle than Dhungakate and Ghatte Khola. Furthermore, around confluence with Dhungakate Khola and Bhottekhoria Khola, the riverbed gradient varies remarkably, and the average of the riverbed gradient in Palung downstream from there is 1/42, which is about a half of that of Bhottekhoria Khola. The profile of Phedigaon torrent vary remarkably, and it would be changed easily in future by medium or small floods.

Geology of the study area is mainly composed of schist, phyllites and metamorphic sandstone of Kulekhani Formation, which is one of the formation of Bhimphedi Group, and quartets and phyllites of Marukhu Formation distribute in the northern part of the area. The bedding plane generally dips towards north with dip angle of 30° to 40°. In this area, affected by the geological structure, cuesta terrain which gentle slopes towards north (dip slope) and steep slopes towards south (opposite dip slope) are found obviously.

2.1.2 Vegetation

This area situated at around 1,800 m to 2,200 m altitude may be categorised in Middle Mountain forest among five categories of forest types which include High Himal Forest, High Mountain Forest, Middle Mountain Forest, Siwalik Forest, Terai Forest.

It is assumed that in old days the forests had been mainly covered with hardwood trees such as Castanopsis spp, Quercus spp, Michelia spp, Lyonia spp, and Shima wallichii, partially including conifers such as Pinus wallichi and/or roxburghii before excessive deforestation has prevailed over the mountainous areas so as to cultivate the land. Few hardwood forests are found which are in a state mixed with coniferous trees merely on the ridges of mountains to which it is inaccessible. Even they are poorly managed.

Various species of grasses are also damaged to a large extent because of over pasture. Dominant species in the area are: A plud mutica, Arunddinella nepalensis, Arundo donax, Bothrichloa intermedia, Chrysopogon spp, Cymbopogon spp, Cynodon dactylon, Eulalia spp, Setaria pallidefus, Saccharum spontaneum, and Impereta cylindrica.

The current vegetational conditions in the Study Area are observed by the Study Team, and summarised as follows:

- Vegetation around the confluence of Gharti Khola with Palung Khola is poor because of the last disastrous event. Dominant trees are isolated tall trees of Populus spp, some clumps of Salix babylonica and Sambucus spp along the river course.

- On the banks adjacent to the river course, some shrubs of aristata, Pyracantha crenulata, and Rubus ellipticus are found. These plants have thorns and grow strong even in a dry condition.

- On the debris deposits, around the primary school in Phedigaon, it is clearly found that such grasses as Artemesia indica and Eupatorium spp have started vigorously growing and plenty of young Alnus nepalensis are invading as a locally dominant species. The growth rate of Alnus nepalensis on the alluvial cone seems to be amazingly rapid, showing a good example as a "pioneer plant" on the virgin parcel of land.

- On the lower hill slopes adjacent to Phedigaon we also find a few kinds of trees such as Pinus roxburghii, Prunus cerasoides, Alnus nepalensis, Zanthoxylum armatum, and Phyllanthus spp. Under these trees there are some kinds of grasses such as Artemisia indica, Eupatorium spp, Polygonum, Hypericum spp, Trifolium spp, Drymaria spp, and Dennstaedita scabra. On the relatively dry slopes where soil is a little rich, we have also found some short trees of other species like Budeja app and Myrsine semiserrataa.

- Collapsed rocky surfaces of landslides, located in the upper reaches of torrents flowing through the alluvial cone of Phedigaon, lack soil, none of tree species is seen, but on stable hillslopes it was found a genuine stand of Querecus lanata.

2.1.3 Landuse

The landuse condition of the study area has been examined by aerial photograph and field investigation. Figure 2.1.3 shows the landuse map. The landuse condition is as described below:

1) <u>Forest</u>
Forest is distributed on the headwater part of Dhungakate and Ghatte Khola, on the southward slopes of Ghatte and Bhottekhoria Khola, on the upper reaches of Dewrali and Soltu Khola; (the tributaries of the left side of Palung Khola), and

on a part of northward slopes paralleled Phedigaon torrent. The dominant tree is mainly large pine.

2) Bush

Bush is distributed in a part of the Dhungakate Khola basin.

3) Grass, Bare land

Grass and Bare land are mainly distributed in the boundary areas between forest and cultivated land. The scale of distribution of Grass and Bare land is similar to forest zone.

4) Land for cultivation

The study area is very much occupied by cultivated land and especially, almost of all gentle slopes are used up by cultivation.

5) Land for housing

Most of the houses are settled on the stable and gentle slopes of the ridges which are also used for cultivation. The houses are distributed in a small group (e.g., four to five houses in a group). The Phatbazar and Palung villages are settled along the river banks of Palung Khola.

6) Area for stone mining

The upper hillsides of the Dhungakate Khola basin are mining for stones, and the unused stones are leaving on the slope.

2.2 Damage Assessment due to 1993 Disaster

2.2.1 Disaster Damages to the Community

By the disaster of July 1993, 58 people's lives were lost in Phedigaon, a lot of houses and farmland were washed away and most of them still remain under the debris by now. A rough estimate of the area covered by the debris is more than 30 ha. (The memorial hall in the primary school shows 55 names of death people in the name plates on the wall, though.) Those people who lost their families, houses, and farmland are still having difficulties to survive: Some victims are living with their relatives if any, providing manual labour works for nominal wages, just a few had a chance to migrate to Hetauda where the HMG/N and an INGO have offered houses for free though the life in these free houses in Hetauda is awful on account of no job, no farmland, no water, and no electricity.

Figure 2.2.1 and Table 2.2.1 show who were killed and damaged at what place by the 1993 disaster. As shown in Figure 2.2.1, the houses washed away or damaged were located mostly in the alluvial cone. The numbers and the letters indicated in Figure 2.2.1 correspond to those in Table 2.2.1. By looking at those numbers, it is possible to identify who were killed at which house.

2.2.2 Result of Aero-photo Investigation

The geomorphological interpretation based on the aerial photograph taken immediately after the 1993 disaster were carried out. Figure 2.2.2 shows the aero-photo investigation map. The result of interpretation are described below:

1) Old landslide configuration

The hillsides of Dhungakate, Ghatte and Bhottekhoria Khola are characterised by widespread gentle slopes. The gentle slopes imply to be landforms due to large-scale landslides in the old ages. Some sharp valleys are formed by intensive gully erosion insides and on margins of the gentle slopes.

2) Structural landform

Liner cliffs interfingered at near right angle for the strike of beds, cracks and lineaments are observed here and there. Furthermore, distinct subsidence is observed on the ridges of the headwater of Bhottekhoria Khola. These singular structural landforms are formed by lines of weakness such as faults, joints, which indicate the division of ground.

3) Debris flow deposit

The result of the 1993 disaster is the debris flow discharged from Dhungakate and Ghatte Khola. From the aerial photograph interpretation, the paths of debris flows can be fairly estimated from its deposits form. A part of debris flow was deposited in the front of a relatively high area where school reconstructed at present, and other residual debris flow passed through the sides of the school, and reached at around confluence of Bhotekoria Khola.

2.2.3 Disaster Mapping

The conditions of the damaged areas by the 1993 disaster are shown in Fig 2.2.3; disaster map, which prepared based on the aerial photograph interpretation and the field investigation. The conditions are described below:

1) Dhungakate and Ghatte Khola Basins

a. Large plane slides occurred in the right bank of the lower part of Dhungakate Khola and are the main sources of sediment yield. Hard rocks have cropped out in the sliding surface. The slopes around the landslides had many cracks and sliding cliffs on the surface. The toes of the slopes were eroded and are very unstable.

b. In the neighbourhood of the watershed boundary between Dhungakate Khola and Ghatte Khola, four gullies whose heads are situated at knick point turning from the upper steep slope to the gentle slope were formed. The detailed cross sectional survey for 12 sections were carried out to assess the gully erosion in the area as shown in the location map of Figure 2.2.4. The cross sections are described in Figures 2.2.5 through 2.2.7. As the outcrops of the bed rock are not observed along these gullies, it seems that the gullies have considerable possibility to extend due to erosion in the future. Moreover, three large landslides were observed on the upper steep and concave slopes. The colluvial sediments are deposited at the foots of the landslides and along the gullies, and are not discharged to downstream.

c. Large landslides also occurred in the headwater area of Ghatte Khola. Landslides were frequently observed at the right bank slope of the torrent. In contrast to this, the left bank slopes of the torrent were affected by geological structure and cliffs remark.

d. Around the slopes with the deposition at the outlets of Dhungakate and Ghatte Khola, the debris flow eroded, and the slump slides occurred. These slump slides with head scarps (1m to 2m head) were found near residential areas, which are dangerous for the dwellers.

e. The debris flow inundated over the lower alluvial cone covered an area of about 230,000 m^2, whose deposits have a depth of about 2 m and a gradient of about 6°. The debris is composed of sediment having grain whose size is maximum 4.6 m, and 15 cm to 30 cm is representative grain size.

2) Bhotekoria Khola basin

a. Old debris flow deposits are present at upper part of main stream in the neighbourhood of the torrent. Both sides of the debris are secondarily eroded and formed gullies. Landslides due to the stream erosion were frequently observed on the right bank slope of the debris. The landslides have considerable possibility to extend gradually to the upper part.

b. In the right bank slope of the tributary on the southern side of the wide-spread gentle slope, landslides occurred frequently. The colluvium has been accumulated thick in the valley and a part of that pushed out into the confluence with the main stream, which is deposited and forms the cone. The sediments are about 5m in thickness, about 10 cm in average of grain size.

c. In the bare and grass slopes on the right bank of the main stream, big or small failures are observed. Large failures occurred along cracks in weathered rocks, and their depth is 1.0m to 1.5m. On the contrary, the small failures occurred on the surface materials, and their depth is about 0.3m to 0.5m.

d. In Bhottekhoria Khola, in comparison with Dhungakate and Ghatte Khola, the yield of sediment due to landslides is small, and the gradient of torrent bed is gentle. Because of this, the debris flows are poorly deposited and completed at the front of the confluence with Ghatte Khola.

3) The right bank slope from Dhungakate Khola to Palung Khola

Many cracks and deformations were observed on the ground surface in the upper and middle parts of the right bank slope of debris flow deposit areas. It seems that the deformations are probably a predictive phenomenon of plane slide, and had been formed before the 1993 disaster in view of the conditions. Therefore, it is considered that the stability of the slope would be maintained, unless the lower part of slope is cut or eroded in future. Moreover, many old landslides configuration are present in the lower parts of the slopes, but there is no indication of movement now the slopes seem to be stable.

4) The right bank slope of Palung Khola

There is no considerable mass movement except for small failures in the bare and grass land.

2.3 Mechanism of 1993 Disaster

Based on the results of field investigation, aero-photo investigation and disaster mapping, the mechanism of disaster are assessed. The main causes of damage are as follows:

a. Destruction of houses due to the debris flow at the alluvium cone area.
b. Washout of house due to gully erosion at upstream of Dhungakate Khola.

1) Disaster due to debris flow

Initiation of the debris flow results from the yield of sediments due to landslide and gully erosion in Dhungakate and Ghatte Khola basins, and the sediments are brought by these Khola. The alluvial cone formed by the debris flow deposits is essentially high hazard-prone area. Actually, the large-scale debris flow occurred in 1915 also caused extreme damage.

Based on the initiation mechanism, the landslides in the upper part of these Khola are divided into two types as plane slide and slump slide. The plane slides occurred on northward dip slope whose dip direction is equivalent to the bedding plane. The thickness of the weathered bed rock was observed 3 to 4 m, thus the thickness of the landslide can be estimated to be 2 to 3 m. Most of landslides are equivalent to this type which are characterised by large-scale one. The bedding plane dips about 30° to 40° which also help to slide down. The plane slide is mainly caused by a pore water pressures increased by the infiltrated excessive rainwater inside the weathered bed rock, then sliding surface formed over the hard rock.

On the other hand, slump slides were observed in the unconsolidated colluvium and on the slopes of weathered mass. It is estimated that the landslides of this type are mainly caused by toe erosion of the slope, due to which slope became unstable and slide down.

2) Disaster due to gully erosion

The narrow and long gullies are observed on the gentle slope at the upstream of Dhungakate Khola which are composed of colluvial deposits by old landslides. The gullies are formed by gathering rainwater on the hillsides and infiltrated water in the unconsolidated bed. The damaged houses were located along previous small tributary, thus it is estimated that the bank of the tributary washed out due to erosion, as a result, the houses were washed out at the same time.

2.4 Hazard Mapping

Based on the condition of the 1993 disaster, hazardous areas were examined and a hazard map is prepared for the local disaster prevention. The procedures mentioned in Section 1.4 in this report are taken for Hazard mapping.

Hazard map for Phedigaon community is shown in Figure 2.4.1. The following disaster phenomena are considered to prepare the hazard map for Phedigaon.

	Type of Disaster	Description
I	Estimated hazard area of landslide and failure	Each zone for landslide and failure are classified into three hazard level A, B and C. The high hazardous areas defined as level "A" are concentrated on the upstream part of Dhungakate and Ghatte Khola located on the western slope of the community.
II	Estimated hazard area of gully erosion	Identified hazardous gullies are shown in the map. There is no hazard degree classification for gully erosion. The identified hazardous gullies are located in Dhungakate and Ghatte Khola basins.
III	Debris prone are	The zone for debris prone area are estimated based on the same as the damaged area by the 1993 disasters.
IV	Inundation area by flash flood	The zone for flood inundation area are estimated based on the same as the inundated area by the 1993 disaster.
V	Existing landslide and failure and rock exposure	The zones in this category are shown that landslides and failures have occurred by the 1993 disasters, and currently defined as the hazardous area. There is no classification of hazard level.
VI	Safety zone	The zones in this category is relatively safer than the other areas.
VII	Dangerous houses	The location of houses in the high and medium hazard areas of category I or hazard area of category B are identified as the dangerous houses.

3. DISASTER ANALYSIS AT NAMTAR/TILAR

3.1 Natural Condition and Background of Disaster

3.1.1 Topography and Geology

Manhari River originates from Mahabharat Range, flows through Namtar, and joins Rapti River in the Terai plain after incising the mountains. The Namtar/Tilar area is located on the river terrace with the altitude of about 860 m, about 10 km downstream from the headwaters of Manhari Khola.

Figure 3.1.1 shows the longitudinal profile of Manhari river. As shown in the profile, the clear knick point at which the river gradient changes suddenly is found about 4 km upstream from the Namtar community. The average river gradient on the upstream part is from 1/6.5 to 1/5, and the downstream part is 1/59.

The geological formation of the study area consists of Nuwakot Complex (upper Paleozoic) and Bhimphedi Group as shown in Figure 3.1.2. The watershed, upstream from Namtar, is composed of granites, amphiboles, marbles, quartzites, limestones, schists, conglomerates, sandstones, and siltstones. The rocks generally dip towards the north-east with an angle ranging between 50 and 80 degrees. In addition to MBT and MT, there are also many transverse faults.

The granite is deeply weathered and gives rock fragments which contain sands, gravels, cobbles, and boulders. In contrast to other rock types, the persistency of joints in granite is very good.

A thick sequence of quartzites (Dunga Quartzite Member) is observed at the confluence of Dunga Khola and the Manhari Khola.

Bhimphedi Group contains relatively high-grade meta-sedimentary rocks. Bhimphedi Group begins (in the ascending order) with Raduwa Formation which is composed of coarse crystalline, garnetiferous biotite-muscovite schists with quartzite intercalations.

The coarse crystalline, thick-bedded marbles constitute the rocks of Bhainsedobhan Marble.

Kalitar Formation consists of dark green-grey biotite and biotite-muscovite schists and micaceous quartzites. The schists from the lower part of the formation contain granites. A high alternation of schist and pale-green quartzite is observed in Pandrang Quartzite Member. From the villages of Namtar/Tilar to Kalikatar, Manhari Khola flows frequently through Pandrang Quartzite Member. Many rockslides observed on the banks of Manhari Khola are on schists and quartzites of Kalitar Formation.

A characteristic landform in the upper basin of Manhari Khola can be recognised. As shown in Figure 3.1.3, the top of Range, known as the Sim Bhanjyang area, consists of a gentle tilting low-relief surface with the altitude of about 2,500m, merging with the clearly knick lines. There are tor landforms on the low-relief surface. They are found on the tops and the slopes. Tor landforms are geomorphologically designated as a residual mass of upward projecting bedrock exposed by weathering and removal of weathered debris. They are most commonly associated with intrusive igneous rocks such as jointed granites, metamorphics, and some sedimentary rocks. The tor blocks may be both rounded and angular. The tors frequently rise abruptly from a surrounding relatively smooth surface. The tor blocks which will be washed out as a block stream are rarely found on valley floors.

So far, large boulders of granite originating from such tor blocks can be found in the present riverbed materials and the terrace deposit materials around Namtar/Tilar.

It is assumed that the uplift of Mahabharat Range was started early in the Pleistocene and the rate of uplift is about 1.2 to 2 mm per year. The tectonic movement may be the main causes of the uplift. The eroded surfaces on the summits and the steep slopes of the present range also indicate that the Manhari upstream basin and Namtar/Tilar can be considered as a technically dative area. As a result, Manhari River has been making deep and meandering channels. Due to the uplift motion, the river has made several river terraces which are being vigorously eroded.

3.1.2 Vegetation

The area is located in the upper reaches of Manhari Khola: A lower part of Manhari Khola can be classified as the "subtropical zone," but the higher one seems to be as the "warm temperate zone." The forests in this area are categorised "Siwalik Forests" where the dominant species are Acacia Catechu, Dalbergia Sissoo, Adina Cordifolia, Anogeissus Larifolia, Lagerstroemia Parviflora, and Eugenia Jamboland. Nevertheless, in the lower parts of the basin along the river course, particularly near the Namtar village, it seems that Shorea Robusta, Pinus Roxiburghii, and Shima Wallichii become some dominant ones. They can be observed at many places in Namtar.

The species identified along the local road from Chuniya to Namtar can be enumerated as below:

Trees: Pinus Roxburghii, Sima Wallichi, Shorea Robusta, Quercus Glauca, Castanopsis Indica.

Grasses: Pogonatherum Paniceum, Miscanthus spp, Artemisia spp, Euptorium spp.

The species identified around the Namtar village are as follows:

Trees: Ficus spp, Murraya Koeinigii, Albizia spp, Acanthapanax spp, Saurania Nepalensis, Dalbergia Sisso.

Grasses: Eupatorium spp, Artemisia spp, Polygonum Capitatum, Cynodon Dactylon.

3.1.3 Landuse

Figure 3.1.4 shows the land use map of Namtar community. The houses and cultivated fields are scattered around the river terraces and the toes of the slopes and ridges.

Paddy are planted mostly on the lowest terrace, corn, potatoes and cauliflower on the lower terrace, maize on the high land, and ginger and garlic on the middle where cultivated fields exist. The fruit plantation is observed in a wide range over the Khade Khola basin.

No particular distribution pattern of the houses is observed, but most houses are located on the wide terraces and the gentle slopes. Some houses are located on the margin of the terraces and directly under the terrace scarps.

Several water mills and cultivated land are found on the present river channel which was filled up by the sediment deposits brought by the 1993 disaster. Now there are five water mills and the farmers are trying to plant maize and paddy over the flood plain made by the 1993 disaster.

3.2 Damage Assessment due to the 1993 Disaster

3.2.1 Disaster Damages to The Community

Although there are many landslides observed along Manhari Khola, Syarse Khola, Gorduwa Khola, Khade Khola, and other small torrents, only few places are defined as the hazardous area except for the area along Manhari Khola.

The flood of July 1993 devastated the lower terraces on both sides of river banks and a lot of farmland and houses were washed out. Three years have passed by now and some residents have been back to their original places by constructing huts on the riverbed. There are several water mills constructed after the disaster near the confluence of Syarse Khola and Manhari Khola. The land reclamation along the river is seen in some places but most part of the lost land by the 1993 disaster is left as it is.

As the landuse at the high hazardous areas along Manhari Khola has not been so far recovered by the villagers, those areas can be regarded as non-dangerous areas. The river width of Manhari Khola was widened up to about 200 m by the disaster while it was between 30 to 50 m before the disaster. The loss of about 150 m wide of residential area and/or farmland on both sides of the river is currently classified as "a river", which is without doubt classified as the high hazardous area. There is such a high hazardous area for 6 km long along Manhari Khola from the confluence of Syarse Khola and Manhari Khola to the downstream.

3.2.2 Aerial Photograph Investigation

Figure 3.2.1 shows the location of slope failures around Namtar/Tilar.

The topographical map delineating the distribution of slope failures was prepared based on the aerial photographs taken after the July 1993 disaster.

The areas under investigation are the basins of Manhari Khola; Syarse Khola, Khade Khola and Dhobi Khola. The noteworthy points from the aerial photograph investigation are summarised below:

1. It is judged that the collapses of the slopes around headwaters triggered the debris flow along Syarse Khola.
2. The Characteristic of the collapses around Namtar/Tilar is that most of the collapses have made long narrow gullies and the collapses are small in scale.
3. Although some landslides are observed in the upstream, it seems that only the weathered soil on the surface is unstable and that deep rock slides are unlikely.
4. A number of unstable debris are deposited along the upstream and (downstream) near Namtar/Tilar of Manhari Khola and it seems that these deposits will be carried down to the downstream gradually. The detailed investigation results for location of gully erosion, slope failures and

landslides on the upstream of Manhari Khola is shown in Figure 3.2.2.

5. It is judged that the river basin does not have a severe fracture and there are just a few geologically vulnerable zones. Hence, there may be few possibilities to have a large-scale collapse in the future.

3.2.3 Disaster Mapping

Figure 3.2.3 shows the disaster map in Namtar due to the 1993 flood. The map indicates that the banks washed out by the turbulence flow which was affected by the debris from the torrents are found in the entire section along the mainstream, particularly along the downstream from the confluence with Syarse Khola for 6 km long. The river channel was much widened due to the bank erosions for about 30 m to 200 m long along the mainstream, and the sediments spread over the whole section. The same phenomenon is observed along Syarse Khola and Khade Khola.

Figure 3.2.4 describes the landform characteristics around the Namtar village. The figure indicates that there were four stages of the river terraces along Manhari Khola on the right bank. The lowest terrace was completely washed away by the turbulent river flow. The same phenomenon was observed at the downstream for about 6 km long from the confluence of Manhari Khola and Syarse Khola. As the river banks are not strong enough against the turbulence flow during the flood, the villagers fear that the bank erosion or the terrace removal will be repeated by another flood.

As mentioned in the former sub-section 3.2.2, the debris flow occurred at Syarse Khola and flew down to the Manhari Khola. However, the severe failures at the most upper areas are not observed as the source of debris flow. On the other hand, the heavy river bank erosion at the left bank of the Syarse Khola are found based on the field investigation. Four cross sections at Syarse Khola are investigated as shown in Figure 3.2.5. The detailed cross sections are shown in Figure 3.2.6, which indicates that the river width of Syarse Khola was widen by the bank erosion by the 1993 disaster, and the eroded material became the source of debris flow to the downstream.

A remarkable colluvium is observed on the upstream of Namtar community at about 1 km downstream from the confluence of Manhari, Chyau, Bardeu and Mahabir rivers. On the right bank along Manhari Khola, slope failures are continuously found for 500 m long. According to the DPTC survey, the volume of collapsed material is estimated at 102,500 m3 with a collapsed area of 25,625 m3. The mechanism of the colluvium are shown in Figure 3.2.7.

3.3 Mechanism of 1993 Disaster

Based on the results of filed investigation, aero-photo investigation and disaster mapping, the mechanism of disaster are assessed. The major disaster phenomena at Namtar are as follows:

1) Bank washed out on the right bank at Namtar community,
2) Bank scouring at Manhari Khola
3) Landslide and collapse at Gorduwa Khola

(1) Bank washed out on the right bank at Namtar community

Before the 1993 disaster, the Namtar bazaar was located on the lower river terrace on the right bank. The Tilar village was located on the upper river terrace on the right bank. The channel of Manhari Khola was narrow and close to the left bank as shown in Figure 3.3.1.

During the 1993 disaster, the villages of Namtar/Tilar were severely damaged. The river channel was filled up with the sediments transported from the mainstream and the discharge spread over the flood plain. Then, the river flow from the mainstream was blocked by the debris brought by Syarse Khola and Gorduwa Khola. The debris brought by Syarse Khola and Gorduwa Khola formed the temporary debris cones at the confluence. Consequently, the main course of Manhari Khola shifted towards the opposite bank, and the debris cone was washed away and the lower terraces were destroyed. Various turbulence occurred and changed the river course which accelerated the land scouring. Houses, farmland, the VDC office, and other public facilities were all washed away. A suspension bridge was also destroyed by the same event.

Prior to the bank erosion activities at the community, it is observed that the severe erosion at the upstream area of the mainstream. As shown in Figure 3.2.2, the gully networks are well developed in the granite area, and all the tributaries are severely eroded by the rainstorm of the 1993 disaster. It must be yield tremendous amount of sediment and being transported to the downstream.

As shown in Figure 3.1.1, the knick point exist at about 1 km upstream from Namtar Community, and the river gradient are remarkably changed at the knick point. The river width are remarkably widen from the knick point to the downstream and the river became winding from the point. The sediment deposition will be concentrated from the knick point to the downstream, particularly at Namtar. Based on the sediment transportation mechanism, the disaster potential at Namtar seems to be quite high. In fact, many villagers reported that the remarkable river bed aggradation was observed with several meters prior to the bank washed out. This river phenomenon must be one of the key factors of the disasters.

Figure 3.3.2 shows the detailed river profile nearby Namtar. According to the profile, it is indicated the river gradient become gentle at every bending portion, particularly, at the confluence of Syarse Khola. In the view point of the river morphological aspects, the sediment material are concentrated to be accumulated at such portions. Namtar community located just downstream of the confluence with Syarse Khola would have high possibility for sediment accumulation, debris flow attacked from Syarse, and flood course are fluctuated.

(2) Bank scouring at Manhari Khola

In addition to the flood-prone area in the lowest river terrace, the edge of the second terrace from the river will be critically dangerous due to a further bank erosion by a turbulence flow. Some specific locations, particularly at the undercut slope and a river bend, will be attacked by another flood. Figure 3.3.3 shows the general mechanism of scouring at the undercut slope along Manhari Khola.

On the edge of the second terrace from the riverbed at the opposite side around the confluence of Syarse Khola and Gorduwa Khola, the bank erosion will occur during a flood by a turbulence flow, and it will be defined as the hazardous area. Particularly, some houses existing near the right bank of the suspension bridge in Namtar will be classified as the hazardous area.

(3) Landslide and collapse at Gorduwa Khola

At the western edge of Ward No. 2, high potential of big landslide is recognised along the left bank where the irrigation canal runs through the middle portion. The mechanism of hazard is shown in Figure 3.3.4.

3.4 Hazard Mapping

Based on the condition of the 1993 disaster, hazardous area were examined and a hazard map is prepared for the local disaster prevention activities. The procedures mentioned in Section 1.4 in this report are taken for Hazard mapping.

Hazard map for Namtar community is shown in Figure 3.4.1. The following disaster phenomena are considered to prepare the hazard map for Namtar.

	Type of Disaster	Description
I	Estimated hazard area of landslide	Each zone for landslide is classified into three hazard level A, B and C. The high hazardous areas defined as level "A" are mainly located along Manhari Khola.
II	Estimated hazard area of failure	Each zone for failure is shown in the hazard map. There is no hazard degree classification, and all the location are identified as the low hazard area. The hazard area or failure are mainly located on the terrace along the river.
III	Debris flow	Identified hazardous gullies for debris flow are shown in the map. There is no hazard degree classification for debris flow, all of which are defined as high hazardous. The identified hazardous gullies are located on the left bank of Syarse Khola and Manhari Khola
IV	River bank erosion	Each zone for bank erosion is classified into three hazard level A, B and C. The high hazardous areas defined as level "A" are mainly located along the Manhari Khola nearby the community, and left bank of Syarse Khola.
V	Safety zone	The zones in this category is relatively safer than the other areas. The safety zones are mainly located on the river terrace at higher portion along the river
VI	Dangerous houses	The location of houses in the high and medium hazard areas of category I or hazard area of category B are identified as the dangerous houses.

4 DISASTER ANALYSIS AT CHISAPANI

4.1 Natural Conditions and Background of Disaster

4.1.1 Topography and Geology

1) Topography

In the upper catchment of Agra Khola (i.e., around Chaubas, Damdabas, Chisapani, and Deaurali), there is a characteristic in topography of forming the cuesta and the steep sloped terrace, due to the geological structure. For this reason, the gentle slope with 25° to 30° and the steep slope with 50° to 55° appear alternately.

Figure 4.1.1 shows the topography and the geology in and around the Chisapani village. There are three tributaries flowing in the Chisapani village; Majhuwa, Chisapani, and Garchi Khola. Majhuwa Khola exists on the eastern part of the village where the big scale of landslide and river erosion are observed, and no settlement exists on the right bank. Chisapani Khola originates from the southern mountain of the village flowing to the north-east through the residential area of the village mainly on its left bank. Many villagers depend on their drinking water from Chisapani Khola. Garchi Khola originates from the south-western part of the village flowing to the east.

The three tributaries meet Chalti Khola at the northern part of the village and flow to the north as the major tributary of Agra Khola.

On the left bank of Majhuwa Khola, there is a range of gentle slope which faces to the north-east flows in the direction of the south-west. It has a width of ranging 600-1000 m and a height of 400-600 m. On the right bank there are steep slopes of 50°-55°. Most of the human residents and the farmland are distributed on these gentle slopes (see Figure 4.1.1).

The Chisapani area is located at the most upper part of the above mentioned gentle slopes. The elevation ranges from 1,640 m (at the confluence of Majhuwa Khola and Chisapani Khola) to 2460 m.

2) Geology

Chisapani and its outskirts comprise mainly schist of the Kulekhani Formation. Within the Chisapani area, as shown in Figure. 4.1.1, the bed strikes to the NW - WNW and dips to the 20° to 35° of NE. But the dip has a tendency that it changes sharply from the upper slope to the lower slope.

4.1.2 Vegetation

The area is situated at the elevation higher than 2,000 m in the upper part of Agra Khola and is classified into the cool temperate zone, belonging to Middle Mountain Forest in this country. The worst situation in geology is observed in the area where many landslides and gully erosions have occurred. It is hardly possible to find a better stand of forest at present, although there must have been covered with hardwood forest which consisted of such hardwood species as Quercus spp and astanopsis spp. Self growing of forest is unexpectable.

As for the grass species in this area, it can be assumed that dominant species would be

Andropogon tristiss, Aruniella hookeri, Brachpodium pinnatum, Ergrostis spp, Eulalia mollis, Festucaa gigantea and Pennisetum spp, but substantial over pasture in this area results in deterioration of grassland: Half-bald land is everywhere.

4.1.3 Landuse

As shown in Figure 4.1.2, the land use pattern in Chisapani area is mainly divided into the wood land and the farmland. The foot path near the 2,100 m contour line forms a rough boundary between two areas. Besides, after the 1993 disaster, some parts of farmland have changed to barrens and bushes land.

Most of the wood land consists of copse, and the remaining (near the foot path) consists of shrub. In this area, there are many fresh cracks due to landslides and the slope is very unstable. Thus, the cultivation is not possible.

The gentle slope located on the right bank of Chisapani Khola is utilised as the farmland. The upper part of Majhuwa Khola was ruined by the 1993 disaster and the left bank is barren land. The left bank slope of Majhuwa Khola, facing Garchi Khola, is not possible to be used as farmland because hard rocks are exposed with steep slopes and cliffs. In the west side of the Chisapani area, most of the human residents and public facilities are located on the ridge.

4.2 Damage Assessment due to the 1993 Disaster

The condition of the 1993 disaster is shown in Figure 4.2.1. Figure 4.1.2 shows the main disaster area and its landuse pattern. At the time of detailed field investigation, slope material and gully sections were observed and surveyed. Figure 4.2.2 shows the location of slope material investigation points and cross sections. The survey results are described in Figures 4.2.3 through Figures 4.2.8.

The disaster area is divided into four areas based on inducement and its topographical character. The condition of each area is as follows (area numbers are shown in Figure 4.1.2).

(I) area:

In this area, there is a thick weathered rock layer in the upper slope from the foot path and landslides had already occurred before the 1993 disaster. In 1993, these old landslides slid again. As a result, there are many fresh cracks and head scarps in almost all parts of the slopes. At present, these areas are used for the pasture and the wood land because of its unstable condition. In the slope near the foot path, there are many small landslides due to the toe cutting of the slope by the foot path construction.

(II) area:

There are numerous fresh cracks all over the (II) area due to the plane slide. Hence, at present, this area has changed to the barren land from the farmland.

In this area, there is no sharp knick line, so it is expected that the range where the loose materials will be lost by the plane slide will extend over the ridge and the foot path to the Phedigaon village will be lost.

As the hard rock is underlain by the weathered rock layer, it is not possible to use this land for any activity if the weathered rock layer has been lost,.

(III) area:

This is a cultivation area in the Chisapani village. Gully erosion occurred in this area. As a result of this gully erosion, the weathered rock layer and the soil used for farmland were washed away. There are many cracks on the slopes along the gully due to plane slide caused by gully erosion.

If the gully is left as it is, it will spread and also the plane slide will be activated. As a result, it is expected that the farmland will be lost in the future and economic activities can be hardly continued. The river bank failure is spread in the slope facing Chisapani Khola, and the farmland is lost. If the farmland is lost, it will be impossible to restore it. There are some houses on the margin of the gully and the slope where the plane slide occurred. The probability of losing human lives is high in such a hazardous zone.

(IV-1) area

On the slope facing Majhuwa Khola, many plane slides have occurred retrogressively at the foot of the river bank and at the head scarps. If they are left as they are, the loose materials will be lost.

(IV-2) area

There is a sharp head scarp at the top of the slope facing Galchhi Khola due to the old landslide. At present, the lower part of the landslide mass slips down abruptly and it is impossible to re-use it as farmland. If it is left as it is, this slope will be lost abruptly and will become rock-exposed land.

(v) area

In this area, there is a sharp head scarp due to the old landslide. On the steep slope facing Chisapani Khola, there are many fresh cracks due to the river bank failure. If these conditions are left as they are, the foot path will be destroyed by the bank failure in the future.

Other area

There are many cracks and the abrupt drops near the top of the river bank failure and the plane slide at the III, IV and V areas. Some parts of these cracks and abrupt drops are near the. Therefore, if the slope mass with cracks and abrupt drops fails down, the houses will be destroyed.

4.3 Mechanism of the 1993 Disaster

4.3.1 Topographical and Geological Background of Disaster

1) Relation between Landslide Distribution and Geological Structure

It is known that there are many factors to trigger landslides. In the case of the study area, however, it has been found that the geological structure is a key factor for the high potential in landslides. The Study Team carried out the intensive site investigation in terms of topography, geology, and landslide locations. Based on the investigation results, the sliding areas concentrate on some part of the slopes but not the whole slopes of the study area.

As described in Section 4.1.1, the cuesta is the main topographical character in the upper most catchment of Majhuwa Khola, Agra Khola, and Palung Khola. Figure 4.1.1 shows the location of the landslide areas and the geological structures forming the dip slope in and around the study area.

Figure 4.1.1 indicates that:

- the areas where landslides occurred are mostly the dip slope, in other words, the dip slope is one of the leading factors for landslides;

- generally, many landslides occurred on the slope where the bedding plane has dip angles of 20° to 30°.

2) Types of Mass Wasting

Generally, in the cuesta area, the rock creep caused by the gravitational deformation occurred at the opposite dip slope (back slope) and landslides occurred at the dip slope.

In the Chisapani area, the similar tendency is observed and the mass wasting model as shown in Figure 4.3.1 explains this tendency. This model can well explain the observed landform phenomena such as creep deformation and landslides in Chisapani and Phedigaon. The details are as follows:

(1) Creep deformation

Generally, at the opposite dip slope, the weathered rock layer is thick in comparison with the dip slope as explained in Figure 4.3.1, and there is much creep deformation due to the river deepening and the bank cutting. As a result, at the top of the dip slope, double ridges and cenote have been formed. Moreover, as the river deepening will be in progress, the slope will not be able to support the upper deformed rock mass and rock will fail abruptly like a huge failure. The part marked by (A) in Figure 4.1.1 is such creep deformation.

(2) Landslide

The landslides mainly occurs on the dip slope as shown in Figure 4.1.1. The landslides found in the Chisapani area are divided into two types as the block slide and the plane slide. The details are described as follows:

Block slide

The mechanism of the block slide is explained in Figure 4.3.1. The block slide is a translational slide in which the moving mass consists of a single unit of the rock block that moves downward. In such a case, the rock on the slope is separated by faults and joints. The separated rock mass slips down parallel to the bedding plane. In this phenomenon, after slipping down, a straight escarpment along the fault and the joint is formed and the side range is left on the ground surface. A part marked by (B) in Figure 4.1.1 is one of the straight cliffs.

It is considered that the above mentioned phenomenon has occurred mainly due to the river deepening and the river bank erosion. Therefore, for the time being, there is less possibility to have a block slide unless the deepening abruptly progresses or the foot cutting is made by road construction.

In the case of the block slide, the sliding rock mass consists of mainly hard rock and the sliding surface is generally deep.

Plane slide (Translational slide)

The mechanism of the plain slide is explained in Figure 4.3.1. The plane slide is a mass movement on a plane surface and is a phenomenon that the weathered materials and cracky rocks slip down on the surface of hard rock. Sliding materials may range from loose unconsolidated soils to cracky slab of rock. Generally, weathered materials are 2 m to 4 m thick, and therefore, the depth of sliding surface is shallow. Because of this, the value of surface deformation is very large. Once the plane slide has occurred on the farmland, the farmland is immediately lost. Mass movements occurred around the Chisapani area in 1993 are mostly plane slides. There are no cases of creep and block slides newly occurred.

4.3.2 Mechanism of Disaster

1) Result of Topographical Analysis

Fig 4.3.2 shows three directional longitudinal profiles of Chisapani area.

It can be seen from Figure 4.3.2 that there is a knick line near the elevation 2,100 m to 2,150 m above sea level along the contour lines. These locations are near the foot path and the boundary between the wood land and the farmland. Generally, in the upper slope from the knick line, the weathered rock layer is thick in comparison with the lower slope. This fact is also recognised by the field investigation in the Chisapani area. In addition to this, there are another knick lines near the elevation 1,995 m to 2,015 m above sea level. But these knick lines show the top of the river bank failure due to the 1993 disaster and do not show the difference of weathering condition.

2) Result of Aero-photo Investigation

Figure 4.1.2 shows the result of aero-photo investigation, taken before and after the 1993 disaster.

The results are summarised below:

- Near the foot path of the lower slope from the knick line, the gully erosion and the river bank failure occurred abruptly by the 1993 disaster;

- It is observed that some sharp head scarps have occurred due to the landslide before the 1993 disaster in the upper slope from the knick line. This fact shows that this area has been a landslide-zone for a long time. Head scarp has 100 m to 200 m width, thus it is presumed that the sliding surface of these landslides are considerably deep. At the 1993 disaster, these landslides repeatedly occurred and at the present time there are many cracks on the land.

- The gullies developed up to the upper most of Majhuwa Khola and Chisapani Khola show that they enclose the deformation area due to landslides and that the ridge which continues near the elevation 2,100 m to 2,150 m disappears around here. These facts suggest that the whole area surrounded by the above mentioned gullies and knick line may be a whole deformation area separated from the lower slope.

3) Causes of Disaster

The 1993 disaster was caused mostly by the plane slide due to the dip slope. It is pointed out that especially at the Chisapani area, the slope was unstable because of the slope angle and the bedding plane angle being almost parallel. And it is also pointed out that the plane slide was caused by the lateral erosion and the river bank failure and that most of the plane slides occurred along the river and the stream. In addition to this, the weathered rock layer is thin, this layer became easily saturated with infiltrated water and pore water pressure was built up. As a result, the rock lost its strength and stability of the slope. At the upper Chisapani area, the surface running water easily concentrates in the gully and the stream is hollow, the gully erosion is easily grown. As a result of the gully erosion, the weathered rock materials along the gully were washed away and the foot of slope was cut abruptly.

4.4 Hazard Mapping

Based on the condition of the 1993 disaster, hazardous area were examined and a hazard map is prepared for the local disaster prevention activities. The procedures mentioned in Section 1.4 in this report are taken for Hazard mapping.

Hazard map for Namtar community is shown in Figure 4.4.1. The following disaster phenomena are considered to prepare the hazard map for Namtar.

	Type of Disaster	Description
I	Plainslide, failure due to the 1993 disaster	All the areas in which plane slide and failures are occurred by 1993 disaster are marked in the Hazard Map. There is no hazard level classification which is considered as high hazard. The plane slide and failure zones are spread on the lower part of the community along the Majuwa, Chisapani and Garchi Khola.
II	Safety zone	The zones in this category is relatively safer than the other areas. The safety zones are mainly located on the ridge with relatively wide portion on the western area of the community.
III	Semi safety zone	Semi safety zone are defined which is not defined in any other categories as hazardous zone but not enough to be safe as the safety zone. Semi safety zone are found in the farm land of which it is far from the gullies, and on the ridge of which the width is rather narrow on the western part of the community.
IV	Dangerous houses	All the houses located in the zone of high and medium hazard are defined as dangerous houses.
V	Integrated hazard zone	Integrated hazard zone are classified into three hazard levels, A (high hazard), B(medium hazard) and C(low hazard). The determination of hazard level are considered integrated viewpoints among landslide, failure, stream bank erosion and slide of the stream bank. High hazard zone are mainly found around the knick line along the trail to Phedigaon.

5. DISASTER ANALYSIS AT MAHADEVBESI BRIDGE

5.1 General

The IDPP of Mahadev Besi Bridge is expected to demonstrate such a project that experienced knowledge of river/sediment control engineering would contribute the safe passage of sediment-loaded floodwater at bridge site, because there happened to occur similar type of bridge destruction at places at the time of the 1993 disaster. Exemplifiable approaches coming majority from sediment control engineering will be set up and hereby an appropriate application of techniques can be transferred so that Nepal would less depend upon foreign assistance of technology and financing.

It is obvious that damages of the bridges and disconnection of important high ways for a long time would be fatal to the development of national or regional economy. Upon the occurrence of 1993 disaster Prithivi Highway was actually cut off in the adjacent district to Kathmandu because three bridges which include Mahadev Besi Bridge were washed away thoroughly due to the onslaught of overwhelming flood water which accompanied enormous amount of debris/sediment from the upstream. Urgent import of bailey-truss for the bridges using chartered flight from Hong Kong barely brought about the restoration of the arterial road, Prithivi Highway. But for such urgent rehabilitation measures it must have been impossible to connect Kathmandu with other cities and to transport food, fuel and all other commodities during the periods of rainy seasons sequence to the 1993 disaster.

The development of bridge protection technique against debris/sediment flows, particularly of arterial road bridges is really significant in terms of effective countermeasures and should be deeply taken into account for the future, although such damages as occurring along a road due to slope failures or landslides might be temporally rehabilitated with a relative ease because they are ordinary events of road damages that can be treated with intensive mobilisation of heavy equipment for construction works

In this chapter, necessary countermeasures from river/sediment control engineering point of view will be discussed to secure the safe management and maintenance of Mahadev Besi Bridge.

5.2 Basin Topography and Geology

Agra Khola is the main tributary of Mahesh Khola, one of the major tributaries of Trishuli River in the Central Nepal. The Agra Khola drainage basin is located in Mahabharat Range. The total drainage area is 112 km^2. The elevation varies from 600 m at the confluence of Mahesh Khola to 2400 m at the watershed boundary of 21 km. All the streams of the Agra watershed are in their youth stage. Agra Khola has dendritic and radial drainage patterns (Figure 5.2.1).

Agra Khola is formed by six small streams flowing down from south to north. Its major tributaries are Chalti Khola and Mel Khola, the catchment areas of which are 12.9 km^2 and 32.8 km^2, respectively. The ridges of the catchment areas are steep. The river gradient is about 25° at the first part of all these streams. The middle portions of the streams have the gentle slopes of about 4°, and the slopes decrease to 1.5° at the last section, about 12 km from the confluence of Mahesh Khola.

The Agra Khola basin is occupied mainly by quartzite, schist, phyllites, limestone, and marbles of the Bhimphedi Group. Granites are also exposed in the part of the western basin. Rocks are intensely faulted, folded, and jointed.

There are many large landslides in the part of the headwaters. These landslides are mostly distributed to Kulekhani Formation. Slides in this basin have four types in the main; plane rock slide, wedge failure, debris slide, and deep-seated rotational slide. Plane rock slide is especially common on the dip slope, whereas wedge failure observed mostly on the counter dip slope. In the area occupied by phyllites, shale, and schist, thick residual soil it is formed by prominent weathering on which dominate plane or rotational weathered rock slide and debris slide are found.

According to Khanal (1993), landslides and slope failures occurred in the years of 1954, 1970, and 1974 due to heavy rain in the Agra basin. It is considered that most of landslides and slope failures are that took place in the 1993 disaster are a continuation of the expansion of past ones.

5.3 Damage Assessment due to the 1993 Disaster

The former Mahadev Besi Bridge was a three-span bridge with steel girders and concrete decks. The three piers and the super-structure on the left side were washed away. The right side pier and the super-structure between the abutment and the right side pier have remained, but the pier was severely damaged due to the strike of boulders on the surface of concrete and the reinforcement bars were exposed and bent.

According to the survey carried out by Snowy Mountain Engineering Corporation, Australia (SMEC), it was not sure how the bridge was broken down. It is reported that some witnesses said that the super-structure was knocked off by a large driftwood. On the other hand, others said that the piers were collapsed first and the super-structure fell down subsequently.

The picture taken from a helicopter just after the July 1993 disaster and being hung on the wall of ground floor of DPTC building indicates that the major stream flows deviates from the right bank toward the left bank to a considerable degree at the immediate upstream of Mahadev Besi Bridge. Judging from this picture it is assumed that the pier on the left side must have been first destroyed by the striking of boulders and sediment being contained in anomalous floodwater. It is also assumable that this anomalous floodwater must have been a hydraulic bore which has terrible kinetic energy to convey even big boulders.

There is an opinion or comment that so-called debris flow which convey big boulders and sediment in a form of massive transportation must have given a fierce attack on the bridge structures. However, the debris flow in usual sense of terminology cannot take place on such a gentle gradient 1 % of riverbed as Mahadev Besi Bridge is located. Study Team is dissident on this point. From the result of our field survey and geomorphological analysis it may be safe to say that so-called debris flows never happened in the river channel adjacent to Mahadev Besi Bridge but the occurrence of a particular flows like hydraulic bore must have generated in the river channel immediately upstream and spontaneously raised riverbed during a big flood must be another factor to be reckoned with. The origin of boulders accumulated near the bridge has become clear: that is, they from the river terraces situated at a few kilometre upstream the bridge.

Disastrous events such as landslides, slope failures in the basin of Agra Khola of which confluence with Mahesh Khola is just located at Mahadev Besi Bridge are reported to have taken place from time to time in the past. Events in 1954, 1970 and 1974 are recorded to be conspicuous, giving rise to serious damages of the infrastructure and other. In this sense of the meaning it can be said that the 1993 disaster happened to occur on its extremely large scale on the elongation of past disastrous events. Emphasis therefore should be put on the necessity of countermeasures against sediment-loaded flood water which may include big boulders.

5.4 River Channel

In order to conform the conditions of river channels, the Study Team carried out field investigation from the headwaters of Agra Khola up to the confluence with Mahesh Khola where Mahadev Besi Bridge is located. Figure 5.4.1 shows the geological / geomorphological conditions and the longitudinal profiles are given in Figure 5.4.2.

1) <u>Chalti Khola</u>

In the most upper reaches of Chisapani Khola, the river width is about 4 to 5 m and the average of riverbed gradient is more than 15°, and some big and small cascades are formed. There are little of sediment deposits on the riverbed due to transportation by debris flows. The river bank is eroded and landslides continue to happen.

In the middle reaches of Chalti Khola several of large collapses are found. Existence of remarkably weathered rocks prevails on the surface of slopes. Aggravated characters of the bedrock will give rise to further extensive landslides. On the foot of existing collapses is seen a huge amount of the colluvial deposit. The riverbed is covered with thick deposits of debris flows and accordingly the width of riverbed becomes wide, varying 50 m to 150 m. For the thickness of debris flow deposits it is estimated 3 m to 4 m at least. The riverbed gradient varies 6° ~ 8° on average and 3° near the confluence with the most upstream of Agra Khola. The mean size of riverbed material is 20 cm ~ 30 cm and the maximum size 1.5 m around. Accumulation of big boulders which is the remnant of debris flows is seen at places.

2) <u>Agra Khola section (from the confluence with Chalti Khola to the confluence with Mel Khola)</u>

There are seldom found landslides on the mountain slopes and river banks of this section. The riverbed gradient is about 2° to 3°, rather gentle than Chalti Khola. the riverbed materials have pebble size of about 10 cm and their thickness is estimated 0.5 to 1.0 m. Big boulders are hardly found in this section.

3) <u>Agra Khola section (from the confluence with Mel Khola to Mahadev Besi Bridge)</u>

In this section, the riverbed gradient is 1.5° to 2.0°, the major components of riverbed material change from pebble to sand. In the incised meandering course of this valley there are found some of boulders that consist mainly of white round boulders of granite. Some of schist and quartzite boulders are mixed with granite boulders. According to the result of sieve analysis carried out by the DPTC (1993), the average size of boulders is about 2.0 m and the maximum size is 3.5 m. In the downstream of this section, rather large-scale landslides are found on the both banks. They are assumed to have taken place due to the undercutting of riverbed, particularly at bent corners of rivercourse. A large portion of collapsed earth still remains at the foot of slid slopes as colluvial deposit in shape of cone.

4) Understanding on the process of sediment transportation along the Agra Khola.

On the basis of the above-mentioned results, the yielding and transportation of sediment can be understood as follows:

i) The sediment yielded in the Chalti Khola basin seems to be washed out downstream in a form of debris flows and sediment-loaded floodwater. The major part of sediment, however, seems to have deposited in the lower segment of Chalti Khola before merging the main stream of Agra Khola.
ii) In the section of Agra Khola between the confluence with Chalti Khola and the confluence with Mel Khola, it seems that the form of sediment transport was or sediment-loaded flow or bed-load, judging from the result of sieve analysis, field observation and the riverbed gradient.
iii) In the downstream of Agra Khola between the confluence with Mel Khola and the confluence with Mahesh Khola where Mahadev Besi Bridge is located, the major component of sediment is fine sand although a number of big boulders of granite exist on the riverbed. It is hardly possible to understand that these big granite boulders have its origin at the uppermost basin of Agra Khola, because of the facts that none of granite boulders is found in the upstream and large-scale landslide did not occur in the areas of granite upstream even on the occasion of 1993 disaster.
iv) The origin of granite boulders that have flowed down to the site of Mahadev Besi bridge in case of 1993 disaster seems to be the alluvial terraces distributing along the lower reaches of Agra Khola. Those alluvial terraces naturally contain granites boulders since geological area.

5.5 Mechanism of 1993 Disaster and Disaster Potential in Future

1) Mechanism of 1993 Disaster

The yielding source of huge amount of sediment can be attributed to the landslides in the upper reaches of Chalti Khola and Agra Khola. Landslides that had been existing before the 1993 disaster since long time ago must have become bigger than before and also plenty of landslides must have newly developed due to anomalous rainfall at the time of 1993 disaster, but the distinction of old and new landslides is not always clear for lack of exact data. This adversely suggest that geological and geomorphological situations are essentially vulnerable to the slope failures and landslides.

In the uppermost reaches of Agra Khola the hillslopes are very steep, showing 30° ~ 45° which is almost equal to or rather steeper than the internal friction angle of the soil or rock mass. It is naturally obvious that such steep slopes of mountains are erodible and easy to fall down, even in case of heavy rainfall.

A geological layer called Kulekhani Formation is highly fractured and deeply weathered. Two to four sets of geological joints are remarkable in the quartzite and schist layers distributed in Chisapani and Chaubas areas. The spacing of those joints varies from a few centimetres to tens of centimetres. Such characteristics of geological formation also implies the high-grade susceptibility of collapses in rock mass.

The discontinuities of the rock mass and their intersections make good sliding surfaces. Plane rock slides are especially common on the dip-slopes, whereas wedge failures are observed mostly on the counter sip-slopes. Plane rock slides occurred on slopes that were close to the surface. They are generally large in comparison with the wedge failures. Consequently, old landslides which has been almost inactive have been aggravated and was expanded tremendously.

Furthermore, prior to the heavy precipitation of 19 July 1993, the soil mass had been already wet and saturated. The overburden soil including organic rich soil mass had been already wet and saturated. The overburden soil including organic rich soil lying over the bed rock is mostly thin (less than 3 m). Thus, in saturated or wet conditions, the overburden soil was washed out and slid.

Besides, none of the catchments has rainfall gauging station, so the relationship between the rainfall intensity and the debris flow occurrence was difficult to examine. Sudden outbreak of 1993 disaster was inevitable.

2) Disaster Potential in Future

From the following point of view, it seems that disaster potential in the future is very high.

i) The amount of sediment yielded by landslides was estimated about 20 million m^3 in total at the time of 1993 disaster. This estimation was conducted through aerophoto interpretation as well as field survey on spots by DPTC. According to the same estimation, it is reported that sediment amount delivered out of Agra Khola basin to the downstream must be 1.3 million m^3 in total. The result of this estimation suggests that a considerable amount of sediment still remains in the basin.

ii) On the right bank of Chalti Khola, there is found rather clear symptom of land creeping which is formed even in the bedrock and of structural deformation in geomorphology. On the left bank of Chalti Khola are also found several landslides which trend to creep gradually. Tension cracks that characteristically appears on the crown of creeping landslides prevail on the left bank of Chalti Khola and Agra Khola upstream, the dimension of such cracks is 5 cm to 30 cm.

iii) Although there would not occur some big events of landslides in the river-channel from the confluence with Chalti Khola up to the confluence with Mel Khola, it is feared that in the rivercourse downstream of Agra Khola, in the section not so far from Mahadev Besi Bridge, existing unsettled boulders and sediment would remove downstream in case of big flood occurrence because of incised meandering of floodwater as well as unstable longitudinal profile of riverbed. Alluvial river terraces and the talus still have potential to deliver sediment which may cause the disastrous event due to outflows of debris/sediment.

iv) Deforestation, Cultivation on hillslopes may exert terrible influence on the potential of sediment-orientated disaster because steep hillslopes without vegetation, needless to say, are very susceptible to erosion, apt to cause landslides. Yielded sediment may aggravate the equilibrium of river regime for a long time.

v) From long-term point of view, disaster potential leading to disastrous event can be said to be augmented by deforestation and intensive use of cultivation. For the present, the disaster potential is continuously increasing. From short/middle term point of view, the damage potential would derive from the sediment accumulation on the riverbed. Boulders and sediment accumulated in the lower segment of Agra Khola will be influential on the safety of Mahadev Besi Bridge.