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FORMATION DES INGÉNIEURS FORESTIERS

Landslides and gullies in managed watersheds: risks, mitigation strategies, upstream-downstream linkages.

ICIMOD

Example from the Kathmandu valley, Mid-Hills of Nepal

Master thesis

Nicolas Dolidon

Forest Engineer training – Graduation year 2008

August 2008

Picture on the front cover: Godamchaur village, rice fields, degraded area and forested hill. Lalitpur, Kathmandu Valley, Nepal.

Source: N. Dolidon

Paris Institute of technologies for life, food and environmental sciences.
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Food and Agriculture Organization of the United Nations - FAO

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Abstract:

Landslides are soil or bedrock movements which can lead to important damages to natural or man made elements of interest, such as natural habitats, infrastructures, industries, agricultural land, dwellings and even human lives. They are of concern throughout the globe and constitute an issue tackled by several international organizations, including FAO. Gullies are another erosion process which constitute a threat to livelihoods of people living in mountain areas of the world. Gullies can eventually lead to landsliding.

Slope stability is an issue embedded in a broader system including human lives and activities, linked to natural phenomena. Based on a global literature survey and a field study in the Mid-Hills of Nepal, the present document aims to give an integrated approach of the risks related to landslides and gullies, as well as some key components for their mitigation. The complementary roles of vegetation, soil and water management are of highest importance. The emphasis is put on the high interest of the watershed scale approach to best address these issues and the study highlights upstream-downstream linkages.

Résumé:

Les glissements de terrain sont des mouvements du sol ou de la roche-mère qui peuvent conduire à d'importants dégâts à des éléments d'intérêts, naturels ou construits par l'Homme, tels que des habitats naturels, des infrastructures, des industries, des terres agricoles, des logements, ainsi que des vies humaines. Ils sont un sujet de préoccupation partout dans le monde et constituent une question abordée par plusieurs organisations internationales, notamment la FAO. Les ravines sont le résultat d'un autre processus d'érosion et constituent une menace pour les moyens de subsistance des personnes vivant dans les zones de montagne du monde. Le ravinement peut parfois conduire à un glissement de terrain.

La stabilité des pentes est une question ancrée dans un système large, comprenant des vies et activités humaines, ainsi que des phénomènes naturels dynamiques. Basé sur une étude bibliographique à l'échelle mondiale et un exemple de terrain dans les collines du Népal, le présent document vise à fournir une approche intégrée des risques liés aux glissements de terrain et au ravinement, ainsi que certains éléments clés pour en atténuer les effets. La complémentarité entre les actions sur la vagétatio, le sol et l'eau tinet une place centrale dans la poursuite de cet objectif. L'attention est portée sur le grand intérêt de l'approche à l'échelle des bassins versants pour mieux répondre à ces questions et l'étude met en avant les liens amont-aval.

Acknowledgments

The work carried out during this study would never have been possible without the support of many different persons.

I would like to thank in particular Thomas Hofer for giving me the possibility to undertake this master thesis at the service of FAO, for his kind professional and personal support during my whole stay in Rome, and for all his efforts to stay close to my work despite the distance during the field phase in Kathmandu. Thank you also to Moujahed Achouri for keeping the eye of a chief on this work.

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Many thanks to Michael Kollmair and Eklabya Sharma for welcoming me at ICIMOD in Kathmandu.

My special thanks go also to Keshar Man Sthapit, Isabelle Providoli, Jagannath Joshi and Madhukar Upadhya, who provided me useful support and guidance in Nepal.

I would like to thank all the persons who contributed to the success of this assignment, by facilitating administrative tasks, providing practical help during the data collection, bringing in interesting ideas through exchanges, or by translating during the discussions. I think in particular of Dipak Gyawali, Nani Ram Subedi, Sanjeev Bhuchar, Madhav Dhakal, Dhrupad Choudhury, Lucy Luna, Mamata Shrestha, B.B. Basnet, Narayan Kargui, Rupak, Rupesh, Anand and Rambadur Khadka, Lucile Reboul, Marianne Sanlaville and all the inhabitants of Godamchaur and Bistachhap I might forget, as well as ICIMOD and FAO staff and external researchers or watershed management professionals.

Foreword

This study was carried out within and in collaboration with four different institutions in two different countries (Italy and Nepal). It was foreseen to include a part in Bangladesh but due to administrative reasons the travel had to be canceled at the last moment. Hence, the work carried out has not been planned as a homogeneous study from the beginning, but had to be adapted to a changing context.

This led to some delay in the work. Moreover, the absence of my supervisor during the last month did not allow setting up the report together.

This report is also a master thesis report, aiming to explain my work to my university. It is not a pure scientific document, but contains an auto-analysis of the work carried out.

Consequently, the present document is not a definitive one. It is the result of six months work, but not the final study. I would like to better analyze the data collected in Nepal and include more precise propositions. Moreover, I would like to discuss this to further precise the expectations of FAO, ICIMOD and the DSCWM. A more synthetic but complete document would be the output of such discussions.

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Index of Acronyms

CEE: Central and Eastern Europe.

CFUG: Community Forestry User's Group.

CIS: Commonwealth of Independent States.

DSCO: District Soil Conservation Office. Local representation of the DSCWM.

DSCWM: Nepalese Department for Soil Conservation and Watershed Management. Part of the Ministry of Forests and Soil Conservation.

FAO: Food and Agriculture Organization of the United Nations.

HKH: Hindu Kush-Himalaya.

ICIMOD: International Centre for Integrated Mountain Development.

ICL: International Consortium on Landslides.

NARC: Nepalese National Agricultural Research Center

NWCF: Nepal Water Conservation Foundation

UN: United Nations

UN/ISDR: United Nations International Strategy for Disaster Reduction.

WLF: First World Landslide Forum

Introduction

Landslides are natural or man-made processes which occur in mountainous areas. They are characterized by a downwards movement of soil mass, rocks. They are often triggered by heavy rainfalls or earthquakes, but human activities can create favorable conditions for landsliding. The size of a landslide is a simple and efficient way to classify it. It can range from very small landslides, to massive ones, involving up to several tens of thousands of cubic meters. Landslides are also classified according to the type of movement and the nature of the moving mass. Some parts of the present study talk about landslides in general; when limits have to be set, for example regarding the depth of landslides against which forests may have an effect, it will be mentioned.

Gully erosion is another type of soil loss, which can also lead to natural disasters, in particular landslides and mudslides. These phenomena are strongly linked to each other. A gully is the result of a concentrated soil loss along a specific line. It is a whole in the soil. The difference with a rill is that a gully can not be rehabilitated with a plough. Hence, its can be from about 50 cm wide to several meters. The length has no theoretical limit; this document will talk in particular about gullies reaching up to 400 m length.

Gully and landslide mitigation are of high relevance for food security. Indeed, a good soil state is a necessary condition to guarantee livelihoods. Human activities interact with natural phenomena and influence the soil stability in the slopes. Hence, it is important to adapt human activities to local conditions, ensuring soil stability.

Starting from one given point, run-off resulting from rainfall, snow melt or glacier melt flows always to the same direction, given by the slope of the terrain. An area so as the entire run-off starting from any point included in this area flows out the area by a single outlet, eg. a water stream, is called watershed, or catchment area.

The present study aims to explain the interest of addressing soil conservation issues such as gullies and landslides on a watershed scale, identify possible consequences of soil losses, understand the processes occurring and provide clues for the soil conservation integrated at a sound scale – the watershed one whenever possible.

It is based on a work carried out at the Food and Agriculture Organization of the United Nations headquarters on one hand, and on a case study of the Kathmandu valley, Nepal. The work last for six months and took place at several geographical and institutional scales.

The first part of the present document explains the institutional framework of the study; it is followed by the results of a literature survey carried out at FAO in Rome on the role of forest and watershed management in landslide risk mitigation. The third and fourth part present the field study carried out in the Mid-Hills of Nepal, enlarging the scope to the gullies. Finally, a fifth part allows discussing the work carried out, the lessons learned, and proposing further research topics.

1. A global issue, local problems and institutional answers: a multi-scaled study

After explaining the importance of landslide related issues worldwide, this part will deal with the institutions within, or in collaboration with which this study has been carried out. The purpose is to see the different institutional answers to the exposed problems, the place of the study within these institutions and the role they played for the study.

1.1. Landslides and soil losses: a global issue

During the period 1991-2005, 12 733 people were reportedly killed by landslides (source: United Nations International Strategy for Disaster Reduction- UN/ISDR). Representing 1.3 percent of the 960 502 reported casualties killed by natural disasters worldwide, it is a rather small proportion, but still a large figure. However, this percentage varies depending on the place in the world. In the Central and Eastern European (CEE) countries and Commonwealth Independent States (CIS – former Soviet Union), landslides have caused the death of up to 11 percent of all casualties killed by natural disasters. Moreover, 9 369 out of the 12 733 victims of landslides lived in developing countries, which represents a proportion of about 73 percent. These figures show that landslides are a big issue, in particular for countries which have not a wealthy economy and thus have not the means to implement prevention and protection measures.

Moreover, beside the massive landslides which lead to direct casualties, smaller and more shallow landslides can have a less impressive, slower, but also very important effect. They are indeed major erosion processes, which threat food security in some regions of the world, through different processes. For example landslides are identified as one of the main causes for soil erosion and increased sediment load in rivers of Nepal and downstream (ICIMOD, 2007). This phenomenon is a two-fold problem. On one hand, on-site agricultural productivity is threatened by the soil losses. On the other hand, the increased sediment load in rivers leads to deposition in the plain downstream and thus to lateral shifting of rivers. Good examples illustrating this phenomenon are the Kosi river in India and Nepal, as well as the lower Ganges-Brahmaputra river system in India and Bangladesh, of which the shiftings cause major problems for agriculture development and thus food security (Thompson et al. 2007, Hofer and Messerli 2006). At a smaller scale, we will see that erosion can have negative impact on irrigated fields through increased sediment load as well.

To best address the issue of landslides, several organizations and institutions are working and collaborating on it at different scales. Following paragraphs will explain the role of some of them: the Food and Agriculture Organization of the United Nations (FAO) and the International Consortium on Landslides (ICL) for the global scale, the International Centre for Integrated Mountain Development (ICIMOD) at the regional scale, the Nepalese Department for Soil Conservation and Watershed Management (DSCWM) at a national and local scale, as well as a Community Forestry User's Group (CFUG) of the Kathmandu valley at the local level. Moreover, for each organization, I will explain how the study was integrated in its work, and what the organization brought to the study. It constitutes the global methodology of the study.

1.2. The Food and Agriculture Organization of the United Nations – FAO: the global point of view

The mission of the Food and Agriculture Organization of the United Nations (FAO) is to work towards a world without hunger. It aims to enhance people's livelihood wherever requested and fighting against food scarcity in the world. Precisely, as described above, natural disasters can have a very important impact on food security. Therefore, FAO has developed some competences and partnerships in the field of natural disaster management.

In-house collaborations between several services have been developed, such as the Interdepartmental Working Group on Disaster Risk Management. Moreover, FAO is member of international partnerships dealing with natural disaster risk management, such as the International Consortium on Landslides (ICL). Thomas Hofer, as head of the Forest and Water Program, undertakes the communication and partnership with ICL. The forest and Water Program, a unit of five to six persons, is part of the Forest Conservation Service within the Forestry Department of FAO.

ICL has been organizing the 1st World Landslide Forum (WLF), to be held in Tokyo from 18 to 21 November 2008. This forum is "*a global cooperation platform for all types of organizations from academia, United Nations, governments, private sectors, and individuals which are willing to contribute for landslide and other related earth system risk reduction*" (quoted from ICL website). It will allow a better exchange between different types of actors of disaster risk reduction. It is expected to be a cross-sectoral forum, to address issues ranging from scientific to policy level, and from strict geomorphological studies to socio-economic impacts of landslides.

As a member of ICL and co-organizer of the 1st World Landslide Forum, FAO through the Forest and Water Program has to organize one of the 18 parallel presentation and discussion sessions to be held, entitled "Role of forest and watershed management for landslide risk reduction". In the present document, it will also be called "session 18". The idea of this session is to show the influence of forests and their management on landslide mitigation and to explain the importance of other land uses in both ensuring sustainable livelihoods and protecting the soils from landslides and other kinds of degradation. This session, on which several UN Agencies and ICL members agreed, shows that landslides are recognized as an issue for food security. Moreover, FAO is likely to organize the next World Landslide Forum in 2011. This is also the recognition for the importance of the broad topic "landslides and livelihoods".

In the framework of the 1st World Landslide Forum, ICL will publish a book entitled *Landslides: disaster risk reduction*. It will include among other things one chapter per session organized during the forum. Contributing to the organization of the session on "Role of forest and watershed management for landslide risk reduction" and to the writing of the corresponding chapter, called chapter 33, have been two of the main tasks carried out during this master thesis. It constitutes the theoretical part, the global survey and literature review of the study. Thus, I will allow quoting some important extracts from the chapter in the present document.

My contribution to FAO's work:

- Contribute to the organization of the session on Watershed and forest management for landslide risk reduction of the First World Landslide Forum.
- Write the corresponding chapter for the book *Landslides: disaster risk reduction*.
- Through the mission in Nepal, support other regional and national institutions on food security related issues.
- Synthesize available knowledge on a food security related issue, as well as documentation of a specific case study (after the field phase).

Place of this work in my global methodology:

- Literature survey, introduction to the topic through a global overview.
- Identification of major sub-topics to be taken into account

1.3. Addressing soil conservation issues in the Hindu-Kush Himalayan region: one of the tasks of the International Centre for Integrated Mountain Development - ICIMOD.

"The HKH region extends 3 500 km over eight countries from Afghanistan in the west to Myanmar in the east. It is the source of ten large Asian river systems -– the Indus, Ganges, Brahmaputra (Yarlungtsanpo), Irrawaddy, Salween (Nu), Mekong (Lancang), Tarim (Dayan), Yangtse (Jinsha), Amu Darya, and Yellow River (Huanghe) - and provides water, ecosystem services, and the basis for livelihoods to a population of around 150 million people in the region. The basins of these rivers provide water to 1.3 billion people, a fifth of the world's population."

This presentation of the Hindu Kush Himalayan (HKH) region on the website of the International Centre for Integrated Mountain Development (ICIMOD) shows how important is the watershed and large scale river basin approach in this particular context. Water, linking remote regions one with each other, forces development actors to have a shared overview on natural resource management and thus livelihood related issues. This is one of the reasons for the creation of ICIMOD in 1983, in order to improve livelihoods of the people and the management of the natural resources in this geologically unstable, meteorologically extreme and demographically dynamic region.

Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan are the eight members of this international governmental organization. They all have a part of their territory in the action area of ICIMOD, shown on the map in annex 1. ICIMOD allows better exchange of knowledge and experiences, improved budget, and a better overview of the region, for sound development actions. The regular budget of the organization is provided by the member countries. Specific projects are funded by external donors. The headquarters are located in Kathmandu, Lalitpur, Nepal, and host a total of about 120 people, including managers, natural resources management and mountain development experts, as well as administrative personnel.

As an actor of natural resources management in this mountainous area, ICIMOD logically has to deal with natural disasters, soil conservation and watershed management. Among others, the watershed management team is running projects to rehabilitate degraded areas in Afghanistan; it recently completed a large project on best watershed management practices with study sites in Nepal, Pakistan and India; and is part of the emergency rehabilitation unit set up after the earthquake which hit the North West Frontier Province, Pakistan, and the Pakistan-Administered Kashmir in November 2005. Soil conservation and watershed management are an issue in all these activities, and landslide risk reduction is one of the central themes in Pakistan. It is worth noting that the FAO Forest and Water Programme, in which the theoretical part of the present study took part, is also strongly involved in this project.

The collaboration with ICIMOD has been set up because they are implementing a project led by the United Nations Development Program (UNDP) in the Chittagong Hill tracts, Bangladesh, to which a study in the framework of this mater thesis could have brought an interesting contribution. It was foreseen to prepare this project at ICIMOD headquarters in Kathmandu, Nepal, and then go to Bangladesh. For administrative reasons, the trip to Bangladesh had to be canceled and a new study had to be found and created in Nepal. Thus, it is not integrated in any ICIMOD project, but we will see that it matches with ICIMOD activities, since it contributes to the documentation of different case studies, brings a reflection on low cost soil conservation methods and aims at contributing to the improvement of livelihoods in one of the regions of the HKH.

Carrying out this study with ICIMOD allowed to receive local expertise and benefit from a long experience regarding these topics. This took place mainly through field visits in particular with Keshar Man Sthapit, introducing me to watershed and soil conservation related issues. Beside this technical support and this teaching phase, ICIMOD provided working facilities such as an office and communication tools, vehicles whenever needed and material for field measurements.

MY CONTRIBUTION TO ICIMOD'S WORK:

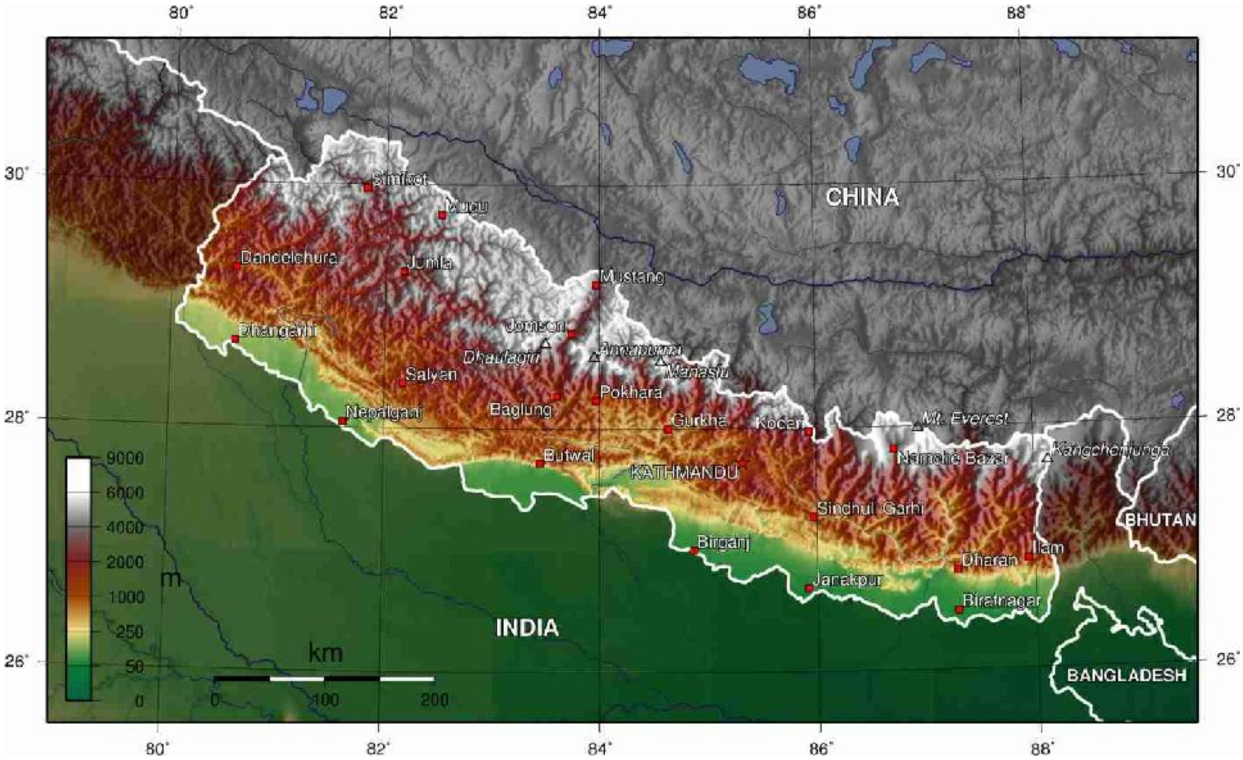
- SUPPORT LOCAL ORGANIZATIONS AND GOVERNMENT OFFICES TO CONTRIBUTE TO THE LIVELIHOOD IMPROVEMENT.
- DOCUMENT SPECIFIC CASE STUDIES ON MOUNTAIN DEVELOPMENT RELATED ISSUES IN THE HKH.

PLACE OF THIS WORK IN MY GLOBAL METHODOLOGY:

- VISITS AND LITERATURE REVIEW TO BETTER UNDERSTAND LOCAL CONTEXT AND TECHNICS.

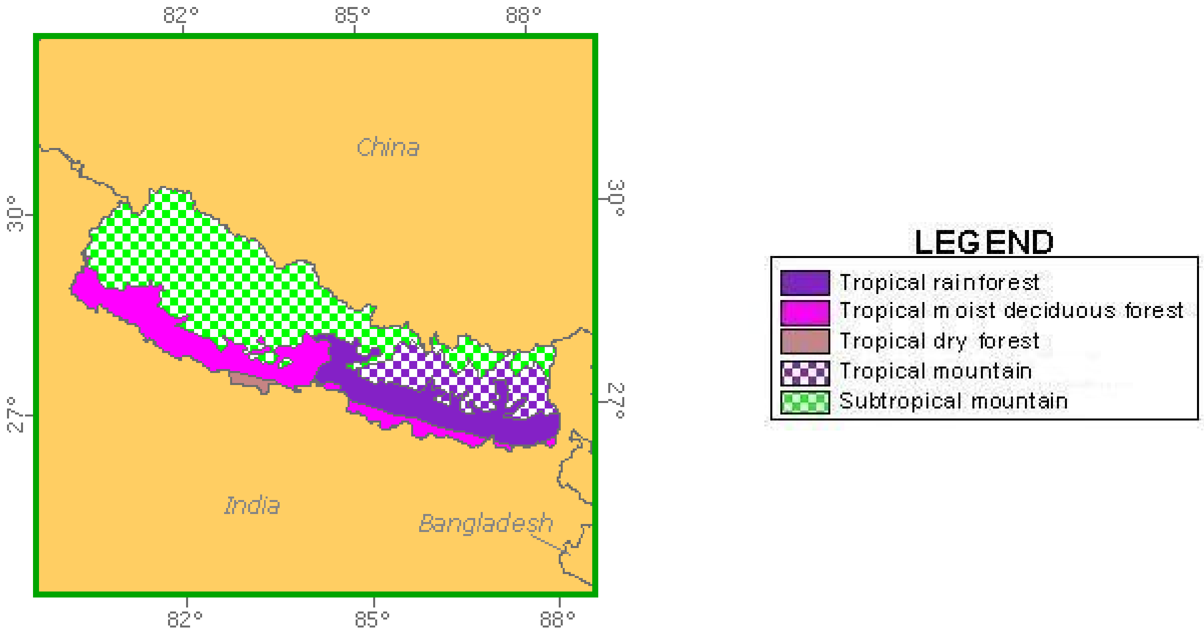
1.4. The Nepalese context and the Department for Soil Conservation and Watershed Management - DSCWM

Nepal is a 147 181 sq km large country (about one fourth of metropolitan France), located around 28º N latitude and 84º E longitude. It borders China in the north and India in the south, east and west. One of its most remarkable geographical characteristics is the wide range of altitudes encountered in the country, shown on the topographical map 1 below. The lowest point's altitude, Kanchan Kalan in the Tarai region, is about 70 m, whereas the highest place of the country is the highest peak of the world, the 8 850 m high Mount Everest. Eight of the ten highest mountain peaks of the world are located in Nepal. The country is rectangular shaped, oriented from west-north-west to east-south-east. It is about 820 km long and 240 km wide, at the largest place. This relatively small figure shows that the increase in altitude takes place on a short distance. For instance the distance between the Mount Everest and the southern border, which is at the altitude of 90 m in that place, is only 150 km in straight line.



Map 1: Topographical map of Nepal. (Source: solarnavigator.net)

This very large increase in altitude on a short distance leads to a great diversity of natural contexts. Climate is monsoon driven in the whole country, but the amounts of rain vary a lot and so do the temperatures. This allows the easy identification of three major natural zones: the plains of the Tarai region in the south and south-west, the Mid-Hills, and the Himalayas in the north-north-east. The climates range from subtropical monsoon climate in the plains to arctic climate in the high mountains, with several variations in between. The Mid Hills present a subtropical mountain climate. Map 2 presents the main ecological zones of Nepal. The structure of the climatic variability in the different climates is clear on this map.



Map 2: Ecological zones of Nepal (source: Global Forest Resources Assessment 2000 - FAO)

This diversity reflects also in the different types of natural disasters Nepal has to face. Because of the important tectonic activity, the fragile geology of the young mountains and the heavy monsoon rainfalls, water induced and earthquake induced disasters are an important issue, which vary with the topography. People of the high mountains have mainly problems with glacier lake outbursts and massive landslides. In the mid-hills, shallow landslides and mudslides are the main issue, whereas the plains experience mostly floods (Joshi, J. personal communication).

To face these problems of natural disaster hazards, the government of Nepal has established several executive bodies. The Department of Soil Conservation and Watershed Management (DSCWM), within the Ministry of Forests and Soil Conservation, is one of these bodies. Its mandate is soil erosion control and watershed management. Thus, the shallow landslides of the mid hills are integral part of its competence field.

The DSCWM has a central direction, based in Kathmandu, and 56 District Soil Conservation Offices (DSCO). Altogether they are active in 60 districts, out of the 75 districts of Nepal. The DSCOs elaborate their own program, propose it to the centralized DSCWM and implement it according to the budget they receive. This allows to work in close collaboration with the local communities, in order to identify problems, adapt the solutions, implement them and ensure their sustained maintenance whenever necessary. The central office of DSCWM is there to coordinate the actions and to ensure a correct repartition of the budget, but the approach is really a bottom-up one.

DSCWM has six so-called technical sections, which work on issues relevant for the whole country. The role of one of them, the technology and development section, is to carry out testing of technologies, adapt suitable technologies to different situations, do research work and demonstrate soil conservation and watershed management methods. Working for the technology and development section, Dr. Jagannath Joshi has started the development of a demonstration site in Godamchaur, district of Lalitpur, in the Kathmandu valley. A five years long project started in 2005 aims at testing technologies on a degraded site in Godamchaur, and to show this example to other actors of soil conservation and watershed management.

This project has been the starting point for the field phase of the present study. It constitutes the local example which allows illustrating concretely the issues discussed in the general case. A first phase of my work has been proposed by Jagannath Joshi and consisted in assessing the eroded volume as well as the influence of the treatment of the gully on downstream located rice fields. Since it was not enough for my master thesis, I developed the second phase to complete the study. It is interesting for DSCWM and usable for the improvement of the demonstration site, but is an additional and external input to the initial project. It involves other gullies than the one treated by the project. More details are given on this personal work in sections 3 and 4.

My contribution to DSCWM's work:

- Document the demonstration site to better understand it and provide more information to visitors.
- Propose treatment methods for this site and neighbouring degraded areas
- Provide a reflection on site adaptation of treatment measures

Place of this work in my global methodology:

- DSCWM provided me the starting point for a concrete case to study, which I developed myself
- This collaboration allowed learning about the Nepalese national strategy for soil conservation and watershed management.

1.5. Godamchaur Community Forest User's Group and soil conservation

Community Forestry is very widespread throughout Nepal. A community forest is a forest which belongs to the Nepalese government, but which is managed by, and of which the products belong to a Community Forestry Users' Group (CFUG). The CFUG is in charge of establishing management principles and rules for the forest, apply them and make sure they are respected. As a counterpart, the CFUG members are the only ones authorized to harvest products from the forest, of course according to the rules. The CFUG allows to take into account the needs and points of view of a whole community, often part of a village, and establishing an adapted management policy.

Thus, CFUGs do not look after soil conservation in particular, but after all the needs of the community and the services and products the forest can provide. However one of the most remarkable differences for a forester who is used to European production forests is the importance of conservation and the high level of protection of the forest. In many community forests, harvesting living trees is forbidden, except one or two trees in exceptional cases, such as the construction of a house. Even the access is restricted only to the CFUG members on specific days of the week. Most of the products used are non-wood forest products such as medicinal plants and fodder, as well as the dead branches and shrubs which are used as fuel wood. This rather "passive management" is actually a protection measure for the forest, and thus for the soil.

The demonstration site of DSCWM in Godamchaur is located in a community forest. The CFUG is called "Godamchaur CFUG" and includes people from the wards 1 to 3 of the village, which means around 315 families, or 2500 people. The area of the community forest is 27.8 ha. Neighboring gullies which have been studied are located in the Bistachhap Community Forest, located on the southern part of the same hill.

Like everywhere in Nepal when the DSCWM starts a new project, the local CFUG - here the Godamchaur CFUG - has been involved since the beginning. Its members, in particular the representatives, participated in the whole process of problem identification, search for solutions, and were responsible for the implementation of soil conservation measures. Thanks to this early involvement in the project, Mr. B.B. Basnet, chairman of the Godamchaur CFUG, knows a lot about the topic. Thus, discussions with him allowed me to have a local point of view, as well as to learn a lot about the area, the life style, the impact of the soil losses on the inhabitants and other important related issues. Moreover, other CFUG members, and in particular Rupak Khadka, helped by translating during the discussions. The contact to CFUG allowed better understanding the links between local people and soil conservation related issues, such as possible reasons for man-made soil degradation, the impact on livelihoods, the role local people can play in its mitigation. Thus it helped better understanding possible scopes for the study and it will help adapt propositions to the reality.

My contribution to Godamchaur CFUG's activities:

- Document the demonstration site to better understand it.
- Propose treatment methods for this site and neighbouring degraded areas.
- Make proposals local people may not have thought about, because of cultural difference.

Place of this work in my global methodology:

- Interviews with local people: better understanding of social elements at stake.
- Documentation for cost estimation (not exploited in the present document).

Working within, with and for different organizations and institutions allowed having a broad overview of the different perceptions of landslides, from the broad international expert's one to the local farmer's one. Starting at the international level has been a good introduction to have an overview of all possible elements at stake. Carrying out a field study on a specific example showed me how major soil erosion can affect people's life and how they cope with it. Hence, this diversity of working contexts and of tasks has been an advantage for my personal experience, my curiosity and the better understanding of the whole topic "Watershed management for soil conservation".

However, because of this situation and of the unforeseen cancellation of the trip to Bangladesh, the study could not be planned as one homogeneous project from the beginning. The literature survey in Rome and the writing of a global paper helped getting into the topic, but still it was separated from the study on a specific example in Nepal. This is why next part will explain both methodology and results of the theoretical part in Rome, and part 3 and 4 will deal separately with the work carried out in Nepal and its results. The entire study and its teachings will be put in perspective in part 5.

2. A general overview on landslides within watershed systems

My terms of reference at FAO included the participation in the organization of the session 18 of the First World Landslide Forum and the writing of the corresponding chapter. The United Nations University, through Libor Jansky, based in Bonn, Germany, and the Kyoto University, Japan, represented by Roy Sidle, are co conveners of the session. Hence both tasks have been done in collaboration with them. This work has been a way to learn about the topic, to answer some questions and to raise other ones, thus developing my perception of watershed management, forest management and landslide risk mitigation with a broad point of view.

2.1. Methodology: discussions and readings

2.1.1. Meetings, discussions and e-mails to organize the session on "Watershed and forest management for landslide risk reduction" of the First World Landslide Forum

The first steps to organize the session were to identify relevant sub-topics to be treated, in order to invite competent speakers who could make presentations about them. At the beginning of the present study, March 3rd, 2008, a draft list of propositions already existed on ICL website. This list was drafted during a preparation meeting at the United Nations Educational, Scientific and Cultural Organization (UNESCO - also member of the organization committee of the World Landslide Forum) headquarters in Paris in November 2007. Using this list of propositions, the three main co-conveners (Thomas Hofer for FAO, Libor Jansky for UNU and Roy Sidle for the Kyoto University) made a first proposition of potential speakers.

This set a base for in-house discussions. Indeed, the second step has been a meeting between Libor Jansky, Thomas Hofer and me in Rome, followed by a brainstorming meeting gathering people from the Interdepartmental Working Group on Disaster Risk Management and the Interdepartmental Working Group on Mountains, as well as Mr. Jansky. These groups include FAO staff who work on relevant issues (disaster risk management and/or mountains in this case) within different departments of FAO. Both meetings allowed to better set the aims of the session, identify precise topics, modify the proposed ones and find new potential speakers.

2.1.2. A literature survey and discussions to write the background paper of the session

The preliminary discussions for the preparation of the session constituted already a good first introduction in the field of landslide risk management and allowed having a rough overview of different relevant topics. But the true study started with the literature survey necessary to write the chapter corresponding to session 18, which had to be finished by the end of April.

It was decided to divide the session in six sub topics, which we considered as most suitable to deal with the most important aspects of the role of watershed and forest management for landslide risk reduction. These six themes are explained and justified in part 2.2.1. Each sub topic will be presented by one different speaker during the 1st World Landslide Forum. Once the speakers had been contacted and agreed on participating, they had to provide a two pages long abstract of their presentation. They would constitute the second part of the chapter. I had to write the first part, which would introduce the reader to the topic, justify the organization of this session, and place it in the global framework of landslide risk management. This first part, fruit of the present study, is rather global. But to understand what it is about and to replace it in the global context, I had to learn also on precise technical aspects of landslides. Because in order to understand the possible mitigation measures, it is important to understand the physical processes of sliding.

Thomas Hofer provided me with some literature. I also found documents by looking on the Internet, by reading the references quoted on the already available literature and by direct contact with some experts. The main resources used include scientific publications on landslides and their mitigation, published in journals such as *Landslides*, edited by ICL, books and handbooks published by different institutions such as ICIMOD and the British Columbia Ministry of Forest and Range for the technical part. Regarding watershed management, the almost only publication used is the FAO forestry paper #150: *The new generation of watershed projects and programmes*. It provided the framework in which the session was supposed to be integrated. I did not find any publication which was clearly linking watershed management as a whole with landslide risk reduction.

2.2. Integrated approach of landslide risk reduction at the watershed scale: results of the discussions and literature study

Following section will explain the choice of the six different topics for the session as well as the results of the literature study, presenting how forest and watershed management relate with landslide risk reduction. Except for the presentation of the different topics, which is here only a brief description and justification of our choices, following section is mostly constituted by contents of the chapter 33 of the book to be published.

2.2.1. From natural phenomena to policy processes: the six issues addressed during the session.

The first topic proposed for the session is “The role of trees and forests in landslide risk mitigation”. The aim is to understand the natural phenomena at stake before talking about the influence of human activities on them. It will present a case-study from Iran, where different roles of vegetation have been studied.

Following step is to talk about forest management practices and their influence, during the presentation entitled “Effect of forest management activities on landslide risk”. This presentation will deal with the effect of all forest management activities on the landslide risk of already sensible places: the debris fans. It will present guidelines for risk assessment and mitigation established by the British Columbia Ministry of Forests and Range.

Road building is one of the rural and forest development activities which can increase the landslide risk very severely. Therefore it was decided to make a presentation entitled “Effects of forest/mountain roads on the occurrence of landslides and land degradation”. This presentation will be based mainly on American experience regarding consequences of forest roads on landslide hazard and corresponding mitigation measures, a well as the increased sediment load due to forest roads.

Different land uses, and different practices for each land use may have different influences on landslide hazard. To illustrate how people can manage their land on a proper way and develop suitable agricultural practices to ensure both slope stability and sustainable livelihoods, the fourth presentation in the session of the WLF will show a successful example of Honduras. It will be entitled “Honduras: people's participation brings food security".

After these technical aspects on forest management, road building and agricultural practices, the fifth presentation aims at addressing a socio-economical aspect of soil conservation and landslide risk reduction at a watershed scale. Motivation of the land user to implement the best practices, for the benefit of other watershed stakeholders is obviously an important factor. If these best practices do not match with the economical interests of the land user, an additional motivation might be necessary. Therefore the topic 5 of the WLF session is entitled "Potential of payment for ecosystem services schemes for landslide risk mitigation". Based on six different examples of payment for ecosystem services schemes in South America and Asia, it explores the possibility of applying them for landslide risk reduction.

Finally, the sixth topic will deal with political aspects of watershed management for landslide risk reduction. It will be entitled "An example of a policy for managing a forested watershed to mitigate landslide risk: the French Risk Prevention Plan" and present an example in which hazard mapping and assessment of the potential of forests for reducing landslide hazard allow a sound spatial repartition of different activities, as well as a targeted prioritization for hazard mitigation measures where they can be implemented.

After the choice of the topics to deal with, done thanks to discussions among session conveners and colleagues, the aim of the literature study was to explain the framework of the presentations and justify these choices. Following sections constitute the core of the literature survey and of the chapter 33, background for a better understanding of the presentations.

2.2.2 What is a risk?

In order to understand the interrelated roles of watershed and forest management in landslide risk reduction and their links to each other, one first needs to define and understand clearly some key-concepts. The first step is to define *risk*, through its different components.

First component to be defined: the *hazard*. Varnes (1984) says "natural hazard is the probability of occurrence within a specific period of time and within a given area of a potentially damaging phenomenon". The Canadian Standards Association (CSA, 1997) defines a hazard as a source of potential harm or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment and other things of value; or some combination of these. UN/ISDR proposes following definition for a hazard: "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation" (UN/ISDR, 2004).

In the case of landslide management, the landslide is the "source of potential harm", the "potentially damaging phenomenon". These definitions imply that a potential landslide, to be considered as a hazard, has to constitute a threat to something of value such as human lives, property, or the environment for example. Under such a perspective, landslides which have no harmful potential would not be considered hazards (Wise, Moore & VanDine eds. 2004).

This is not a view shared by everyone. Some other definitions consider that the probability of the phenomenon itself, characterized by the susceptibility of the terrain, the frequency of landslides and their magnitude, is always a hazard, even if it does not threaten anything of value (Lee and Jones 2004, quoted from Fourniadis, Liu and Manson 2007).

It is proposed, for the purposes of this study, to adopt the following definition: a landslide hazard is the existence of a probable landslide of a given magnitude in a specific area within a given period of time. The hazard is assessed by its probability of occurrence. Of course landslides are natural and normal processes and if they do not threat anything of value it does not make any sense to mitigate them.

This leads to the second component of a risk, which are the *elements at risk*. The British Columbia Ministry of Forests and Range (2002) lists potential elements at risk as human life and bodily harm, public and private property (including building, structure, land, resources, recreational site, and cultural heritage feature), transportation system/corridor, domestic water supply, fish habitat, wild life (non-fish) habitat and migration, visual resource and timber.

The nature of the element at risk is as important as the hazard to define and characterize the risk. Indeed, the impact of a given hazard depends on the *vulnerability* of the element at risk.

UN-ISDR suggests that a risk is “the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions.”

Varnes (1984) defines the specific risk (R_s) for a given element at risk as the product of the hazard (H) and the vulnerability of the element at risk (V).

$$R_s = H \times V$$

He defines vulnerability as “the degree of loss to a given element or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude”. For example, a thick wall may be less vulnerable to a small landslide than a wooden house. The total risk (R_t) is then defined as “the number of lives that could be lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon”. It is the product of specific risk (R_s) and the element at risk (E).

$$R_t = R_s \times E$$

The introduction of the factor E corresponds to the total value given to the element. For instance a forest road has not as much value as human lives, and one sawmill has less value than a whole settlement or several industries.

The complete formula to describe a risk can finally be following one, according to Varnes:

$$R_t = H \times V \times E$$

According to this description of risk, there are *three factors that can be influenced to reduce it*: the hazard itself (H), the presence of the element at risk (E) and its vulnerability (V). If one of these three elements is nil, there is no risk. The hazard itself is not enough to define a risk (see figure 1).

The formula proposed by Varnes is valid for a given element, threatened by a given natural disaster hazard. To assess total risk at a larger scale, for example the one of a watershed, the formula has to be changed in order to better integrate the spatial repartition of different phenomena, threatening different elements. The first step would be for example to express total risk as follows:

$$R_{ta} = \sum (H_i \times \sum V_j \times E_j)$$

where
R_{ta} is the total risk for a given area, for example a watershed,
H_i is the value of the hazard for each sub-area at risk,
V_j and E_j are respectively the vulnerability and the value of different elements at risk within the sub-area characterized by H_i.

This formula allows separating independent hazards and different elements at stake. However, it does not allow taking into account the interrelations between several hazards, nor the amplification of the phenomena. Moreover, the definition of the considered area has to be very precise. For example, on figure 1, do both landslides have to be considered as a whole, or as separates and independent phenomena?

Figure 1: Massive landslides in Peru. The process of landsliding is clear and corresponds to the hazard. However looking at this picture it is not possible to say whether there is a risk, except for the environment, because there is no visible element at risk, nor assess its vulnerability.
(Source: B. Kiersch)

The mathematic formulation of the risk is not the aim of the present study, but it is important to keep in mind that modeling the risk at a large scale needs further precision in the used parameters and formula, as well as the limits of the different possible models. It seems to be a research question, depending on local natural context, considered disaster and on the aims of the study.

2.2.3. What are the main possible risk reduction strategies?

The first thing one often thinks about in risk mitigation is to try to reduce the probability of occurrence of the hazard. A variety of different methods may be adopted to mitigate hazard depending on its type and the local conditions. With regard to reducing the probability of landslides, some methods relevant to watershed and forest management will be addressed in this session.

In a naturally dangerous zone however, even if all efforts are undertaken, there is no guarantee of a zero probability of hazards. Hence, it is important to work on hazard reduction, but the first option to be considered is to move vulnerable elements away from the zone at risk, avoiding the building for instance of new dwellings, industries, or infrastructures there. It must not be forgotten that the safest way to reduce the risk is to minimize exposure to hazards. Current research efforts aiming at understanding landslides involve the mapping of hazard probability in a given region (Sassa et al. eds. 2005 and Sassa et al. eds. 2007). These maps are necessary tools to reduce risk, enabling the sound spatial development of human activities. This should be an integral part of watershed management.

Another response to risk is to reduce vulnerability to the hazard. This is mainly possible through construction methods for buildings and roads. It is not directly a matter of watershed management. However, hazard mapping is also necessary to determine in which areas buildings should be reinforced. Moreover, policy measures can support the extra-expenses of these buildings, if it has been deemed absolutely necessary to build them in dangerous zones. Regarding agricultural zones and forests, their vulnerability could be influenced by their management (healthy young forest stand versus old breakable trees), but it seems that their resilience is the main factor which can be influenced. This is not part of risk reduction strategies.

2.2.4. What are the main triggering factors?

To understand how forest and watershed management can limit the landslide *risk*, it is of relevance to know how they can reduce the landslide *hazard*. Following part aims at explaining briefly the conditions for soil stability, then the main landslide triggering mechanisms, in order to better understand how forest and watershed management related activities can influence this stability.

- *Factors of soil stability*

Main source for following explanations is the online available course of Eugene Washington entitled *Soil Slope Stability Analysis Using the Friction Circle Method Programmed in EXCEL*. For more detailed information, the reader is referred to the relevant extract of this document, in annex 2. It is based on the example of a rotational landsliding process. It has to be noticed that some landslides are translational, and that the physics to study them is different than in the case of a rotational landslide.

Figure 2 below shows the fundamental friction angle diagram in the example of a rotational landslide process. In this case, the critical failure plane is assumed to be a circle arc (dashed line). However, depending on the cases, it can also have other shapes, such as a rather straight line parallel to soil surface. The system to be considered is the mass of soil between the circle failure plane and the exterior surface of the slope. Three forces exert on it.

1/ Its own weight, which is the impetus for a potential slippage. It is a vertical vector passing through the centre of gravity of the enclosed soil mass.

2/ The passive soil support below the critical failure plane, which resist the slippage.

3/ The cohesion along the critical failure plane, resisting the slippage as well. It is tangential to the failure plane, and corresponds to a glueing effect; it depends on the strength with which the soil particles are linked to each other.

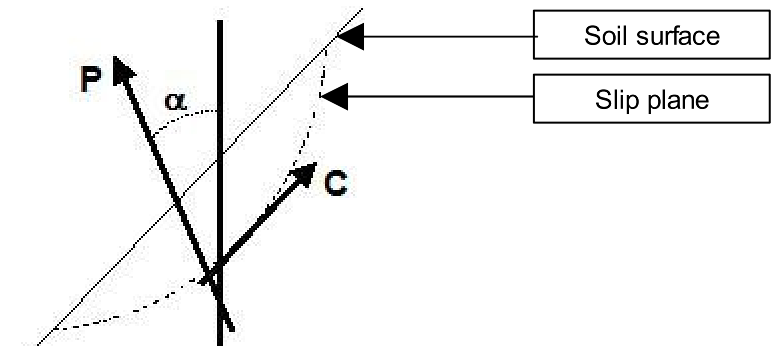


Figure 2: Slip circle diagram (source: E. Washington, modified by N. Dolidon)

W = Soil gross weight including moisture inside the slip plane and the ground surface plus any live load surcharge.
P = Passive weight reaction. It is vertical and has the same value as the weight if the slope is nil.
C = Soil total cohesive resistance (shear).
α = angle between the vertical and the vector P

It is not deemed necessary to go into detailed explanations regarding the justification of the length and the angle of the different vectors for the needs of the present study. The important is to understand that the first force is the one that impedes the slippage and the two others resist. A soil is stable if the result of these three forces is nil. These forces are influenced by different factors. This is the purpose of following paragraph.

- *Influence of external parameters*

Based on this mechanical theory, deducing the effect of different parameters is very logical. The main effects of some parameters on the three forces are summed up in the table 1 below.

Table 1: Main effects of different natural parameters on the three soil stability components (source: N. Dolidon)

	Effect on W	**Effect on P**	**Effect on C**
Slope	-	Increasing slope increases α	-
Soil moisture	Increases W	-	Up to a certain point, increases C Above this threshold, decreases C (ex: mud)
Earthquake	-	-	Decreases C
Toe cutting	Slightly decreases W	Cutting of the lower part decreases P and increases α	-
Vegetation	Increases W	Increases P	Increases C if roots are deep enough

The effect of slope is rather simple to understand: the steeper the slope, the less stable the soil. It is because the angle of the passive resistance of the soil moves away from the vertical.

Soil particles can be more coherent when wet, because the water creates a weak link between them. This is how wet sand castles can have vertical walls. But if there is too much water, the soil gets saturated. This leads to the breaking of the water bond, which then separates the particles from each other, if they are mobile enough. Moreover, it increases the weight of the soil, because water is denser than the air which it is replacing between particles.

Earthquakes provoke vibrations. These vibrations lead to movements of the soil particles, which decrease their cohesion, and eventually can provoke landslides.

Toe cutting occurs when the toe, the lower part of the slope, is cut, or eroded, by a water stream. The stream can range from a small drain to a big river, the process being similar: soil material is flown away by the water, which decreases the passive soil resistance (P) in the lower part. Hence, the resultant is lower and the angle to the vertical bigger.

The effect of vegetation has been simplified in the table. In fact, the expectable impacts are more complex. The weight of the vegetation has to be considered. However, it depends on the scale. For deep rooted landslides, the weight of a whole forest seems not to influence much the landslide hazard; and for a fragile stream bank, the weight of one single big tree is a destabilizing factor.

The root systems increase the passive weight reaction of soil because it links particles one to another. If it is deep enough, it links the given mass of soil to deeper layers, and thus increases also the cohesion.

Roots increase water infiltration into the soil. This limits the surface run-off and thus sheet erosion. However, if the soil rests upon an impermeable layer (eg. clay or rock), the vegetation might increase the amount of water reaching this layer and the velocity with which it infiltrates, and thus strongly reduce the cohesion of the soil.

The vegetation cover may limit the impact of the rain on soil particles and keep a sane biological activity in the soil. This improves the soil structure in the top soil, which limits shallow landslide hazard.

2.2.5. What are the respective roles of watershed and forest management in landslide risk reduction?

- *About forest management*

Forest management covers a wide range of activities and issues including silviculture and forest management planning, as well as their consequences such as tree species, age repartition, stand density, stand health and stability. Silvicultural and harvesting interventions, as well as the forest development, especially road construction, are also encapsulated within this term.

Vegetation cover, and particularly forests, sometimes has a role to play in landslide hazard reduction. It seems, however, they have only minimal influence on deep-rooted landslides. Figure 3 is an example of deep-rooted landslide which has been triggered by an earthquake in Pakistan in 2005. The forest cover did not play any mitigating role for such a deep and massive mass movement. However, in some cases the effect of forests in reducing the likelihood of shallow landslides has been considered significant. (Alcantára-Ayala, Esteban-Chávez and Parrot 2006).

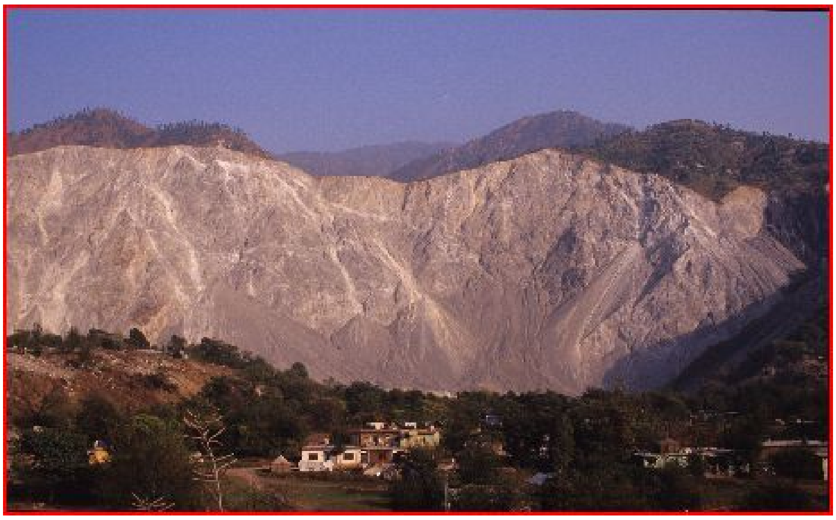


Figure 3: In some cases, forests do not reduce the probability of occurrence of landslides. For example, this massive and deep-rooted landslide, triggered by the earthquake in Pakistan in November 2005 (Source: T. Hofer, FAO)

The condition of the forest may also play a role. A healthy and stable stand, with few gaps and site-adapted tree species can have a better protection role than a stand damaged by, for example, insects or a storm. Silviculture and the way forests are managed is thus important for slope stabilization (Rickli, Zimmerli and Böll 2001). Figure 4 shows a case where landslides have been triggered by heavy rainfall in Switzerland. Even though forest did not avoid all landslides, it limited their number up to a given slope.

Forest development is also of high concern. Harvesting operations and road construction in particular can increase the probability of occurrence of landslides. These interventions highlight the role of forests: once the system is disturbed, the hazard probability increases.

Figure 4: In some other cases, forests stabilize the soil and limit the occurrence of shallow landslides up to certain slope steepness, like in Switzerland in August 1997 where landslides have been triggered by heavy rainfall. (Source: Oberforstamt Obwalden)

- *About watershed management*

Forests, cropland, grassland, roads or buildings have different impacts on the probability of occurrence of a landslide. Risk reduction and especially hazard mitigation can be affected by soil occupation type above, upslope or downslope the failure zone. Different land use practices may also have an impact on soil stability. This means that the security of some people, human activities and natural habitats, may be affected by land owners and above all land users, who are carrying out activities in different areas.

When there is an unstable zone, elements at risk can be located in four distinct areas:

- Of course on the unstable zone itself: in case of a landslide or other massive erosion process, the elements located on the sliding zone can be destroyed.
- Downslope the unstable zone: elements located on the way of the mass movement can be damaged by this mass.
- Upslope the unstable zone: a landslide can be the starting point for an upgrading erosion process, progressing towards upslope. This is the phenomenon taking place in gullies. Moreover, riverbank, channel bank or road cutting erosion can lead to upslope located landslides.
- Downstream the unstable zone: as explained above, elements located along rivers collecting sediments from the sliding area can be threatened by sediment deposition and shifting of the river bed.

The same distinction can be done regarding the zones in which the activities carried out can lead to increased landslide hazard: they can be located on the unstable zone, upslope or downslope from it. In order to preserve the security of the exposed people, land users have to know how to manage their land in the best possible way, so as not to increase the probability of occurrence of a landslide. Figure 5 is a picture taken on my field study site. It shows an example of the possible consequences of a wrong watershed management practice: a drainage dug in a sensible soil grew to become a gully of which the upslope bank evolved to become a landslide. It means that a small drainage meant at protecting the downslope located area from excess run off eventually turned out into a major soil degradation problem. More details on this example will be given in chapters 3 and 4.

Figure 5: An example of man-made landslide process. A badly located drain has been eroded, leading to a gully. One bank of this gully presents recurrent landsliding. (photo: N. Dolidon)

However, land users have to be motivated to implement the best practices. In fact, factors such as lack of land tenure security or market prices may create a motivation to implement inappropriate management schemes (Stocking and Murnaghan 2001). These may be modified where incentives including compensation and other driving factors motivate the land user to adapt his/her methods in light of the responsibility he/she has for the security of other people.

Risk depends also on the distribution of all human activities, infrastructures, settlements, industries, which could be possible elements at risk. So it is of high importance to organize the spatial distribution of these elements in a sound way. This involves risk mapping and the adoption and enforcement of corresponding law and policy to guide the development of different human activities.

It is necessary to assess and map landslide hazards distribution in order to determine suitable zones for the development of human activities. This includes assessment of the zones where specific land uses and management practices play a protection role. There is also a need to provide land managers with landslide assessment guidelines and encourage them to implement the corresponding action (Berger and Rey 2004). But why at the watershed scale?

The watershed scale approach seems to be appropriate for landslide risk reduction for several reasons. The percentage of forest cover at the catchment scale has an influence on hydrology and thus may be a driving factor for landslides (Cemagref, ONF & CRPF 2006).

Moreover, landslides are an example of a phenomenon linking upslope management and downslope, as well as downstream effects. In fact, the occurrence of a landslide may have a direct destructive effect, and may also lead to an increased erosion rate, which is a problem often well-addressed by watershed management policies.

If a landslide occurs in one given watershed, it will have hardly any influence on the neighboring one, but it may impact the whole watershed ecosystem concerned and its population through water quality modifications, soil loss, destruction of infrastructures and ecosystems. Similarly, measures taken for landslide risk reduction in one given watershed will have limited influence on risks in neighboring watersheds. This is why not only the watershed scale matters, but also the adoption of an ecosystem approach to watershed management.

From a practical point of view, as explained by FAO (2006), people who otherwise may not have met can be linked to each other thanks to a watershed approach. It is very important in landslide management that all stakeholders understand each other's position, needs and constraints. Therefore, gathering all stakeholders in one given watershed enables more informed decision making on landslide risk mitigation. It also allows for implementation of the best adapted and accepted legal, financial, technical and political actions.

However, it is important to keep in mind that even though the watershed is most of the time *theoretically* the best scale to work at, it is hardly possible to implement any action at this scale. The main reasons for this are mainly the often too big size of watersheds, as well as the absence of any legal institution capable of a sustainable implementation of the policy. Moreover, a diversity of traditional groups (communities, villages) which might interact within a watershed make a coherent work more difficult (see for example Sthapit, 2001). Moreover, watershed management has often to shift to "problemshed" management. This term employed by Gyawali and Thompson (2007) reminds the decision maker that whatever the scale, whatever the natural context, people living around a specific place at stake have priority problems. And only if the priority of other problems is low enough, the natural aspect can be addressed on the ideal way. Otherwise it is always a matter of compromise...or not even.

Despite of these difficulties, it seems important to understand issues at a watershed scale, work towards true watershed management, and then to adapt the "ideal" solutions to the reality of problems and implementation possibilities, and to make the "best compromises".

2.2.6. Why watershed and forest management together?

Watershed management deals with several land use types, policy issues, involvement of all stakeholders of natural resources and seems thus much broader than forest management. So why should we address them together if the scale of approach is not the same?

Forests represent the most important land cover of mountain areas worldwide. In the Millennium Ecosystem Assessment, the authors of Chapter 24 on Mountains (2005) present five studies according to which forests are variously gauged to occupy between 25 percent and 48 percent of mountainous areas. Because of climatic conditions, forests are not located in the highest mountainous areas but in valleys and middle altitude slopes, where the population density may not be as high as in plains, but is still rather high. This means that the proportion of forest cover in densely populated mountain areas is higher than the average proportion of forest cover in the mountains in general. That is to say, that in the main populated mountainous areas, the mean forest cover might be higher than 50 percent. Consequently, all issues that deal with mountains and people, such as landslides, have to take into account this strong forest component.

Almost 1 billion of the world's poor people rely directly on forests for their livelihoods (World Bank, 2004). Forests play a role both in food security and in income earning. They are the home of many indigenous peoples and constitute an important pool of biodiversity and many different specific natural habitats. They may play a role in climate change mitigation through their carbon sequestration function and provide several other environmental services. Forests are also subject to industrial commercial exploitation by the timber industry as well as a source of many non-wood products. The recreational role of forests is often understated but is now becoming of increasing relevance for development of sound management strategies. Because the activities linked with forests are relevant to and concern many different stakeholders, it is important to address all forest related issues in a coherent way which both links people together and comprises all related ecosystems. Watershed management provides this framework, at least in theory.

Since forests are often very extensive ecosystems, management plans have to be made at large scale when possible. A sound forest road network for example, should be planned at a large scale, and the watershed level happens to be a good one. Therefore, it is of interest to embed certain issues of forest development and management plans in broader watershed development plans.

3. Case study at the village scale in the Mid-Hills of Nepal: context and problematic

Based on an ongoing project from the DSCWM in the Kathmandu valley, I carried out a study with the aim of addressing several important issues identified during the preparation of the WLF. Following part will deal specifically with this study. The context will be explained in a first step. The questions raised and the different problematics will follow, as well as the methodology. The results will be presented and discussed in the chapter 4.

3.1. Context

3.1.1. The project

Kathmandu is located in the Mid-Hills of Nepal, around 27°42 E Longitude and 84°19 N Latitude and is surrounded by a rather flat area called Kathmandu valley. Its location is shown in annex 3. The bottom of the valley is about 1 300 m high. The highest peak surrounding it, called Pulchoki, is located at the south of the valley and reaches the altitude of 2 600 m. The climate is the one of tropical mountains (FAO 2005, map 3 in the present document), sometimes called subtropical or warm temperate climate in the surrounding hills (source: ICIMOD). It is characterized by the monsoon, which leads to very heavy rainfalls in the summer, the warm season. Moreover the soils are deep loamy and red clayey soils. The heavy rainfalls combined to the sensible soils lead to numerous soil degradation problems, including gully erosion and shallow landsliding.

The DSCWM started a project in 2005 in Godamchaur, tackling one of these soil degradation problems. This project had been the base for the personal study I carried out in Nepal. Therefore I will first describe it and then deal with the enlargement to the personal study.

The information available at the beginning of the study was provided by Dr. Joshi. It includes a project proposal he wrote in 2005 (annex 4) and discussions with him during a field visit to the demonstration site. This project is part of the means of the Technology and Development section of DSCWM to complete its mission, including following goals:

- to develop appropriate soil conservation technological packages through testing and research,
- to rehabilitate a heavily eroded or degraded site and convert it into a productive area with simple/low cost techniques, which can be replicated by the District Soil Conservation Offices and local people,
- to disseminate the technology through demonstration, training, seminars, workshops and study tours,

The place chosen for this demonstration site is located at the foot of a hill in the Godamchaur Community Forest, about 20 km south of the center of Kathmandu, at an altitude of 1480 m. The hill is about 200 m high, ranging from 1430 m to 1640 m above see level. Figure 6 shows the terrain of the Kathmandu valley and the location of the study site.

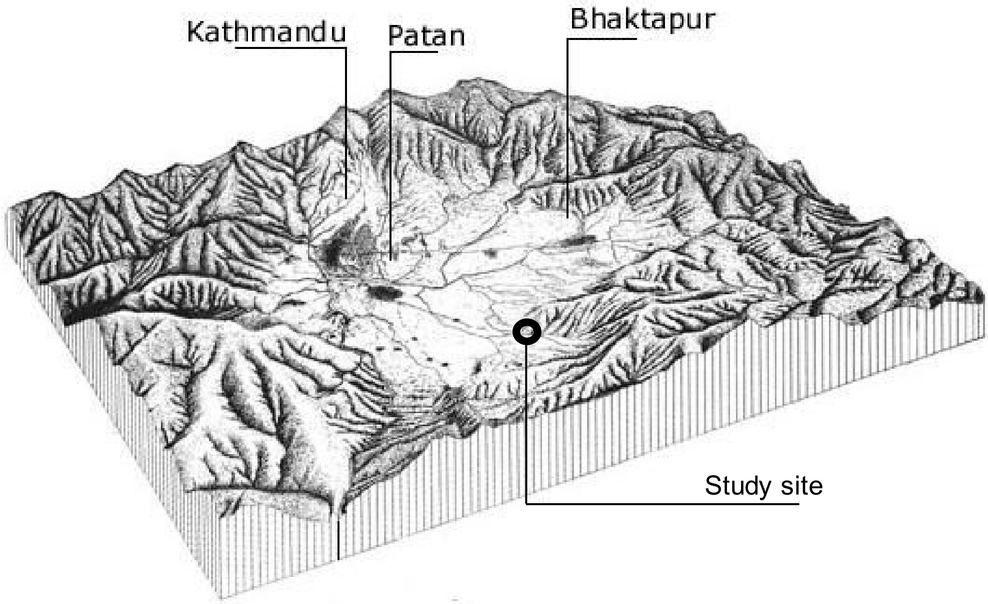
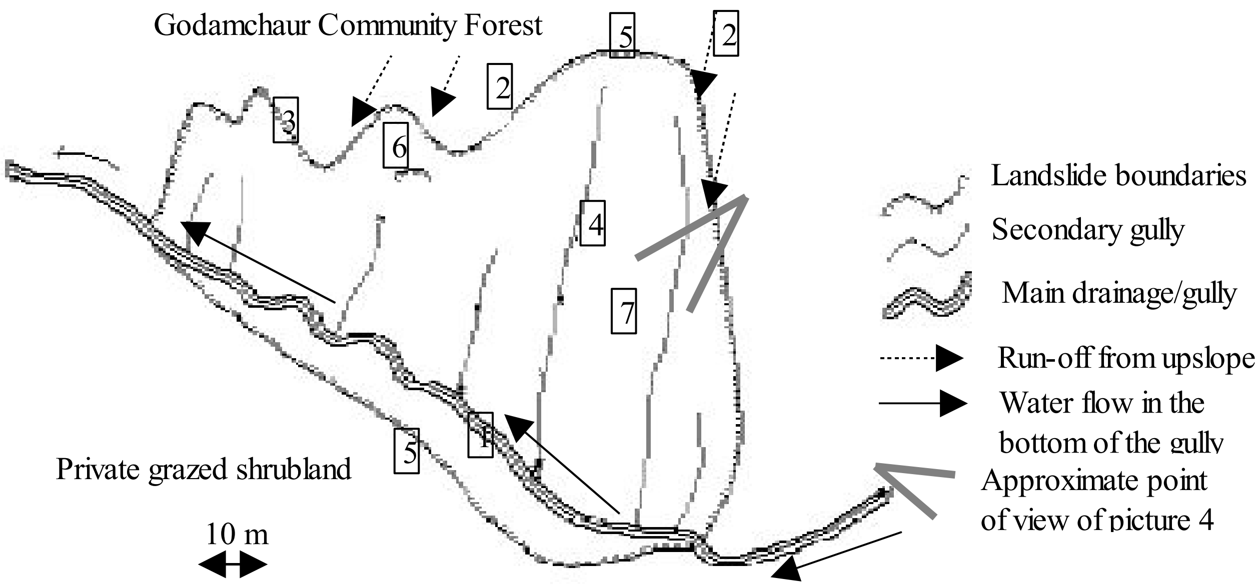


Figure 6: Physical aspect of the Kathmandu valley and location of the study site – the scale is variable (Source: H. Gurung, modified by N. Dolidon)

The degraded area is due to a drainage built about 100 years ago diagonal to the main slope, which increased due to erosion, and became a gully. It includes four distinct parts. The first one is a small to medium gully. The second one is the most degraded one. There, the right bank, located upslope, became a recurrent landsliding area, creating a 0.3 ha heavily degraded zone. The third part of the gully is very narrow and less deep than the previous one. Just before the outlet, a more important erosion process takes place again, leading to more massive soil losses. The main working zone is the landslide; however the three other ones have not been neglected in this project.

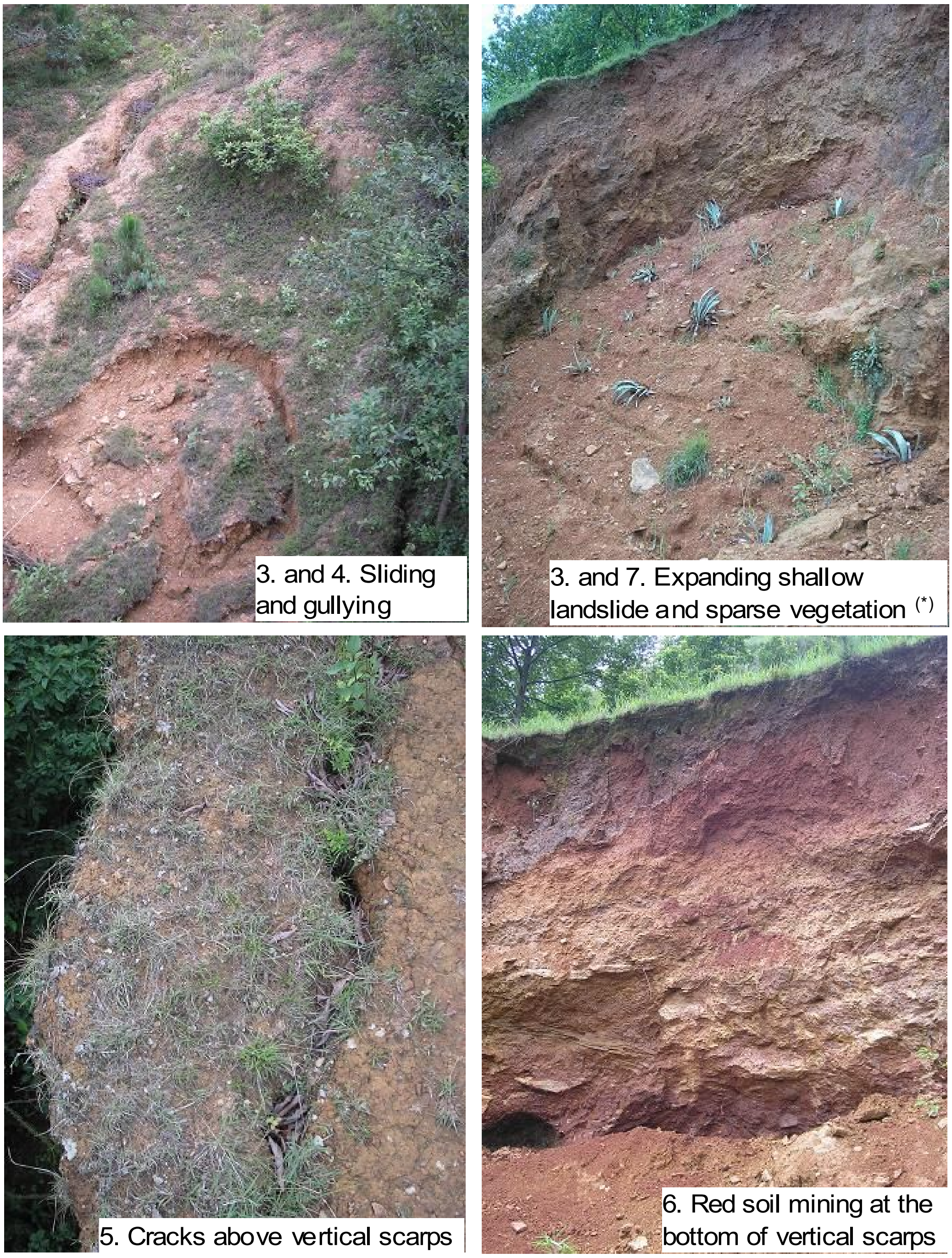
Map 3 is a sketch map of the degraded area. The figures from 1 to 7 refer to the identified problems listed below.



Map 3: Sketch map of the main degraded area of the demonstration site in Godamchaur. (Source: J. Joshi, DSCWM - modified by N. Dolidon)

Following problems had been identified on the site:

- 1. Toe cutting by drainage
- 2. Run-off concentration from upstream on the main scarp of the landslide
- 3. Shallow landslide expanding upstream and north western part (see figure 7 below)
- 4. Rills and gullies developed on slipped accumulated mass (see figure 7 below)
- 5. Cracks developed above scarps in Northern and southern part (see figure 7 below)
- 6. Red soil mining from bottom of the vertical scarps (see figure 7 below)
- 7. Sparse vegetation (see figure 7 below)



(*) the plants shown on the picture (*Agave americana*, Ray-grass and other grass seeds) have been planted and sown few days before the date of the picture.

Figure 7 : Some of the problems identified at the beginning of the project (Source: N. Dolidon)

The catchment area is about 3 ha big and comprises in its upper part a pine forest (*Pinus roxburghii*), and in its lower part a young plantation of *Schima wallichii*, locally called chilaune. All the part upslope from the gully belongs to the Godamchaur Community Forest, as well as 98 % of the degraded area itself. A small part in the south west, as well as all the land located downslope from the gully are private properties.

The project is planned to last for 5 years in total; which means 2 more years from the time the present study has been carried out. Since the beginning, several activities had been planned. Among them, following ones had already been implemented at the time of the study:

- A. Toe/supporting wall construction: its function is to support the sliding mass of soil, and to prevent toe cutting from run-off (see figure 8.A below).
- B. Diagonal hedge rows plantation above main scarp: the aim is to divert the water flow and prevent it entering the most degraded area.
- C. Fascine, palisade, brush layering and brush wood check dams for rill and gully control: they are supposed to control the erosion on the upper part of the degraded zone, where secondary gullies are small. They act through both slowing down the water flow and trapping sediments (see figure 8.C below).
- D. Stone filled gabion check dams in deep gullies and drainage: the aim is to trap the sediments coming from the whole area and to prevent the further development of the deepest gullies. Most of these check dams located in the main degradation area are full (see figure 8.D below).
- E. Grass seed sowing and plantation: grass cover should limit splash erosion as well as rill erosion.
- F. Live fence around demonstration site: this is to protect the area from grazing animals. It has been partially done but not yet completely.
- Moreover, red soil mining has been prohibited.

Pictures 6.A, 6.C and 6.D: Some soil conservation measures implemented on the study site. (Source: N. Dolidon)

Following soil conservation activities had been planned but had not yet been implemented at the time of the study:

- G. Conservation pond construction for run-off water collection: is aimed at preventing the run-off water from entering the eroding zone.
- H. Safe drain: same function as the water pond. Actually the drains could collect the water from the catchment area and lead it to the pond.
- I. Slope correction: where the scarp is vertical and keeps slumping, slope correction to a gentler slope could help stabilizing it.
- J. Crack filling: to prevent water entering the cracks and extending them

3.1.2. Questions raised and problematic

At the moment when I contacted Dr. Joshi to look for a project to work on, he proposed me to carry out following tasks:

- To assess the eroded volume in the gully of the demonstration site.
- To assess the age of the gully by asking local people and thus derive an average annual erosion rate. This particular point will be further discussed below, in part 4.1.1.
- To assess the effect of the landslide treatment on the downstream located fields, also by talking with local people.

This work has been carried out in a first step. Doing it allowed me to start to understand the processes going on inside the gully, the expected effects of different treatment methods and their actual efficiency in this context, as well as the lives of the local people and their main constraints. To complete the study I considered necessary to broaden the view and not to focus only on the degraded area. In fact, the aim is to understand upstream-downstream linkages and to try to have a watershed approach. Therefore, I visited the surrounding forest, on the whole hill, which is divided between the Godamchaur Community Forest and the neighboring Bistachhap Community Forest. Several other gullies have been observed on the same hill, showing different shapes, vegetation cover, on different slopes, and within different micro-watersheds. Based on these observations, discussions with and propositions from Jagannath Joshi as well as Madhukar Upadhya, researcher at the Nepal Water Conservation Foundation (NWCF) who has experience with gully treatment, the main questions raised were:

- Is it possible to improve the already planned treatment on the demonstration site? If yes, how to do it?
- Where are the priority places to implement conservation activities?
- Do slight differences between gullies in the same climatic and geologic context change the best adapted treatment methods?
- What are the main factors stabilizing a gully?
- How important is the role of vegetation to mitigate the development of a gully? And what role does it play on a shallow landslide? At what spatial and temporal scale?
- What are possible impacts of major soil losses such as gullies and landslides on downstream located fields?

Therefore, the aims set for the study were:

- To contribute answering the questions raised above.
- To increase the knowledge on the demonstration site in Godamchaur by assessing the volume and erosion rate of the main degraded area.
- To contribute to the development of the demonstration site by documenting neighboring gullies, providing some facts to show and explain to future visitors of the demonstration site.
- To provide some inputs for guidelines in the future management of the Community Forests of Godamchaur and Bistachhap.

The starting point was the proposition of study on the erosion of the demonstration site as well as the impact on the fields. However, the questions and goals explained above have been set by myself. It was not a request from the DSCWM, nor from the CFUG, but the study is aimed at contributing respectively to their work and welfare.

3.2. Methodology

The methodology included two steps, since the work proposed by Jagannath Joshi has been carried out separately and before having set the whole study. However, it will be explained as a whole, because similar data has been collected on the four different gullies.

3.2.1. Visits to the field allow choosing four gullies to study

The gullies to compare include of course the demonstration site, which will be called from now on gully "central". The visit of the hill allowed discovering another one in the north, called gully "north", of which the biggest part is located in the Godamchaur Community Forest, and the lower part in the village of Godamchaur, close to dwellings. A third gully is located in the Bistachhap Community Forest, further south on the same hill. It will be called gully "south". It is located in the middle of a chir pine forest (*Pinus roxburghii*). A last gully was showed to me by the chair person of the Bistachhap CFUG, Narayan Kargi, and is located close to the gully south, partly along a football ground. Therefore it will be called gully "football". Map 4 below shows the location of the four gullies, and table 2 their main differences, explaining the interest of comparing them.

Map 4: Location of the four different gullies on the hill (Sources: Google, QGIS, N. Dolidon)

When the field experience allowed locating the gullies precisely on the map, it has been done even though it does not always match with the collected GPS points. The blue point downstream the gully "north" is actually not the gully outlet, but a man-made drain, extension of the gully. Concerning gully "football", since there was no football ground at the time where the picture has been taken, it was more difficult to locate the gully. However, the vegetation and the road give useful landmarks. When it was not possible to know if the GPS point was on the right position or not, it has been used as a reference in particular for gully south. For gully central, GPS points match very well with the aerial photograph.

Table 2: First comparative assessment of the four chosen gullies. (Source: N. Dolidon)

Name of the gully	**North**	**Central (demonstration site)**	**South**	**Football**
User of the ground	Godamchaur CFUG and private	Godamchaur CFUG	Bistachhap CFUG	Bistachhap CFUG
Approximate length	500 m	250 m	100 m	50 m
Size of the section	Small to medium	Small to big	Small	Medium
Vegetation cover upon the gully	Dense shrubs	Dense shrubs and sparse vegetation	Pine forest exclusively No underlayer	Some broadleaved trees. Mainly shrubs
Vegetation cover of the catchment area	Diverse: grown pine forest, young broadleaved forest, dwellings and agriculture	Upper part: grown pine forest Lower part: young *Schima wallichii* plantation	Chir pine (*Pinus roxburghii*) forest.	Chir pine (*Pinus roxburghii*) forest
Stabilization	Not sure. Signs of degradation	Active	Seemed active, but according to local people, looks like this since 20 years.	Active
Landsliding problems	No	Yes	No	No
Aspect	West	West	South	South
Lateral slope	+/- 0°	17 to 40°	+/- 0°	+/- 0°
Soil type	Red clay	Red clay	Red clay	Red clay

The rather similar points between these gullies are the geology and soil characteristics, as well as the climate. The bedrock belongs to the Chandragiri formation, which is mainly made out of limestone and sandstone. It is overlapped by a quaternary alluvial fan deposit (Shrestha et al. 2008). Soils are red clayey to silty soils. With increasing depth, the medium size of the soil particles increases, including sand after 50 cm to one meter, and gravels deeper, depending on the places. Clay and silt are found at all observed depths. In some places bedrock appear between 1 or 2 meters depth, in some others it is not reached after 9 m (maximum depth observed). The climate is assumed to be the same one, since there are less than 700 m between the two most distant gullies, gully north and gully football. However, the aspect might play a role on vegetation.

The differences observed concern numerous aspects, as shown in table 2. This diversity regarding several characteristics makes the comparison interesting. It will allow understanding what kind of features can make a difference in the best adapted treatment method. Of course the sample is not big enough to identify statistically significant factors or phenomena, but it is not the aim of the study. These four gullies will allow an interesting comparison, but also provide a wider perspective on the upstream downstream linkages; some processes can be evident in one of the gullies, which would not be the case in another one.

3.2.2. Different information for different goals

In order to achieve the goals set, data had to be collected through different ways. To prepare field sheets and questionnaires, it is important to identify the needed information.

3.2.2.1. About the gullies themselves

The data comprises four main aspects: general information (history, uses by local people...), geometry, soil, and vegetation.

- *General information on the gullies*

General information on the different gullies has been collected through discussions with local people, in particular B.B. Basnet and Narayan Kargui, respectively chairman of Godamchaur Community Forest and Bistachhap Community Forest.

The information needed are the age of the gullies, their uses, their perceived effects and potential threats according to local people, and the propositions they have to stabilize them. These pieces of information help understanding the natural processes going on, as well as the actions carried out so far, and the needs and constraints of local people. Moreover, these discussions often provide interesting and unexpected outputs. Sometimes not directly linked with gullies, some facts are revealed which allow better understanding of the farmers' lives, who are also CFUG members. This is very important to know what could be feasible or not, in order to adapt the proposed mitigation measures, and to understand part of the causes for the gullying, which is necessary to prevent the development of new gullies.

- *Information collected on the geometry of the gullies*

Regarding geometry, the assessment of the volume is an important parameter to characterize the gullies, as well as the size of the section and its evolution along each given gully. Knowing the volume implies knowing the length. The slope is logically an important factor to understand the processes at stake. The orientation of the gully, for evident reasons of mapping and proper documentation, is important as well.

To be able to derive this information, cross sections have been measured along the gullies with different methods (see 3.2.3. An evolving protocol) thanks to a measuring tape. The distance between two measured cross sections has been measured too, allowing to derive volume and total length. The orientation and slope of the gullies have been measured thanks to a compass and a clinometer.

Main literature to learn about gully treatment have been slide shows from the training course on Low Cost Soil Conservation Techniques and Watershed Management organized by ICIMOD in spring 2008. The parts on gully treatment, check-dams, run-off calculation and retaining walls have been particularly useful (respectively Pradan, 2008a, Pradan, 2008b, Sthapit 2008, and Parajuli 2008). The second main source of information has been a publication by the DSCWM entitled Soil Conservation and Watershed Management Measures and Low Cost Techniques (DSCWM, 2004). Regarding geometry of the gullies, reading this documentation confirmed the need for all the data mentioned above.

- *Information collected on soil characteristics of the gullies*

These documents explain the importance of determining the angle of repose and the bearing capacity of the soil to dimension potential retaining walls. Therefore, these parameters have been collected whenever possible, thanks to a standardized table linking soil texture with bearing capacity and angle of repose respectively provided by Mr. Sthapit. Moreover, the soil structure has been written down as an indicator of its biological activity. For more precision, the gullies have been divided into five longitudinal compartments:

left side (from one meter from the ridge to 10 m), left bank, bottom, right bank and right side (see figure 9). Data on the above parameters have been collected whenever possible on these five different parts of a gully.

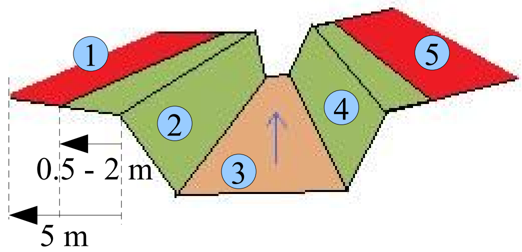


Figure 9 : the different compartments of a gully section. 1 : left side. 2 : left bank. 3 : bottom. 4 : right bank. 5 : right side. The blue arrow indicates the direction of the stream.

- *Information collected on vegetation characteristics of the gullies*

Gathering information on the vegetation cover is a rather new approach in this methodology. No literature has been used to determine which parameters to assess. After visits, the line of reasoning beyond the choice of data to be collected has been following one:

- The rain drops are stopped or slowed down by the vegetation cover;
- Dense low vegetation may limit sheet erosion;
- Root systems may give more cohesion to the soil;
- Too big trees or shrubs on the gully banks may destabilize them;
- Different species may have different evapotranspiration rates;
- Different species may be indicator for more or less stabilize soils, and on the other hand have different stabilizing effects on the soil;
- The role of vegetation may be different depending on its place within the gully.

Hence, in order to address these issues, vegetation has been classified into three layers: herbs (< 50 cm), shrubs (50 cm < < 7 m) and trees (> 7 m). For each layer, and for each of the five compartments of each gully, vegetation cover and main species have been collected. For trees and shrubs, an indicator for stem numbers per length unit has also been used. However, because of changes in the methodology explained below, this indicator appeared to be useless. The idea was to separate the effect of leaves on water (vegetation cover) from the effect of stems and roots (stem numbers).

The data on soil characteristics and vegetation have been collected for given lengths along the gullies. However, the method has evolved during the study, adapting to time constraints and getting improved thanks with experience. These differences will be the purpose of part “3.2.3 An evolving protocol”.

The above mentioned data has been collected to have information directly on the gully. Other aspects had to be taken into account to achieve the goals, in particular understand upstream-downstream linkages.

3.2.2.2. About the micro-watersheds

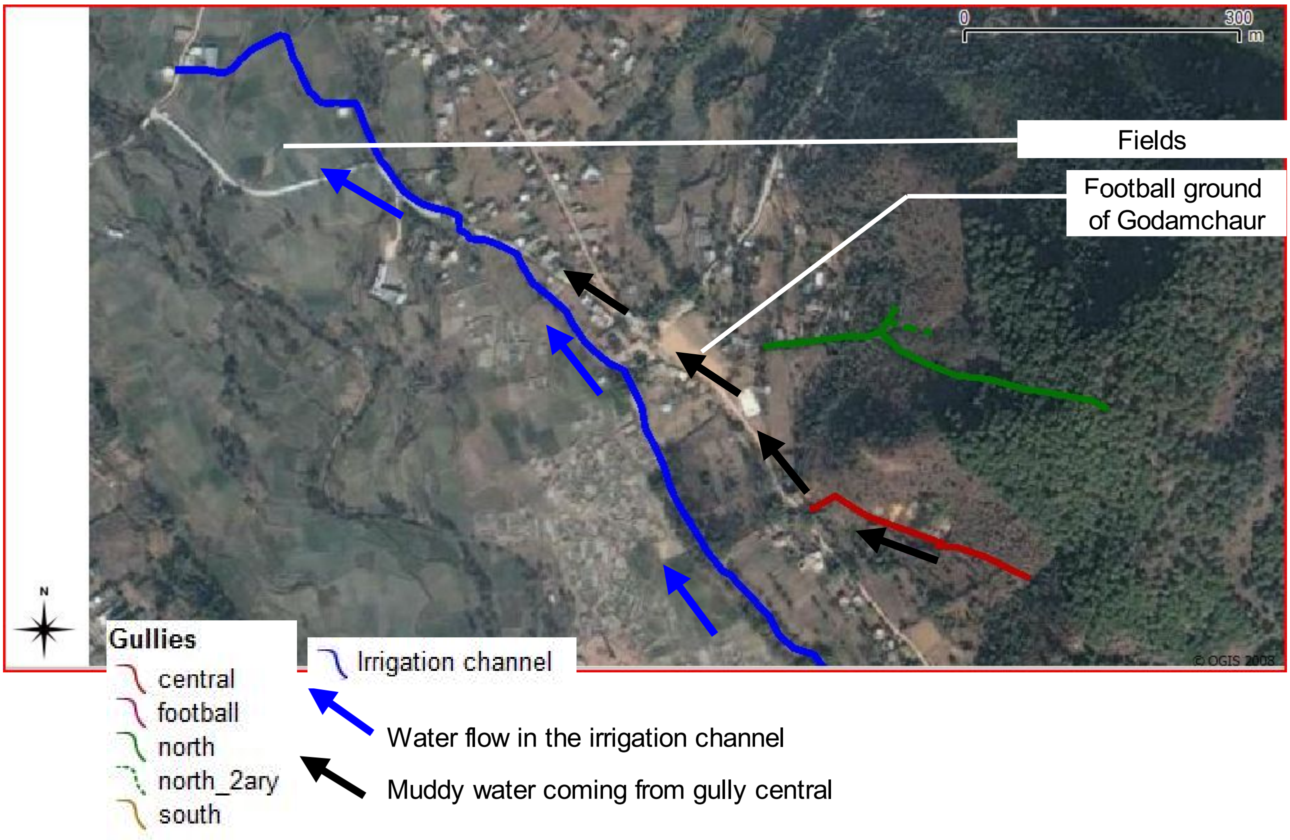
The characteristics of micro-watersheds, or catchment areas of each gully, play a very important role and have to be documented as well. In order to assess the maximum run-off passing through a gully, the length, area and soil occupation of a catchment area are needed (Sthapit, 2008). A survey in the field would have been of interest for this purpose. However, because of time constraints, it has been possible only for the gully "south". Indeed, it was of higher importance to do it for that one, because its watershed boundaries are much less visible on photographs than the ones of gullies "north" and "central". The boundaries have been determined on the field without instrument. They have been localized thanks to a GPS.

Given the lack of time, it has been deemed more important to complete the data collection on the gullies themselves than trying to characterize the entire micro-watersheds of the other gullies. These latter ones have been observed from the gullies. Their boundaries have been identified thanks to pictures taken from some distance and to aerial photographs (Google earth). This allowed assessing their area with a GIS software.

The history and uses of the catchment areas does matter as well, to explain the creation of the gullies for example. Discussions with CFUG members allowed knowing about this aspect.

3.2.2.3. About the fields downstream

One of the aims was to assess the impact of landslide and gully treatment carried out in gully central on fields which rely on an irrigation channel receiving water coming out of this area. Indeed, after flowing through the gully central, run-off goes on a road and a football ground, central place of the village of Godamchaur, and flows into an irrigation channel. The irrigation channel comes from upstream the valley, and is used for the irrigation of several hectares of rice fields downstream (see map 5 below).



Map 5: Water flow from gully central to the irrigation channel and to the fields.
(Source: Google, QGIS, N. Dolidon)

Dr. Joshi knew that the treatment of the gullies with check dams started three years ago had had a positive impact on the yields of fields downstream. He proposed me to further ask the farmers about this, to get more information. The study carried out is qualitative and does not have a statistical signification, but allows understanding the potential impact of upstream phenomena on downstream located fields, and thus on food security. Five farmers have been interviewed, representing four different farms, among which two rely on the irrigation channel and two do not. They have been asked about the changes witnessed in the rice and wheat yields, potential changes in their cultural techniques, the evolution of the climate they could have witnessed, as well as for other information, again to better understand their lifestyle and mentality.

The arrows on the map show only the flow coming from gully central, because it is the one which has been treated and thus the one of which the effect has been studied. However, the water coming from gully north might also carry an important sediment load. Moreover, of course other fields use the water from the irrigation channel upstream the ones shown on the map. However, the water they use does not come from the gully central; they are not influenced by the treatment implemented.

3.2.2.4. About the rainfall

In addition to the general particularities of the local climate explained above, it could be interesting to look more in detail in the rainfall pattern of the site. There is no climatic station in Godamchaur, and given the local variability of the climate, it is of interest to assess it better than with the data available at the Kathmandu airport.

Godamchaur is located between two other places where climatic data are measured every day: the National Agriculture Centre (NARC) in Khumaltar, Kathmandu, and the ICIMOD Demonstration and Training Centre in Godavari. The study site is about is about 6 km away from Khumaltar and 3 km from Godavari. Given the spatial variability of the climate at the same time, it would not be sufficient to assess rainfall and temperature in Godamchaur with the average value between Khumaltar and Godavari. However, we can say that the average rainfall, maximum and minimum temperatures in Godamchaur are somewhere between the ones of Godavari and the ones of Khumaltar.

Keshar Sthapit from ICIMOD provided monthly weather data from 1996 to 2007 as well as daily weather data from 2000 to 2007. Hence, I asked Mr. Ghanashyam Malla from NARC to provide me similar data, which he kindly did. Both datasets will be treated separately but allow approaching the real weather data in Godamchaur, in particular the rainfall.

3.2.3. An evolving protocol

As explained before, the first step of this study has been to assess the volume of gully “central”. This will be explained in detail as an example in part 3.3.1. Therefore, it has been focused on the geometry, without taking care of the soil and vegetation in a first time. The area of several sections have been assessed on a regular basis, every 10 m (except in case of terrain constraint), with help of CFUG members, Rupak and Rupesh Khadka.

The second step has been to collect all necessary parameters for the complete study on the gully “south”: geometry, vegetation and soil characteristics. I also received help from French colleagues, Lucile Reboul and Marianne Sanlaville to carry out these measurement. Thus, it has also been done on a rather regular basis, each parameter being measured where the cross section were measured. This is a very precise method, but the precision at this scale is not needed for the vegetation and soil characteristics. Moreover, another disadvantage is that it is hard to know where to put the limit between two homogeneous segments.

Then, working on the gully “north”, which is much longer and more difficult to access, and this time without help, especially to hold the measuring tape, a simpler and quicker protocol has been established: the gully is divided into segments, which are deemed homogeneous regarding vegetation and geometry. Their length is measured, but section has been either measured, or sometimes only assessed, only twice: at the biggest place and at the smallest one. The parameters on soil and vegetation have not been collected for each measured section, but for each homogeneous segment. This information is less precise but allows characterizing the segments.

A mixed method has been used for gully "central" and gully "football". Indeed, the geometry of gully "central" was already known, through the first measurement phase. The other parameters have been assessed on a segment base, limits between segments also being determined according to shape or vegetation cover criteria. The length of the segments has been measured, which allowed assigning each measured cross section, of which the place was known, to the corresponding segment. This has been deemed the best compromise, and thus implemented for gully "football", which is short and hence suitable for this method despite the rather stight time table.

The differences in the data collection protocols make the comparison of the data a bit more complicated. However, it was more interesting to improve the methods with the time, learning by experience, and improving the quality of the data collected. Table 3 below summarizes the different protocols used for the different gullies, with their advantages and disadvantages.

Table 3: Different methods adapting to gully and time constraints. (Source: N. Dolidon)

Name of the gully	North	Central (demonstration site)	South	Football
Cross section have been	assessed	measured	measured	measured
Average length between two sections (m)	16.2	11.0	8.4	5.3
Vegetation and soil characteristics collected for each	segment	segment	section	segment
Precision of the geometrical description	low	high	high	high
Precision of the description of the vegetation	low	low	high	low
Definition of different segment types	easy	easy	difficult	easy
Design of check -dams or retaining walls	difficult	easy	easy	easy
Time consumption	low	high	very high	high

(*)In one place the gully is interrupted by a deposition fan. The eroded volume in this part is nil. So, there the distance between the two measured sections is 27 m.

The average length between two sections has to be taken as an indicator for the precision and reliability of the measurements. The smaller this value, the higher the precision.

The results on the segments of the different gullies will not be detailed here, due to time and space constraints. However, this distinction of several segments allowed deriving indicators for the importance of some gullying processes (see 4.3.)

3.2.4. Calculation of geometrical parameters of the gullies

This part explains the methodology for treating the data collected. In particular, it deals with the calculations allowing to derive cross section areas and volume of gullies.

We will detail the method of calculation of the volume for the gully "central", which has the most complicated shape. The principle is exactly the same for gullies “south” and “football”, and somehow simpler for gully “north”.

- *Principle*

This assessment needed to be feasible by one person in a short time with basic material. Therefore the principle of the method had to be simple and easy to implement.

The idea is in a first step to measure some particular dimensions of several cross sections and derive their area. Then, the multiplication of each of these areas by half the distance respectively to the previous and the next measured cross section gives an elementary volume around each measured area. The result of the addition of all these elementary volumes is an assessment of the total eroded volume.

- *Orientation in the space*

To allow deriving the volume, the distance between each measured cross section had to be measured on a straight axis, perpendicular to the plans of the cross sections. This axis, called ***x***, had to be parallel to the axis of the gully. However, because of changes in the orientation of the gully, as well as in its shape, it has been more convenient to establish 6 axes, from ***x1*** to ***x6***. This allowed a better adaptation to the shape of the gully and thus improving accuracy in the measurements and calculations. On each ***x*** axis, the ***y*** and ***z*** axes were defined respectively as the horizontal and vertical perpendiculars, orientated respectively to the right and to the up of the ***x*** axis. Thus there are also six different ***y*** axes, but only one ***z*** axis, which is vertical.

Figure 10 shows on a map view the axes 3 to 6.

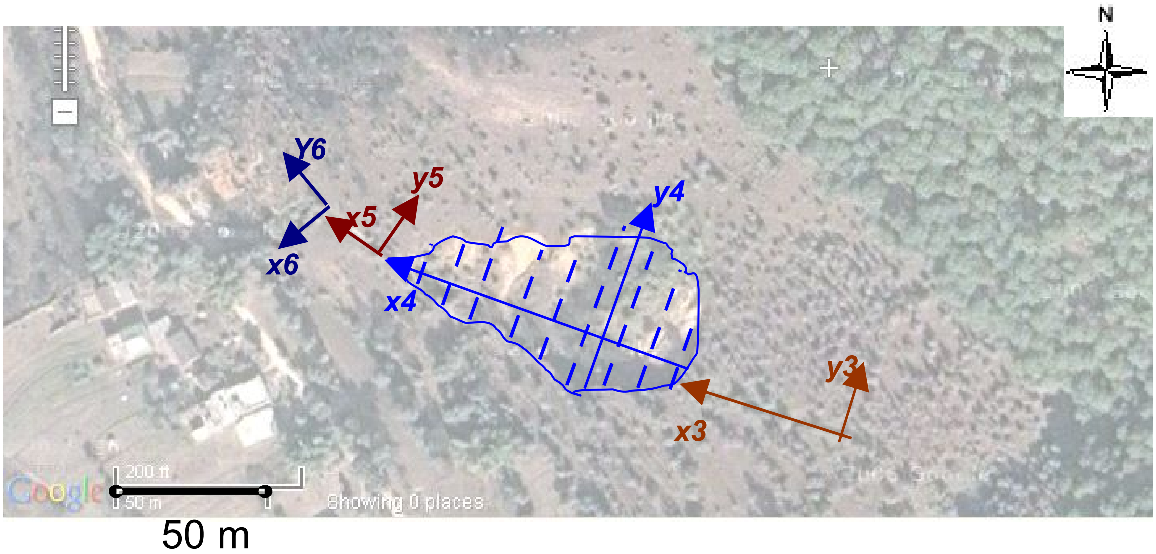


Figure 10: Map view of the area, with axes ***x3*** to ***x6*** (Source: Google, N. Dolidon)

The ditches measured along axes ***x1*** and ***x2*** are too small to be seen on the aerial photograph and thus are not represented here. The biggest landslide is included in the blue area. The dashed lines indicate the measured cross sections. They are indicated only for ***x4***, because the other ones are too small to be well visible on a sketch such as this one.

- *Description and measurement of the cross sections.*

Several cross sections have been measured along the different axis. Each section was included in the (***y,z***) plan. The variation in the shape of the cross sections and of their heterogeneity along the different ***x*** axes led to different measuring patterns. Table 1 shows how the cross sections were described along the different x axes. The different mentioned description patterns (rectangle, hexagon or trapeze) are explained below the table 4.

Table 4: The different description patterns for the cross sections measured along different axis. (Source: N. Dolidon)

Number of the *x* axis	Orientation (degrees)	Length (m)	Shape used to describe the cross sections	Number of measured cross sections
x1	255	16	Rectangle (fig. 7a)	1
x2	315	31	Rectangle (fig. 7a)	1
x3	290	67	Hexagon (fig. 7c)	8
x4	290	93	Hexagon (fig. 7c)	10
x5	305	36	Trapeze (fig. 7b)	3
x6	230	28	Hexagon (fig. 7c)	4

Rectangle:

The cross section was considered rectangular in the upper ditch. In this place, the erosion process has actually been very limited, and the present ditch might almost represent the initial size of the human dug drain. Hence the cross section was regular and a rectangle allowed a good assessment of its area.

Moreover, the section was constant on the axes ***x1*** and ***x2*** respectively. On these two sections, the total volume was therefore assessed by multiplying the cross section area, measured only once, by the length of the ditch.

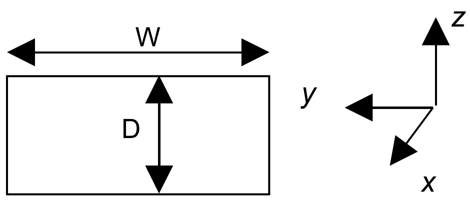


Figure 11a: Measured dimensions on the cross sections of axes ***x1*** and ***x2***. (Source: N. Dolidon)

The area of the cross section, written S, was then calculated with:

$$S = W \times D$$

Trapeze:

The cross section of one segment of the gully central, measured along the axis ***x5***, was deep but not wide. Measuring angles on it could have been less reliable than lengths, because of these short distances. The access to its bottom was avoided by vegetation, except in three locations (beginning, outlet and one place around the middle). For all these reasons, areas of the three measured cross sections were derived from the formula of the area of a trapeze.

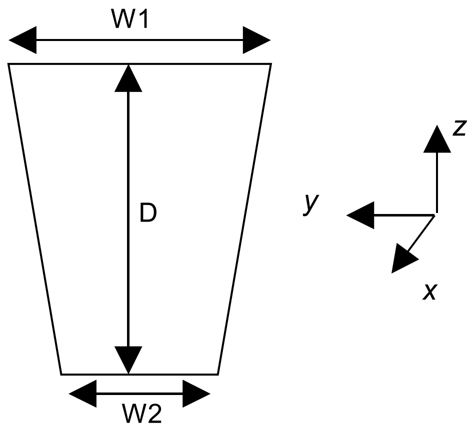


Figure 11b: Measured dimensions to assess the area of cross sections on axis ***x5***. (Source: N. Dolidon)

The area of the cross section *S* was then calculated with:

$$S = \frac{1}{2}(W1 + W2) \times D$$

This formula has been used for most of the sections of the other gullies. This shape is actually most probably a triangle, dug by heavy rainfalls, at the bottom of which sediments were carried and deposited during rainfall events of lower intensity. Hence the results of the assessment will actually correspond to the total eroded soil minus the inputs of deposited sediments.

Hexagon:

The most complex shape, as well as the most representative in terms of concerned volume of the gully "central", was the one of a hexagon (ABCDEF on figure 11c), at the bottom of which there was sometimes an additional rectangular ditch (PQRS on figure 11c).

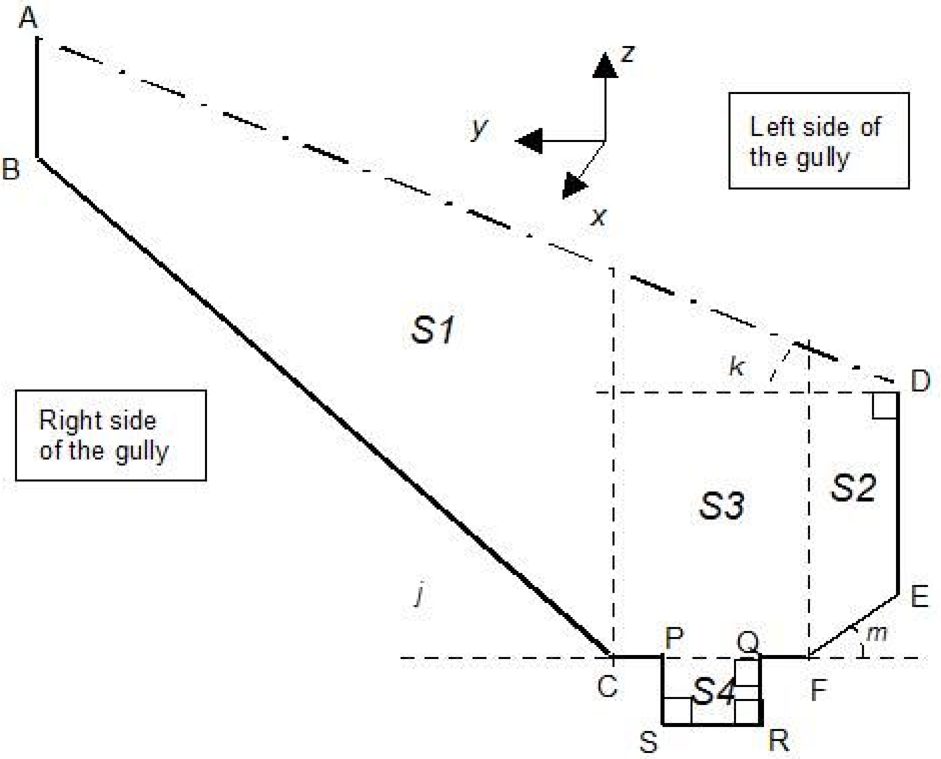


Figure 11c: Cross section of the gully in the landsliding area, looking upstream the gully. (Source: N. Dolidon)

A: Top of the scarp above the slide
B: Foot of the scarp upslope/ head of the sliding slope
C: Right side of the bottom of the gully
P, Q, R, S: corners of the ditch at the ground of the gully.
k: former hill slope angle
m: slope angle of the left bank of the gully

D: Ridge, top of the cliff on the left bank
E: Foot of the cliff downslope / head of the left bank of the gully
F: Left side of the ground of the gully
j: slope of the landslide, on the right bank of the gully
S1, *S2*, *S3* and *S4* are sub-areas which can be calculated

This shape has been deemed the most suitable to accurately describe the cross sections and thus assess their area, without however complicating too much the task.

The total area *S* was assessed as:

$$S = S1 + S2 + S3 + S4$$

With:

$$S1 = \frac{1}{2} \times \left(\frac{\cos j}{\tan(j - k)} + \sin j \right) \times \cos j \times \left(\left[(CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED \right]^2 - AB^2 \right)$$

$$S2 = \frac{1}{2} \left[FE \times \sin m + 2 \times ED + (FE \times \cos m \times \tan k) \right] \times FE \times \cos m$$

$$S3 = \frac{1}{2} \left[2 \times (FE \times \sin m + ED) + \tan k \times (2 \times FE \times \cos m + CF) \right] \times CF$$

$$S4 = PQ \times PS$$

More details on the calculations which allowed assessing the area of the cross sections described with this shape are given in Annex 5.

Figure 11c shows the most complex shape encountered. However, for particular cases located on the axes ***x3***, ***x4*** or ***x6***, eg. EF = 0 (left bank vertical, no intermediate slope), or PS = 0 (no ditch in the ground), the same formulas have been used.

The measured parameters on each cross section were following ones:

- Distances: *AB*, *DE*, *EF*, *CF*, *PQ* and *PS*

- Angles: *j*, *k* and *m*

Note that measuring the distance BC was not necessary (see Annex 5).

➢ *From cross section area to gully volume*

From one cross section to the next one, the standard distance was 10 meters. However, due to terrain conditions or at the end of each given ***x*** axis, this distance may vary. In order to have correct calculations, this distance had to be measured parallel to the ***x*** axis, and the cross section had to be perpendicular to this axis. This was checked thanks to a compass.

After data collection, it has been treated in an excel sheet. It allowed calculating the areas of each cross section. Each of these areas has been multiplied by half the distance on the correspondent ***x*** axis to the previous measured cross section and half the distance to the next measured cross section. The result was an assessment of the volume of the eroded soil around each measured cross section. For a better adaptation to the shape of the gully, the different ***x*** axis have been treated separately. The cross sections of the origin and the end of each ***x*** axis have been multiplied only by half the distance of either the next or the previous measured cross section, respectively. The sum of all these elementary volumes is an assessment of the total eroded volume.

➢ *Particularities for the different gullies*

The method explained above is exactly the one carried out for the calculations in gully “central”, the largest one. For gully “football”, the same method has been used; the only difference being that all sections have been described with trapezes. Each section is multiplied by a given length, to assess the volume around it. Sometimes the limits of these elementary volumes did not match with the limits of the segments. Hence, some additional data treatment has been necessary to assign the exact volume, represented by the right cross section, to each segment.

For the gully “south”, this additional operation was not necessary. Indeed, the segments are determined by the distance between sections, and one given section is considered as the one of its corresponding segment. One section for one segment, and the corresponding length.

For gully “north”, the sections have only been assessed most of the time; measured some times. The segments were determined first, and then within each segment the largest and the smallest were measured or assessed. After calculation of the area of these sections, the average value has been derived for each segment, and multiplied by its length to assess the volume. Thus, the result is much less reliable then the for the other gullies. It inly gives a rough assessment of the total volume.

➢ *Limits of the method*

The method has been designed to allow one person collecting data in only few days. Thus, it has certain limitations regarding its accuracy and the information it brings.

It is impossible to say exactly what the error percentage of the results is. But to give a rough estimation, according to what has been seen on the field, the way the measurements have been done and the shape of the gully as well as the method, 15 percent possible error seems to be a reasonable figure. However, there is no scientific way to verify it.

Regarding the limit of the information collected through this method, an important one is that the longitudinal profile of the gully can not be drawn. Indeed, the respective positions on the ***y*** and ***z*** axis of each measured cross section have not been collected. However, it has been deemed that according to the material and the time at the disposal of the operator, such measurements would not have been precise enough to be interesting. Moreover, they are not needed since the only objective is to assess the total eroded volume.

4. Case study at the village scale in the Mid-Hills of Nepal – Results and discussion

4.1. Comparison of the four gullies

4.1.1. Geometrical aspects, age and average erosion rate.

The computation of the data allowed assessing the cross section area, the length of each segment and, by addition, the length of each gully. Following table 5 summarizes the main data derived for the four gullies. The calculation of the volume has been explained above. The average section of a gully is the result of the total volume divided by the total length. The average distance between two sections has to be seen as an indicator for the precision of the derived values. The smaller this value, the higher the precision.

The average section areas do not make sense regarding the treatment of the different gullies. Indeed, the size varies much along one given gully; the average values are not significant. However they allow underlining big differences between gullies.

The age of the gullies has been asked to local people. This means that it is the age of the already rather critical situation, at least a gully large enough to be noticed by people. Concerning gully central, the age of the drain is about 100 years. The situation became critical, according to B.B. Basnet, about 30 years ago. The last part of gully "central", where lateral slumps take place (segment C7, corresponding to the ***x6*** axis) used to be deeper and less wide. The lateral slumps really started about 50 years ago. Hence, it is difficult to give an age to the whole gully. It has been chosen to use both the values 30 and 50 years, in order to frame reality. Regarding gully south, it has always been seen like this by local people, according to Narayen Kargi, chairman of the Bistacchap CFUG. Hence, it is impossible to give an age to it; it seems to be stabilized.

It is very important to keep in mind that the average erosion rate is only an indicative value. Indeed, as shown by the development of gully central, the evolution of the erosion rate is far not linear. It started with a small drainage which kept "acceptable" dimensions for 50 years, then started increasing, to become critical after 20 more years, and finally increased very strongly over the last 30 years. This will be further discussed in part 4.3.3.

Table 5: Summary of geometrical characteristics and age of the different gullies. (Source: N. Dolidon)					
Name of the gully	**North[(*)]**	**Central (demonstration site)**	**South**	**Football**	**TOTAL**
Total length (m)	389	285	100	43	894
Total volume (m^3)	1 082	10 713	147	195	12 072
Proportion of total length (%)	44	32	11	5	100
Proportion of total volume (%)	9	89	1	2	100
Average section area (m^2)	3	38	1	5	14
Maximum section (m^2)	14	223	4	9	223
Average slope (degrees)	26	7	21	20	NR
Height difference between top and outlet (m)	168	36	36	14	NR
Age (years)	30 to 40	30 to 50	unknown	14	NR
Average erosion rate (m^3/year)	27 to 36	214 to 357	unknown	14	NR

[(*)]Gully North: these results do not include the secondary gullies arriving from the north, shown on maps 4 and 5.
NR= Non-relevant.

The most important remark regarding table 5 is the big range in the size of the gullies. It allows a rationalization of an obvious reality. As an essential component of the volume, the area of cross sections vary much between different gullies.

These figures can be compared with two other gullies in the region which I have been told about during my stay in Nepal. One is located in Dhotra, about 20 km east of Godamchaur. It is about 50 m long, 20 m wide and 15 m deep at the outlet. This would represent roughly a section of 150 m^2 (triangle shape) and a volume of 7 500 m^3. However, this figure is simplified and overestimated, because the section is not constant. It shows that the gullies north, south and football are rather small ones. Another gully which allows a comparison is located in Bhardev, about 10 km south from Godamchaur. It was located on a slope of about 25 degrees, and became 300 m long within 5 years. This shows that the development of the studied gullies is rather slow.

Table 5 shows also big differences in the configuration of the gullies: different slopes and height differences between highest point and outlet. This may be both a consequence of and a cause for different processes taking place and which will be discussed in part 4.3.

4.1.2. Vegetation

Vegetation cover has been characterized by assessing the vegetation cover (tenth of cover) of the three different layers (herb, shrub and tree) in the five different compartments of the gullies (left and right side, left and right bank, bottom). Right and left are defined referring to the water flow. The summary of the vegetation cover assessment is presented in the table 6 below. It shows important differences between the gullies studied. These values are average ones; they do not allow representing the variability along each given gully. This level of detail may be useful for further research, but the average values for the different gullies appear to bring already interesting information.

Table 6: Summary of the data collected regarding vegetation cover for the different gullies: average vegetation cover for different layers and gullies. (Source: N. Dolidon)

Unit: /10 of cover	Gully	left side	left bank	bottom	right bank	right side
Herb cover	**North**	9	7	1	7	7
	Central	8	4	5	5	8
	South	6	5	4	5	7
	Football	5	2	3	3	9
Shrub cover	**North**	3	5	4	4	2
	Central	2	3	3	2	4
	South	0	0	0	0	0
	Football	1	1	0	0	0
Tree cover	**North**	2	3	3	3	1
	Central	1	1	2	1	0
	South	6	5	5	6	5
	Football	1	4	4	4	2

These results show clearly the absence of shrubs around gully “south”, as well as their rareness on the sides of gully “football”. Shrubs growing inside and around gully “north” are mostly *Schima wallichii*. Some other shrub species have been encountered, such as *Alnus nepalensis*, *Castanopsis sp.* and *Osbeckia stellata*. In particular Himalayan alder (*Alnus nepalensis*) and *Osbeckia stellata* indicate rather fresh and moist zones. Schima wallichii is the only shrub on the sides of gully “central”. This area is a former grazing zone, which belongs now to the Godamchaur Community Forest and has been planted around 2003 with *Schima wallichii*. Grazing is now prohibited in the part upslope the gully but authorized in the private land located downslope. Inside the gully, *Schima wallichii* is mixed with other species, in particular Himalayan alder, in the bottom of the gully. Some Chir pines (*Pinus roxburghii*) have been found on the right bank of gully “central”, the sliding zone.

The trees found inside and around the gullies “north”, “central” and “football” are all close to the gully. It seems that their presence is due to the presence of the gully, because of the humidity, or because people do not use the stripe of land close to the gully. These trees are mainly broadleaved species; *Schima wallichii* in the upper parts, with an increasing proportion of *Alnus nepalensis* in the lower parts. With exception of this stripe close to the gullies, trees are rare; shrubs are dominant. The only exceptions are the first and second segments of gully “north”, which are in the middle of the larger pine forest at the top of the hill. Gully “south” is completely in the Chir pine forest. The density of the stand does not change close to the gully.

The results concerning the herb layer show a common trend: the herb cover is more developed on the sides of the gully than on the banks, and more on the banks than in the bottom. The difference between sides and banks exist for all gullies. However, in gully football and central, this difference is less visible. Main herbs are grass species. The second most important plants in the herb layer are two different species of ferns: *Dicranopteris linearis* and *Dryopteris cochleata*. On the sides of gully “north” in the upper pars, it is worth noting the presence of Napier grass, *Arundinella nepalensis*.

Some explanations regarding the causes for this repartition of the vegetation, and in particular its consequences will be proposed in part 4.1.5.3. and 4.3.5.

4.1.3. Soil characteristics

Depth of the soil varies much depending on the place. The two extremes observed are the bedrock at 1.5 m depth in gully south, and still soil after 9 m in gully "central".

Except for the right bank of gully "central" in the sliding area, the soil material is very similar in all the gullies. It includes mostly red clay and silt. With increasing depth, increasingly large soil particles appear, eg. sand and gravels. The bearing capacity of the soil vary with the moisture, between 100 and 300 kN/m^2. However, this variation is always the same: the bearing capacity is higher in the rather dry topsoil and lower in the more moist bottom of the gullies. Moreover, it varies significantly with the duration between the last rain and the time of assessment. In some places, gravels or bare bedrock change the bearing capacity, but the representativity of this situation is negligible in proportion to the length of the gullies, except in the landslides of gully "central".

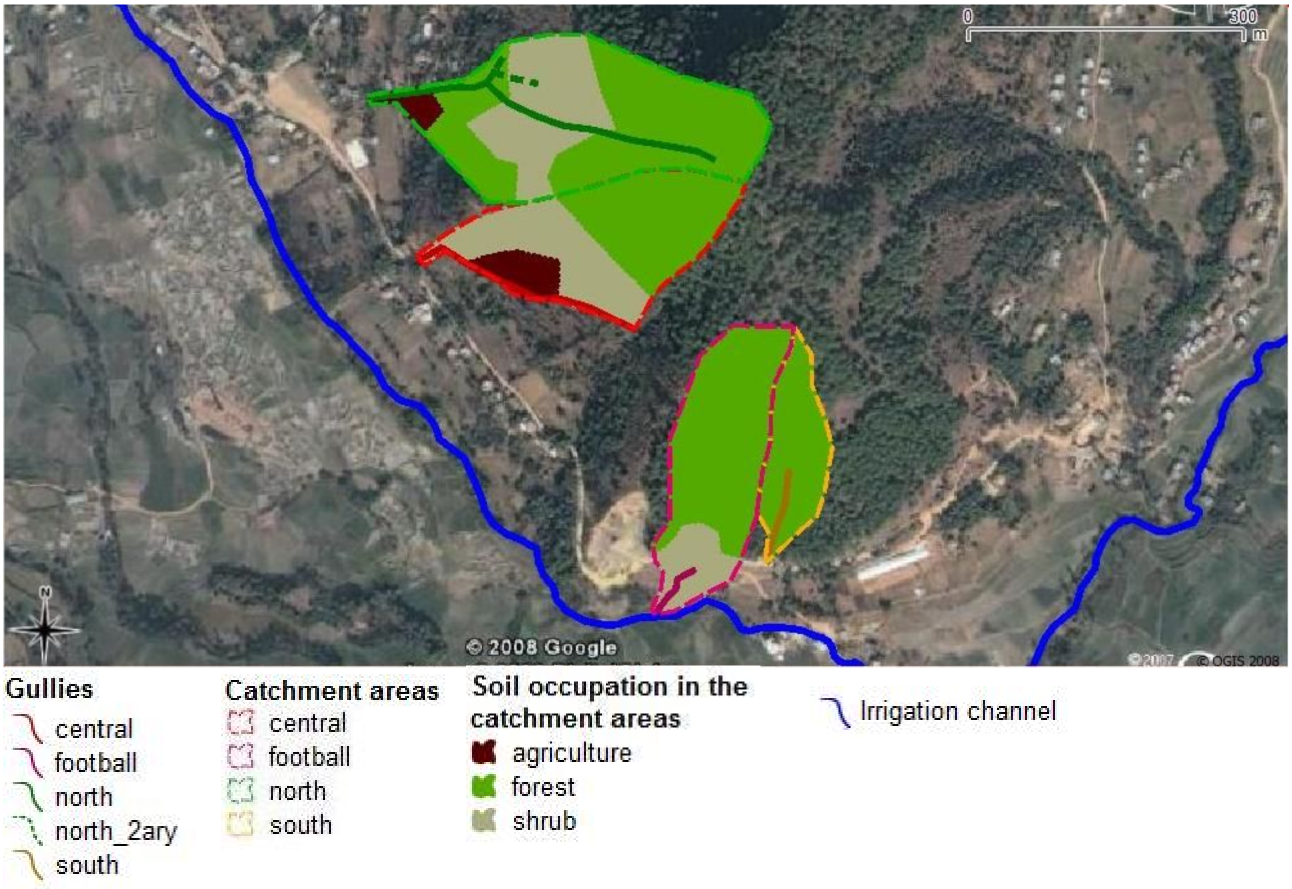
The angle of repose of the soil also presents a certain variability depending on the moisture, but the material is homogeneous. Hence, it is not the cause of variation. The values vary between 20 and 40 degrees. The angle of repose of some very wet zones is about 20 degrees; however the majority of the places assessed show a higher angle of repose.

The structure is always granular except for the sliding area where it is sub angular polygonal. This has to be linked with the lack of vegetation cover of the area. The organic matter content is so low that the aggregates of the soil are no longer coherent.

4.1.4. Catchment areas: surface, vegetation cover and consequences on run-off

Map 6 below shows the different gullies and their respective catchment areas (green, red, yellow and pink respectively). Each catchment area is subdivided in sub-catchments, corresponding to different soil occupations. Three soil occupation classes are used: forest, shrubs, and agriculture. The classification was done thanks to the aerial photograph.

The catchment area of gully "south" is entirely forested. The one of gully "football" is mainly forested, but shows non forested areas in its lower part, and includes a road, where infiltration is very low. Gully "central" is located within a micro watershed which is half forested and half covered with shrubs. The degraded area itself has been considered as agricultural land because of its low vegetation cover, leading to a reduced infiltration. The catchment area of gully "north" is forested in the upper part, as well as close to the settlements. The lower part includes corn fields on the left side of the gully.



Map 6: Catchment areas and soil occupation of the catchment areas. (Sources: Google, QSIG, N. Dolidon)

The aim is to assess the run-off passing by the gullies and to compare the different values. The method is based on a slide show presented during the training course on Low Cost Soil Conservation Techniques and Watershed Management organized by ICIMOD in spring 2008 entitled "Run-off calculation" (Sthapit 2008).

The run-off at the outlet is expressed as:

$$Q = C \times I_{TC} \times A / 360$$

with:

Q: run-off at the gully outlet (m^3/s)
C: run-off coefficient. Proportion of rain becoming run-off, compiled on the whole catchment area.
I_{TC}: intensity, that is the rate of rainfall for designed frequency for a duration equal to the time of concentration, TC (mm/hour)
TC: time after which the run-off is maximal in the outlet of the gully (minutes)
A: area of the micro-watershed (ha)

To each soil occupation type corresponds a specific run-off coefficient. The global run-off coefficient C is derived from the different run-off coefficients corresponding to the different soil occupation types within the micro watershed and their respective areas. The soil is a heavy clay soil. As a consequence, the infiltration rate is rather low, and the proportion of rain becoming run-off is rather high. Thus, the C coefficients were chosen as shown in table 7 below.

Table 7: Run-off coefficients of different soil occupation types. (Source: K.M. Sthapit, modified by N. Dolidon)		
Soil occupation	**Run-off coefficient**	**Comments**
Forest	0.4	
Shrub	0.45	In the original document, given for pasture. This vegetation is considered similar.
Agriculture	0.5	Also used for the degraded area of gully "central" and the part on the road and the football field of gully "football".

A standard formula given in the document to derive the time of concentration is:

$$TC = 60 \times L^{1.15} / 15 \times H^{0.38}$$

with:

TC: time of concentration (minutes)
L: length of the watershed along the main stream, from the outlet to the most remote ridge (km)
H: height of the watershed, height difference between the outlet and the most remote ridge (km)

The following step is the choice of the frequency of the rainfall of which the amount is calculated. I chose to take 10 years and 50 years. The first one allows taking into account rather regular phenomena, which participate in shaping the landscape through their rather high frequency. The second one, the 50 year frequency events represent the extremely intense rain storms, which can lead to major damages at once. Standard rainfall values for one hour are given for different regions of Nepal. This value and the time of concentration allow reading the value of I_{TC} on a graph (see annex 6). I_{TC} represents the rainfall intensity of a rain lasting for a the time of concentration TC and occurring at a given frequency (here 10 or 50 years for the example).

Finally with all these parameters, as well as the total area of the watershed, it is possible to derive an estimation of the run-off. Results obtained for the four gullies studied are given in table 8.

Table 8: Maximum run-off calculation for the four studied gullies, in case of rainfalls with respectively 10 (Q10) and 50 (Q50) years frequency. (Source: N. Dolidon)

Gully	A (ha)	C (-)	TC (min)	I_{TC}10 (mm/hour)	I_{TC}50 (mm/hour)	Q10 (m^3/s)	Q50 (m^3/s)
North	4.86	0.42	2.7	240	275	1.36	1.56
Central	3.33	0.43	3.5	235	270	0.94	1.08
South	1.20	0.40	2.2	245	280	0.33	0.37
Football	2.82	0.41	2.7	240	275	0.77	0.88

The results in table 8 show that given the size of the gullies, the expected run-off in case of heavy rainfall events is rather high. It can be compared to small water streams. There is a big difference between gully "south" and the other ones. It could be explained by the important forest cover. But the very small difference between the compiled values of C shows that the forest is not making the difference. The small value of run-off in gully "south" is explained by the small size of the catchment area. It is likely to explain the fact that gully "south" has stabilized. The small watershed, combined to a complete forest cover, improving water infiltration, may have contributed largely to the stabilization of the gully.

The configuration of gully "central" leads to an increased time of concentration, because the longest way from the most remote point of the catchment area to the outlet is longer, due to the transversal orientation with respect to the main slope.

4.1.5. Other specificities of the gullies

Some characteristics of the gullies could not be written down on a systematic way. They are explained below.

4.1.5.1. Gully “North”: a potential threat for settlements, and a dump

The lower part of gully “North”, segments 11 and 12, borders a path and dwellings on its right side (figure 12). The right bank of the gully is vertical in that place. In case of a slump, the path would be damaged. Moreover, the houses are not far away. If an expansion process starts, it is likely to reach the houses quite quickly. This is also the Mr. Basnet's and Rupak Khadka's point of view. Upslope the dwellings, secondary gullies coming from the north join gully “north”. They are up to 4 m high and 4 m wide. In case of rapid degradation of these gullies, the dwellings could be threatened by landslides or mud flows.

Figure 12: Lower part of gully “north” - Proximity with the path and the dwellings. (Source: N. Dolidon)

Where the gully passes very close to the dwellings, the bottom is covered with domestic waste such as plastic bags, as well as branches (figure 13). This explains the absence of plants growing in the bottom. Moreover, one lady leaving in one of the houses, met by chance, told me that the gully stopped developing two years ago. It is not what Mr. Basnet told me, and personally I also saw signs of further degradation of the gully. However, the erosion rate might have reduced. Rupak Khadka also told me that the waste can be flown away by the rain. Hence, its presence is a sign of less intense rainfalls over the last few years. This is confirmed by the rainfall data in Godavari and Khumaltar, which show less rainfall in 2006 and 2007 than before.

Figure 13: Waste in the lower part of gully “north”. (Source: N. Dolidon)

4.1.5.2. Sensibility to splash erosion

The soil is rather compact and has a low infiltration rate. But in the absence of vegetation, and in particular where the soil has already been moved, the sensibility to splash erosion is obvious, as shown on figure 14, taken in gully “central”. This phenomenon is a small scale one, but keeps the soil unstable because it destroys its structure and prevents young root systems to establish.

Figure 14: Gravels isolated by splash erosion – they protect the soil underneath, but the surrounding particles were eroded. (Source: N. Dolidon)

4.1.5.3. Vegetation: always efficient against gully development?

During the data collection phase, it was noticed that in some places, despite of a correct vegetation cover, the erosion process seemed to take place. Several different situations appeared.

The ferns, *Dicranopteris linearis* and *Dryopteris cochleata* sometimes constitute a continuous and homogeneous cover, without hardly any other plant. Even though the leaves create a kind of protection layer above the soil and avoid splash erosion, there are large spaces between the plants. The water which reached the ground flows down without being stopped by the fens, and sheet erosion is possible. This is mainly the case in gully “north”, as well as in the segment 6 of gully “central”.

In some other cases, a continuous grass cover prevents from both splash and sheet erosion, but it is not enough to prevent from sliding, because the root system is not deep enough. This is happening mainly in gully “central”, in places where the grass cover started growing on unstable soil mass.

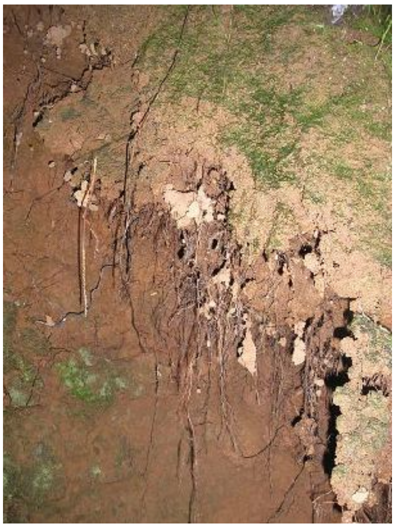


Figure 15: The soil is eroded underneath the root system, leaving the roots without support anymore. (Source: N. Dolidon)

When the gully already exists, the root systems may slow down the erosion of the banks, but are not sufficient to stop the process, as shown on figure 15 above, taken in a secondary gully close to gully “north”. Once the erosion starts underneath the root system, the plants do not play an important role anymore. If it goes on, the whole soil mass may slump, in which case the vegetation would have a negative impact.

4.1.5.4. Shape of the gullies: a clue to understand their development process

The shape of the cross section of the gullies vary between the gullies and along each of them. Moreover the profile is also variable. The most often encountered shape is a large U shape. The slope of the banks is steep, and the bottom rather wide. The profile is not continuous, but presents several steps. This might reveal a two-fold process : during very heavy rainfall events, the gully is deepened and widened. During low to medium rainfall events, it is also eroded and degraded, but the stream is much less strong; hence the sediments taken away are partly deposited in the ground of the gully, giving it this rather flat configuration. During wet periods without any stream, a “slumping process” also takes place, as witnessed during the study. This slumping process maintains the too steep and thus unstable slopes of the banks and the several steps.

Another shape is a very narrow U. It seems to be actually the same process, but less advanced. The segment 7 of gully “central”, which is about 5 m deep, 6 m wide and presents a very important slumping process. Rupesh Khadka told me that it used to be deeper but much more narrow. This means that the narrow U shape is a preliminary phase for further massive development of the gully.

The third important shape is the one of a “half V”: one bank is vertical, and the other one presents a slope, closer or even equal to the angle of repose. This was seen when the direction of the gully was transversal to the main slope of the hill. The bank located upslope starts sliding, because there is no more support at its toe. The bank downslope stays vertical and gets eroded much slower than the upslope one. The toe cutting process goes on in the bottom of the gully, maintaining the sliding process. This leads to the biggest soil losses (see part 4.3.1.).

4.1.5.5. Lessons learned from weather data

The weather data provided for Godavari and Khumaltar were analyzed. There are differences between the two sets; the weather in Godavari is globally a bit fresher and more rainy. However they show very similar trends.

The main conclusion to take out of this analysis concerns the repartition of the rain: one usually says that 80 percent of the 1 300 to 1 900 mm yearly rainfall fall within four months. This is true. But a more precise analysis reveals that between 2000 and 2007, 50 percent of the annual rainfall fell during the 20 most rainy days, and 64 percent of the total rainfall fell during the 30 most rainy days. These days are not all one after each other, thus the soil may partially dry out between the heavy rainfalls. But this shows that the climate is characterized by few very rainy days each year. Indeed, the average rainfall for the 20 most rainy days, mixing the data from Godavari and Khumaltar, is 45 mm. Average rainfall of the 30 most rainy days of a given year is 38 mm.

Moreover on the most rainy day during the period 2000-2007, July 23rd, 2002, the total amount of rain was 228.6 mm in Godavari and 136.4 mm in Khumaltar. This kind of very heavy rainfall is most probably the most erosive one.

Unfortunately I had no access to data on an hour basis.

This suggests that the gullies may be created and developed because of an excess rainfall which falls within a very short time, be it an exceptional event or the regular ones taking place each year. The consequences regarding gully treatment will be presented in part 4.4.

4.2. Impact of sediments on the downstream located fields

A discussion was carried out with five persons, representing four farms, in order to assess the differences in productivity of the fields located downstream the demonstration site. Table 9 presents the results of the discussion which differ from one farm to another one. Common points between the farms and comments are explained below.

Figures in grey cells in table 6 are not precise ones, but they show the trend: farmers relying on the irrigation channel downstream the demonstration site witnessed a strong increase in the rice yields. This evolution has not been seen in the fields not relying on the irrigation channel, nor in the wheat yields. Moreover, according to B.B. Basnet, around 1 to 2 inches of sediments were deposited each year in the fields (2.5 to 5 cm). This phenomenon has stopped after the construction of the check dams.

All the farmers have the same cropping pattern. From May to August they grow rice. After the harvest, from September to March, they grow wheat. Sometimes during the time left, some people plant vegetables; it is not the case of the interviewed farmers.

The techniques and practices seem to be the same ones for all the farmers, except that some of them benefit from an own water spring, others from the irrigation channel, and another one has only rainfed fields. The farmers explain the differences in the yields between the different farms by differences in soil fertility and in water availability.

The farmers did not notice any major change in temperature or rainfall (intensity, period) which could explain the changes in productivity observed over the last years. This seems to be confirmed by a quick look at the weather data provided on Godavari and Khumaltar by ICIMOD and NARC respectively. They did not change their cultivation practices.

All these observations suggest that the construction of the check-dams and implementation of other soil conservation activities led to the increased yields. This would mean that the sediments had a negative effect on rice yields. One hypothesis proposed after discussion with Dhrupad Choudhury from ICIMOD,

Table 9: Data collected thanks to the discussion with the farmers. (Source: N. Dolidon)

Farmer interviewed		B. B. Basnet	Anand Khadka	Rambadur Khadka	Rupak and Rupesh Khadka
Source of water supply		Irrigation channel downstream the gully	Irrigation channel downstream the gully	Rainfed	Own permanent source
Total size of the fields	ropanis	5	3	2	4.5
	hectares	0,3	0,2	0,1	0,2
Number of fields		2,0	2,0	2,0	NC
Respective size of the fields	ropanis	2 and 3	1 and 2	about 1 each	NC
	hectares	0,1 and 0,15	0,05 and 0,1	about 0,05 each	NC
Current rice yield	bags/ropani	4,0	4,0	1,5	10,0
	kg/hectare	3937	3937	1476	9843
Rice yield before construction of the check dams	bags/ropani	3,0	2.6 (8 bags for 3 ropanis)	1,5	10,0
	kg/hectare	2953	2559	1476	9843
Current wheat yield	bags/ropani	2,0	2,0	A bit more than 0.5	4,0
	kg/hectare	1969	1969	492	3937
Wheat yield before construction of the check-dams	bags/ropani	2,0	2,0	A bit more than 0.5	4,0
	kg/hectare	1969	1969	492	3937
Evolution of rice yield		33%	54%	0%	0%
Evolution of wheat yield		0%	0%	0%	0%
Number of family members		5	5	3	6
Time for which the own rice production is enough to feed the family	months	6	5	2	6
Time for which the own wheat production is enough to feed the family	months	NC	NC	4	8

1 Ropani = 508 m^2 (=0.05 ha)
1 bag contains approximately 50 kg of grain.

explains this impact through the temperature. The sediment carried come from deep layers from the soil. Thus, the organic matter content may be much lower than in the top soil. This might lead to an increased temperature of the rice field. In June when the rice seedlings are planted, temperatures are already very high. The slight increase due to sediments may lead to a too high temperature, killing the sensible young seedlings. The exact process can be a direct physiological disruption, or a perturbation of the nitrogen cycle for example. These are hypotheses and it is impossible with the available data to conclude on the reasons for the increase in rice yields after gully treatment.

The increase in rice yields is between almost 1000 kg/ha/year for Mr. Basnet's fields and almost 1400 kg/ha/year for Mr. Khadka's fields. One kilogram of rice costs about NRs 22 (Nepali rupees), according to the World Food Programme (2008). This means that the treatment allowed the farmers to save between minimum 21 000 and maximum 31 000 Nrs/ha/year. The project proposal from 2005 states that “more than 100 ropanis” of rice fields rely on the irrigation channel, which represents at least 5 ha. Hence the total value of the increased yields could be assessed between 105 000 NRs/year and 155 000 NRs/year. This amount is shared between the several land owners concerned. But as a whole, it is a significant figure compared to the NRs 400 000 spent in soil conservation activities over the past three years.

According to these figures, it seems that the investment in soil conservation measures could be payed back in 3 to 4 years. Since the ones who make the savings are the farmers, it shows a potential for a payment for ecosystem services scheme.

However, this comparison is not enough. Indeed, another very important role of the developed treatment methods is to preserve the soil of the hill from further eroding. Hence, the value of this land should be taken into account.

The production of rice and wheat is not enough to feed the families (see table 9). Therefore, they have to find an income generating activity in addition to the farming. It depends on the people. Some of the jobs they find include for instance civil servant position, farm worker in bigger farms, construction worker or driver. Present farmers say that some people grow flowers, but it is the only complementary income generating agricultural practice in the village, according to them.

4.3. Deductions regarding processes occurring and treatment priorities

4.3.1. A gully across the main slope leads to more massive degradation

The geometry of the gullies confirms that gully “central” is far the biggest one, even though it is not the longest one. This is because it is the only one in which a landsliding process is taking place on a rather large scale. Indeed, a more detailed study of the repartition of the eroded volume clearly shows the importance of lateral sliding in soil losses: it represents 87 percent of the eroded volume in gully “central”, for only 37 percent of the length. The front slope plays a role on the stability of the soil, as well as on the water speed. However, one can deduce that the lateral slope seems to play a much more important role. The rupture of the soil continuity created by the drainage/gully is the equivalent of a toe cutting phenomenon and leads to landsliding, through strong reduction of the passive weight reaction P and its angle α with the vertical.

However, this effect of lateral slope is not enough to entirely explain the sliding phenomenon. Indeed, some parts of gully central, which are also across the slope of the hill but where the lateral sliding has not started yet. Differences in soil characteristics or in vegetation cover might explain the difference in soil degradation. It is also possible that the massive landslide is located in a slightly steeper place of the catchment area, and that it collects more water.

4.3.2. Slumps and steps: the most represented gullying phenomenon

The entire gully “football”, the entire gully “south”, gully “north” and gully “central” respectively on on 80 and on 70 percent of their lengths present a profile where the slumping processes are the major ones. This is without counting the segments where different types of cross sections are encountered on very short distances. This shows that the slumping process are the most important ones regarding the proportion of gullies affected. However, the corresponding volume is only 1648 m^3, that is to say about 13 percent of the total eroded volume, adding the four gullies.

This “bank and bottom slumping” phenomenon is characterized by rather steep banks, but also and above all by several steps in the bottom of the gully. The foot of each step shows signs of water accumulation: sometimes water can be found, and dead leaves are always accumulated there. On the top of the steps, there are no dead leaves, they have been flown down by the previous rain, to the foot of the step. figure 16 shows one of the most impressive steps observed in a secondary gully linked to gully “north”.

Figure 16: Inside a secondary gully in the north of the network linked to gully “north”: a very high slumping step. (Source: N. Dolidon)

Moreover, the upper part of the landslide in gully “central” is constituted of a vertical scarp. This is also presenting slumping processes. This means that describing the big landslide only with the sliding process would not be enough. The vertical scarp is expanding upslope and towards north. Hence, in this area, fixing the slumping process would allow stopping massive soil losses as well.

The biggest part of soil losses is due to clearly identified toe cutting and sliding processes: 9925 m^3 – 82 percent of the total volume. This process is supplied by massive upslope slumping.
The most represented erosion process is slumping from the banks and the steps in the bottom of the gullies: 678 m – 76 percent of total length, but only 13 percent of the volume.
The remaining 5 percent of volume are due to mixed processes.

As a consequence, the most urgent task is to limit the development of landsliding processes. The best hope for long term limitation of gullying process however is to mitigate the slumping process.

4.3.3. An exponential evolution

The history of gully "central" was already mentioned (4.1.1.). It shows the increasing speed of the erosion process. It is not a linear evolution. This is also suggested by the respective ages and sizes of gully "football" and gully "north", as well as the particular history of segment 7 of gully "central" (narrow for years, and then very quick widening).

The bigger the degraded area, the bigger the area without vegetation. The deeper the narrow gully, the most sensible the banks. In both cases, we are facing an auto-amplification phenomenon. Moreover, it is much more difficult for vegetation to colonize again a degraded area, because of lack of particle stability, bad structure and lack of organic matter. It is also a vicious circle.

> IT IS VERY IMPORTANT TO IMPLEMENT MITIGATION MEASURES AT EARLY STAGES. ONCE THE PROCESS OF HEAVY DEGRADATION HAS STARTED, THE PRIORITY IS TO TREAT THE MOST DEGRADED AREAS. HOWEVER, IN PARALLEL OF THIS CURATIVE ACTION, IT IS VERY IMPORTANT TO ENDORSE PREVENTIVE ONES, EMPHASIZING ON THE PLACES WHERE THE PROCESS OF GULLY EROSION HAS JUST STARTED.

4.3.4. The action of water

Without water they would be no gullies. It is the factor which leads to gully erosion. But what are the main processes and what are the main mitigation strategies?

The weather data show that rainfall can be very heavy on short periods, concentrated on three to four months. The shape of the gullies show that both toe cutting and soil moisture leading to slumps are very important phenomena. The analysis of the watersheds and the expected run-off in case of very heavy rainfall, suggests that the amount of water received by the gully is a decisive factor for its development.

The parallelogram shape of the cross sections of the gullies shows that heavy rainfalls lead to massive erosion processes, and that between these events, rainfalls of lower intensity keep shaping by carrying and depositing sediments in the ground. Major phenomena dig the gully suddenly, and minor to medium ones tend to give it a balance profile.

Water has also a particular impact on bare soils, through splash erosion.

> SEVERAL ACTIONS CAN BE IMPLEMENTED TO LIMIT THE EFFECT OF WATER. THEY ARE CLASSIFIED BELOW BY DECREASING ORDER OF IMPORTANCE:
>
> - LIMIT THE AMOUNT OF WATER REACHING THE GULLY
> - PROTECT THE SOIL FROM DIRECT RAINFALL
> - SLOW DOWN THE WATER FLOWING IN THE GULLY TO LIMIT EROSION AND INCREASE SEDIMENT DEPOSITION

4.3.5. The vegetation cover can have a significant effect only if all layers present an important cover

It has been shown (4.1.5.3.) that different vegetation layers play different roles and present both advantages and disadvantages. An ideal vegetation cover should be balanced between the three defined layers, in order to benefit from the combination of all positive effects provided by the different layers. Stems should be avoided inside the gullies in order to avoid turbulences in the water flow, which would lead to further digging around the stem. Trees bordering the gullies should be cut down in order to limit their destabilization when the soil gets eroded around their root system. Moreover, it is necessary for the development of plants in the ground of the gullies, where they are not too deep, to let light enter it.

Therefore, the vegetation growth on the banks has to be controlled and limited.

VEGETATION SHOULD PRESENT THREE WELL COVERING LAYERS TO PROTECT THE SOIL FROM THE DIVERSE ACTIONS OF WATER, AS WELL AS TO MAINTAIN ORGANIC MATTER AND THUS AGGREGATE STABILITY. ONCE THE GULLY HAS STARTED, INCOMPLETE VEGETATION COVER HAS A LIMITED EFFECT.

4.4. Soil, water or vegetation management?

It has been shown that the gullies present different mechanisms which lead to various severity and velocity of soil losses, depending on their situation (watershed characteristics, front slope, lateral slope, vegetation). Better understanding the processes occurring allows suggesting some intervention methods and compare them. What is the most urgent issue? On which factor to influence in order to slow down or stop the soil degradation on the hill of Godamchaur and Bistachhap?

There are three main ways of intervening. The first one is engineering pure, acting directly on the soil, such as check dams or supporting walls. These methods influence also the water flow of course. However, some other ones focus more on the water flow: terraces, ponds, several pits to retain the water, or drains. The third category includes the vegetative methods, which actually aim at playing a role on both water and soil.

4.4.1. Soil management: expensive but useful in some places

Supporting walls would prevent the steps from further slumping. But it would be very expensive to build as many supporting walls as major steps encountered. Check-dams are interesting for two reasons. On one hand they trap the sediments, and thus limit the input in the fields downstream. On the other hand, the sediments trapped prevent the deepening of the gully immediately upslope each check-dam. Moreover check-dams slow downs the water flow and thus limit the toe cutting effect. But stone check-dams are expensive as well, and brushwood check-dams need light. Hence, it can be a solution only for few large places in the "dark" gullies such as gully "north" and "football". At least strong check-dams have to be built at the outlet of each one of these gullies, to trap sediments. Moreover, priority should be set on narrow segments of the gullies, before they collapse and get bigger.

Check-dams would both retain sediments and slow down water flow. Slowing down water flow is the third action proposed in the frame of the paragraph 4.3.1.4. "The action of water."

4.4.2. Water management: the most efficient solution

Managing the water flow entering the gully seems to be the most effective method. Indeed, water is the factor which leads to the erosion of a gully. Limiting its flow severely decreases the erosion. The current shape of the hill is the result of millenniums of rainfall on ever increasing hills. It means that it is a balance between the statistically predominant rainfall amount (the heaviest ones on a given period of time) and the resistance of the soil. There is a threshold above which water starts damaging severely the soil. If the amount of water which reaches the gully stays below this threshold, the gully should stabilize, as it may have happened for gully "south".

Hence, a way to improve the infiltration upslope gully "north" would bring an excellent contribution to the limitation of its development. It does not seem sound to build terraces, for economic reasons. The experience of gully “central” shows that building drains would be dangerous. A single pond would need drains to gather the water from the catchment area; hence it does not seem appropriate. The proposition is to dig several pits around the gully and if possible in the whole watershed. This would increase the infiltration rate, decrease the run-off coefficient C and thus reduce the amount of water reaching the gully at once. Moreover, the water would pass in lower levels. Since the gully is not very deep, there is hope that the water passes underneath, where the bedrock has not been reached. Digging pits is very cheap, it allows covering the whole catchment area without putting water in movement such as with drains.

Concerning gully “football”, a first step would be...not to send all the water coming from the recently built football field, as well as from the upslope located road and the whole catchment area directly into the gully. Indeed, a large ditch leads all the water coming from upslope as well as from the football field into the gully. It is reinforced, so there is no risk of widening, but it increases the velocity of water and hence decreases the concentration time. It should be rearranged so as to let the water flow into more stable places, if possible not only in one drain, but spread in several ones. Regarding the catchment area, the solution of the pits seems also suitable for the reduction of the water flow arriving in the gully during heavy rainfall events.

The problem is different for gully “central”. Indeed, the large vertical scarp, perpendicular to the run-off, would keep slumping if it would receive the water infiltrated upslope. Indeed, the scarp is so high (up to 6.4 m) that the infiltrated water may not flow underneath. Hence, the possibility which appears is to build the pits further away from the scarp, in order to retain the amount of water falling on the upper part of the catchment area far away from the scarp. It would only slightly reduce the amount of water. Hence, to divert the flow from the main scarp, hedges of *Flemindgia*, as already planted could be a solution. But the problem is that currently the plantations do not grow; and moreover they lead the water in the upper part of the gully... I suggest to plant new rows of *Flemindgia* leading the water completely away from the gully. If it does not work after two years, the construction of a reinforced drain should be considered.

This proposition of eye-brow shaped pits has to be first tried carefully. Indeed, it could have two strong negative effects. The first one is that the water retained by the pits may lead to a highly increased weight exerting a pressure on the soil mass. The second negative effect is that the infiltration could lead to the concentration of water in a deeper layer, decreasing the cohesive resistance of the soil mass (indicated C on figure 2). Both the increase of the total mass and the decrease of the cohesion can have the very negative of increasing the probability of occurrence of a massive landslide. Hence, this solution has to be tested on less sensible places (not too steep, with a deep soil).

If the eye-brow pits appear to increase the risk, well-protected drains would seem to be the best adapted solution in a first time, until the vegetation develops sufficiently in the whole watersheds.

Limiting the amount of water entering the gullies is the first objective proposed in the frame of the paragraph 4.3.1.4. “The action of water”.

4.4.3. Improvement of the vegetation cover: the necessary complement

Vegetation has an impact on soil stability and water flow, as well as the direct impact of rainfall on the soil particles.

The gully in which reconstitution of the vegetation is the most important is gully “central”. Many plantation, brush-wood check-dams, seedings and fascine have been created and done in this area. It seems to slow down the secondary gullying effect. However, the problem of the sheet erosion and of the permanent instability of the landslide is not solved. I propose in order to contribute to it resolution to create a cover with branches of rooting plants (species to be determined, I do not have enough elements at the time of redaction of this document to make a decision. Possible plants include *Salix sp.*, *Adhatoda vasica*, *Ipomea fistulata, Gagruga pinnata*, *Sepium insegne*). The branches should be in the same conditions as for a fascine (6 to 18 months old, 2 to 4 cm diameter and 100 cm long) and fixed to the soil thanks to wood sticks and wire rope. This would have to be done at the beginning of the rainy season. The cover created by the branches would immediately limit the splash erosion and provide favorable conditions to the growth of the plants. The process of degradation would be stopped and, if the new installations are well maintained (especially encouragement of a permanent growth through regular cutting), the vegetation cover should grow again. The places where it already show that it efficiently stabilizes the soil.

Regarding gully “north” and gully “football”, it seems that vegetation management includes mostly cutting the too big trees threatening the stability of the banks and providing more light to the inferior layers in order to promote the growth of herb species. Some complementary plantations of soil conservation species such as Napier (*Arundinella nepalensis*) could improve the stability of the bottom and of the banks in some places, where there is enough light for the plants to grow.

Thanks to the plantation done five years ago and to the conservative management implemented by the CFUG, the vegetation dynamic of the catchment areas of gully “north” and gully “central” seems on the good way: the young thress are growing, and an underlayer is already being created, thanks to natural Chir pine regeneration and to plantation of diverse species by the CFUG (*Prunus cerasoides*, *Engelhardia spicata* and *Rhus wallichii* in particular). In the Bistachhap forest, occupying the catchment areas of gully “south” and “football”, there is no underlayer. This is due to the harvest of needles, which kills the small plants, as well as to the presence of grazing goats. Hence, a more precise study could be of interest to determine whether local people's livelihoods' security wold be more guaranteed by changing management methods in the forest in order to preserve the soil. However it seems that slowing down the water with pits and above all modifying the drainage system around the football ground should be already efficient measures.

4.4.4. First steps to further improve the water quality in the irrigation channel

After having dealt mostly with the soil conservation related issues upslope, following proposes an easy and quick way of increasing even more the rice yields., located downstream.

It seems that the sediments coming from the degraded area have a negative effect on rice yields. Hence, there is hope that reducing the sediment load in the water of the irrigation channel to a minimal rate allow increasing as much as possible the yields in the fields. This is of course true for the sediments with low organic matter and poor nutrient content.

However, the aspect of the water coming into the irrigation channel at the level of the village of Godamchaur, as shown on figure 17 shows a higher sediment load than the water coming from upstream. Indeed, the picture on figure 17 has been taken after a one hour long rainfall at the beginning of the rainy season (June 3rd) and shows that the sediment load of the irrigation channel increases downstream the confluence with the water arriving from the center of the village.

Possible sources for the sediments coming from the village are several. On is the other gullies, in particular gully north, which has not been treated yet. Treatment measures have to be considered in order to both preserve the soils upslope and limit the sediment input in the irrigation channel. However, given its rather low erosion rate, another possibility has to be considered.

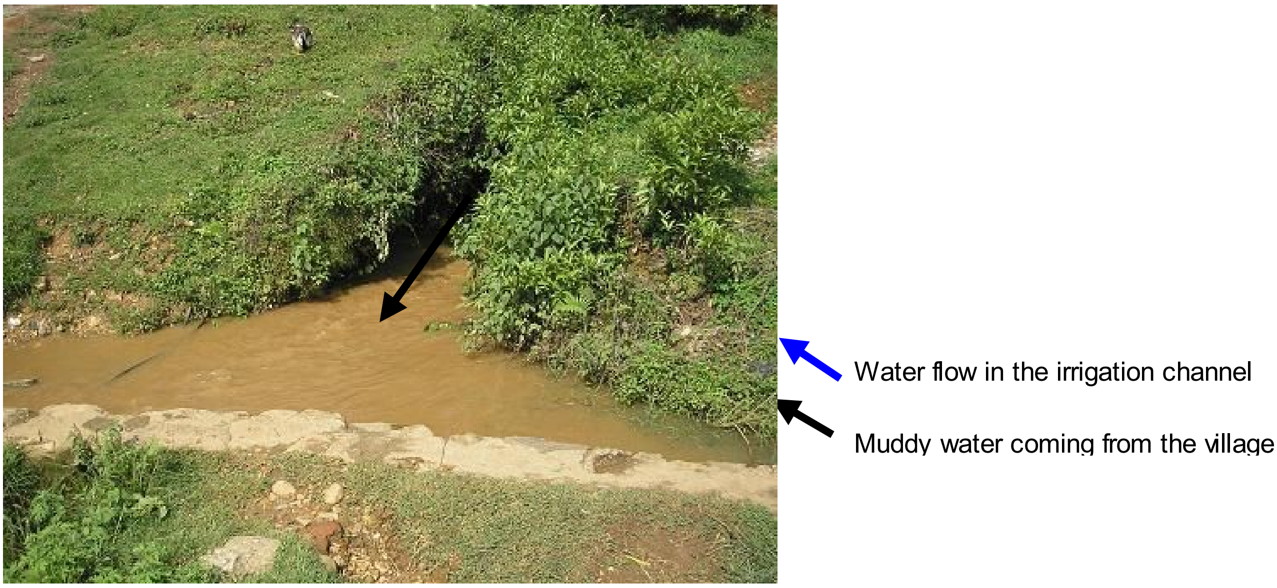


Figure 17: Confluence between the channel arriving from the village (black arrow) and the main irrigation channel along the valley (blue arrow) after a heavy rainfall during the pre-monsoon. (Source: N. Dolidon)

A football field constitutes the center of the village of Godamchaur. There is no vegetation cover on it and its slope is not nil. Thus, it is heavily eroded during rainfall events, as shown on figure 18, taken during a rain storm on June 1st 2008.

Figure 18: Football field in Godamchaur during a heavy rainfall event. (Source: N. Dolidon)

Given its large area and its high sensibility to erosion, it is likely to contribute to a large part of the sediment input in the irrigation channel. Moreover, it receives the water flowing down from gully north, as well as from th dirt road to Bistachhap, which is also an important source of sediments. Hence, trapping the sediments downstream the football field and before the irrigation channel may decrease strongly the sediment load of the water in the water irrigating the fields. A small sedimentation tank or several check dams could be a rather simple, cheap and efficient technical solution. A simple earth dam trapping the sediments and being regularly maintained would also be efficient.

As a consequence, even though slowing down significantly the erosion process of the gullies seems to be difficult and to take time, trapping the sediments has to be considered as a priority aim. It is easier to implement and seems to improve strongly the livelihood of people relying on the irrigation channel.

5. Lessons learned: a completely new approach

This part aims at carrying out a reflexion on the work done, ways to complete it and the personal enrichments acquired during this six months assignment.

5.1. The work carried out: a basis for further actions

5.1.1. Answer to the questions raised

The work explained in the present document answers some questions raised at the beginning. In particular, following issues have been dealt with:

- understanding the processes leading to gully erosion and thus what parameters lead to the stabilization of gullies?
- Where are the priority places to implement conservation activities?
- Do slight differences between gullies in the same climatic and geologic context change the best adapted treatment methods?
- What are possible impacts of major soil losses such as gullies and landslides on downstream located fields?

One of the initial questions however has been partially answered,: “How important is the role of vegetation to mitigate the development of a gully? And what role does it play on a shallow landslide? At what spatial and temporal scale?” The answer to the first part of this question has been developed (role of vegetation on a gully). However, the question of the spatial and temporal scale has not been developed. It was quickly mentioned through the study of the catchment areas and assessment of the run-off. The temporal scale has not been mentioned. Regarding this point, there is an obvious phenomenon: the conservation of the vegetation on the hill, the strong restriction of the uses and the access to the Godamchaur Community Forest, combined to the plantations, provide best conditions for soil conservation on the slopes of the hill. The global impression is that the vegetation is in a good state enough to avoid development of new gullies. Its role regarding the existing gullies however is not documented in this study.

Another question which has not been explicitly treated is the one of the already implemented soil conservation techniques. Is there a need to improve them? If yes, how? The present document did not answer clearly the question, but again the reflexion and the solutions proposed can be compared to the implemented techniques. The main conclusion would be that they are playing an important role, but are not sufficient for now. While growing, the planted vegetation should start protecting the soil better. But for the bare areas, the solution proposed in 4.4.3. seems necessary.

Three of the the four aims of the study are reached:

- The contribution to the main questions is not complete; it is discussed above
- The participation to a better knowledge about the site is successful thanks to the measurements of the gullies and the characterization of the vegetation cover.

- The contribution this work can bring to the development of the demonstration site will depend on its use by DSCWM personnel. A summary of the findings could be of interest to make the information more accessible.
- Even though the propositions have not been detailed, the reflexion allowed providing inputs for guidelines in the future management of the Community Forests of Godamchaur and Bistachhap.

5.1.2. Place of the work in the global topic

The work carried out allowed FAO and ICL having a background paper for the session on watershed and forest management for landslide risk reduction. This should be used as a base of reflexion for a better coordination of landslide mitigation related activities within a watershed. It is of course not a complete study with magic formulas. It sets up a basis, a framework for further discussion, research and action. According to the bibliography studied, the link between different activities within a watershed and th impact on landslide risk are not always well taken into account. Communicating on this issue, partly thanks to the background paper, will allow driving the attention of researchers and in particular policy makers on these issues.

The participation in the organization of the session of the WLF has taken much time, and is still keeping me busy. It is a coordination and communication work, where a good availability and adaptability to others' methods is necessary.

The work carried out in the Godamchaur and Bistachhap Community Forests should be useful for the development of the demonstration site in Godamchaur. It will allow having a broader overview for the persons visiting the demonstration site, thanks to different cases. It allows emphasizing on the fact that to avoid high costly interventions, early soil conservation measures are necessary. Hence, the work provides a support to spread this message. It is going to be used as a case study by FAO to illustrate the issues linking forest, water and livelihoods.

The reflexion on the gullying and landsliding processes and the solutions proposed can be compared to the ideas of the DSCWM team already working on the project, as well as with the ones of the CFUG members. Putting different ideas together may lead to interesting solutions.

The data collected can be a useful base for monitoring purposes. In order for the villagers to monitor the development - or the stabilization – of the different gullies, a check-dam placed at the outlet of the gullies, delineating a given volume in which eroded sediments could be stored seems to be a cheap and easy method. The volume of trapped sediments could be easily measured, by counting the frequency of emptying the storage place. It would be of interest to assess the actual annual erosion rate of the gullies, instead of an average one.

The work carried out for the WLF had to allow keeping a broad overview. Interestingly, the field study in Nepal aimed at looking into the detailed functioning of the gullies;However, I also tried to keep a broad overview,by linking gullies with their catchment areas upstream, and with the rice fields downstream. Moreover, it is obvious that not only forest and vegetation management, nor bioengineering can bring a solution to the problems. The drainage of the football ground in Bistachhap and the sediments of the football ground in Godamchaur constitute issues which have to be solved to allow an integrated soil conservation approach for improved livelihoods.

Both part of the work complete each other. The first one focuses on landslides, but takes into account the larger ones. The second part focuses on soil losses, in particular shallow landslides and gullies. The global overview provided by the first part allowed understanding the technical basics in the field. On the other hand, the example of Godamchaur allowed better understanding all the main issues which should be addressed by landslide risk reduction embedded in a sound watershed management policy.

Both parts could allow further development of reflection, research and concrete action.

5.2. Towards a more complete study, how to go on

Given the conditions in which this study took place, the result after six months till presents some improving possibilities.

In order to be more useful for local people and for the demonstration site, the study should provide more precise propositions. The data collected on the gullies allow for example assessing how many check-dams would be useful, what kind of check-dams and where. This is a task which should be carried out and explained in a report. Moreover, assessing the volume of the pits to dig in the watersheds would also be of high interest. An economical study should be carried out and explained. A payment for ecosystem services scheme however, does not seem relevant here, because the farmers who benefit from the gully treatment in their fields are also the members of the CFUG.

The data on vegetation is very precise. There is hope for obtaining interesting results by working in details, there is hope to find interesting results. Vegetation dynamics and differences along the gully could be analyzed. Maybe some of the species present are indicators for specific soil features (instability for example) which I don't know now and which was not exploited for the study. This would be more “curiosity research”, but may lead to interesting results.

Finally, this work raises some questions which could be the purpose of further research.

Some of them will be addressed through the demonstration site, such as the question of the evolution of the vertical scarp in gully “central”: How is it going to evolve? How to stop it? The monitoring of the vegetation inside gully “central” will also tell if it is a sufficient way to stop the sliding process.

For some other questions, a simple monitoring could provide interesting elements of answer. For example, what role does the forest cover of the watershed play on the gully stabilization? How do the gully naturally evolve? What if interventions are done, which ones would be the most efficient ones?

Another scope for research is the use of the forest. Indeed, local people, through the CFUG rules, receive only very limited benefits from the forest. It would be of interest to explore, in collaboration with the villagers, some management possibilities which would allow harvesting from the forest, be it wood, food, medicinal plants or fodder. It should be done in a very careful way, keeping in main that a mistake could lead to major and problematic soil losses. Would it be possible to harvest more wood? Would the conversion of the pine forest into a broadleaved forest of interest?

5.3. Personal enrichments acquired during this work

5.3.1 The issues addressed: linking people

Watershed management and soil conservation are a very new topic for me. It is related to forestry because it is part of natural resources management. However, the problems, methods and ways of thinking are quite different. Soil stability is a science in itself and it was very interesting to start getting to know a bit more about it. The integrated watershed management is a very interesting one and forces to link a and to think about all different type of users. The case study I carried out shows in an example more showing that it is not possible, and not always necessary, to work on a zone delineated by the watershed boundaries. What matters is considering the impact of some actions and activities in one given place on other places. Water is the link most of the time and it helps better understanding the relationships between several natural habitats, land user groups and human activities. The important seems to link different stakeholders of natural resources together.

Of course I already knew that nature conservation, and in this case in particular soil conservation, is very important for the preservation of human lives. But being involved in two organizations which work for livelihood and food security, and talking with the farmers who rely on the activities carried out in the forest for the yield of their fields made me see the things differently. This gives a supplementary dimension to the work carried out.

5.3.2. The institutional framework: interesting discoveries

Working at FAO and ICIMOD allowed me better understanding the missions and activities of international organizations. It was a first step in the area of development agencies and international development activities in general. Now I have some elements to understand the place of development agencies on the international stage and the different actors. Involved, such as governmental donor agencies.

Moreover, working in a very diverse environment such as FAO and ICIMOD is very interesting, through the contact of the colleagues. Of course, the experience in Nepal allows discovering a natural and socio-economic context which is completely different from the one in Europe. This helps becoming adaptable to different situations. Moreover, it allows looking at the French and European development systems with a new look.

5.3.3. The particular conditions of this study: the best training for later

The work in Nepal was carried out almost alone. I had to set up the study by myself on the last moment, after having been prepared for the Bangladesh. The support from colleagues at ICIMOD, DSCWM and NWCF was useful, but due to the unforeseen character of my presence there, these persons did not have much time to help and guide me. Having to face this situation in a new country and dealing with a new topic was not easy at the beginning, but turned out to be an excellent way of learning. It improved my ability of setting up a project, managing it, and in particular facing unknown and unforeseen situations.

Conclusion

The watershed approach appears to be sound to address landslide and gully mitigation. To understand the internal processes of the landslide, a very local approach might be enough. But on one hand the probability of occurrence of landslides and gullies depends on surrounding activities. Water is one of the main factors affected by surrounding activities which could destabilize a sensible area. On the other hand, these erosion processes have an impact on the surrounding activities. Again, some of the impacts of the erosion processes are transmitted by the water: sediment transport, dam across a river due to a landslide for example. Hence, a watershed approach is absolutely necessary to understand completely all the phenomena linking together erosion processes and other natural habitats or human activities.

The current mountains represent a balance between gravity and the retaining forces of the soil (cohesion and weight reaction), determined by many different parameters, such as rainfall, slope, root system density and soil properties. A landslide corresponds to a rupture of this balance, due to a major change on one of the parameters. Hence, a very good hazard mitigation methods is not to disturb the balance established. But this kind of balance corresponds actually to a permanent correction of the parameters: these are the naturally triggered landslides.

The consequences on human activities can be very important if they are located on the way of a landslide, but also further downstream, and even downstream a gully. This leads to the notions of short term risk and long term risk. A massive landslide threatening dwellings is a short term risk: if the landslide occurs, the damages will be very important in a short time. A farmer relying on an irrigation channel receiving water from a gully seems less at risk. But he is experiencing a long term risk: the gully leads to soil losses and thus to the loss of the support for his livelihood; moreover it might have negative effects on the yields in the fields of the farmer, threatening his/her food security.

The example of Godamchaur shows that some *a priori* harmless acts can lead to severe problems. A sound watershed management policy should include an educational component to avoid this kind of problems. There is always a double component of soil loss in one place and soil deposition in another one, which are often both problematic, of course depending on the nature of the sediments deposited and the elements at stake downstream. Hence, the involvement of the whole community having an interest at the soil and water conservation and management of a given watershed is important. This challenge is true at the scale of a hill, like in Godamchaur, where it works pretty good, as well as on much broader scales, like between Nepal and India for example, or India ans Bangladesh. Indeed the natural, as well as the socio-cultural differences are much bigger, but a cooperation in the water management is the only way to an optimized management of this natural resource and the ones influenced by it, such as the soil.

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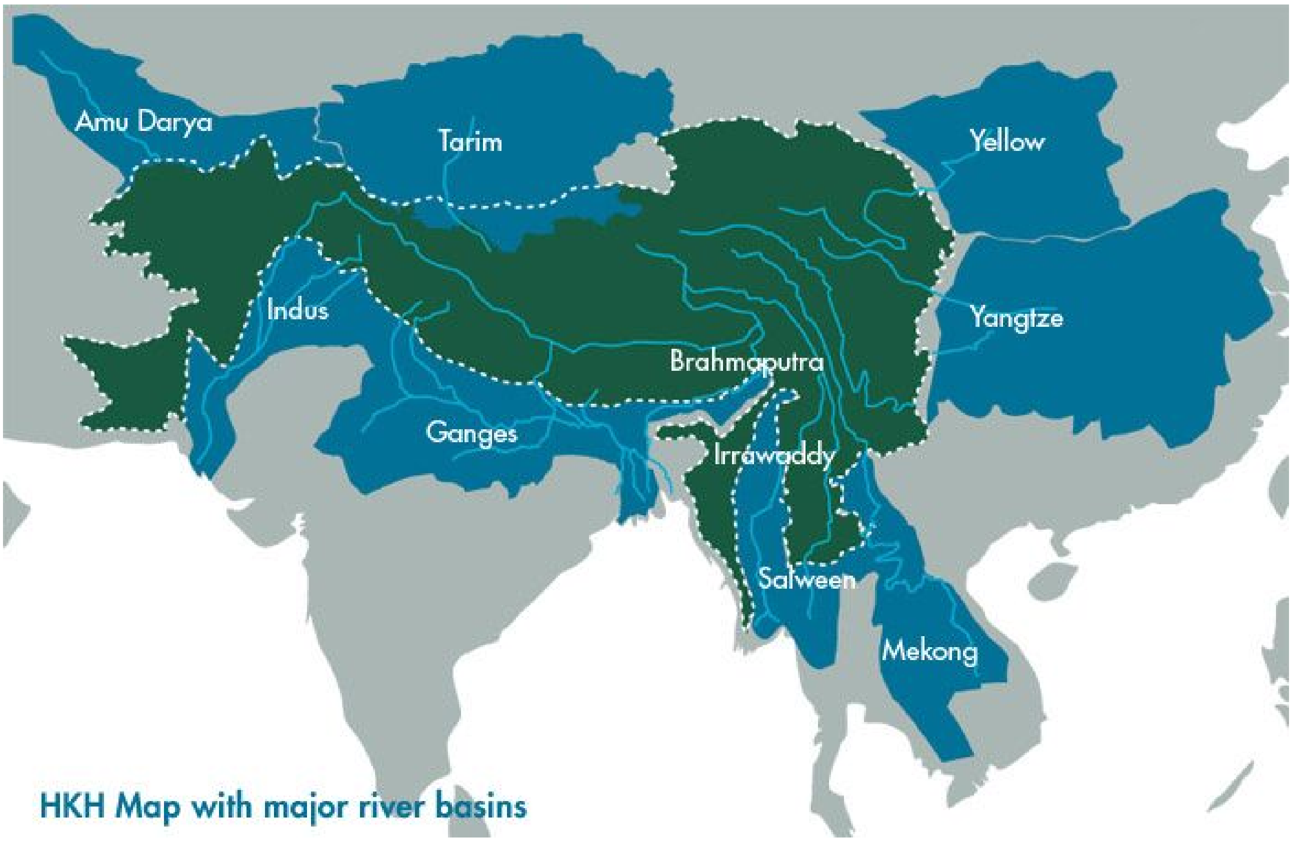
ANNEX 1: Map of the Hindu Kush Himalayan region and related major river basins



Source : www.icimod.org

ANNEX 2: Basics for soil stability analysis

Extracts from "Soil Slope Stability Analysis Using the Friction Circle Method Programmed in EXCEL"

by Eugene Washington , P.E.

Friction circle theory has been around for about 100 years and is probably the most accepted method of analyzing soil slope stability. The theory is deceptively simple. The soil has three basic properties that are fundamental to the analysis:

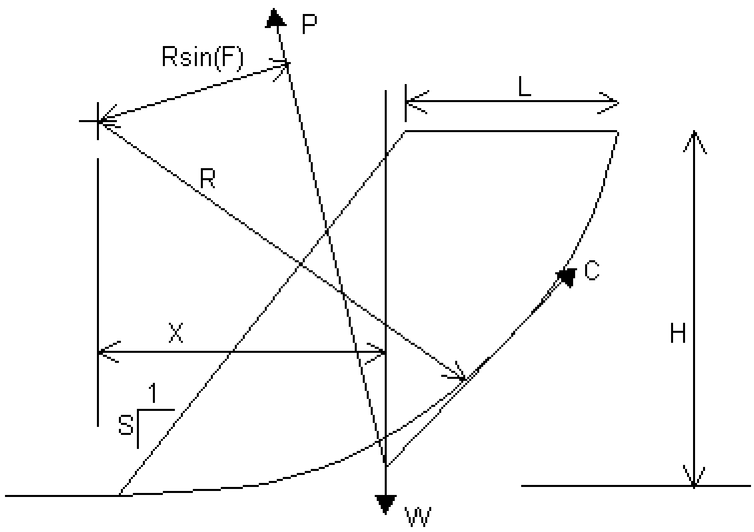
1. Moist density of the soil in pounds per cubic foot (pcf).
2. Internal Friction angle in degrees
3. Cohesion in pound per square foot (psf)

A well prepared Geotechnical report will offer all of this data. Many soils reports do not include the direct shear test that shows the Friction angle and cohesion because it is not often used by the design engineer or the contractor. It is often well worth asking for the data or even having your own direct shear tests performed.

The in situ moisture content of the soil must be added to the dry density of the soil that is shown in the Geotechnical Report for the project site. The friction angle is a measure of the particle shape. Perfectly round ball bearings will not stand in a pile. Ball bearings have a zero Internal Angle of Friction. Dry sand will form a cone when poured on a table. That is because the angular shape of the grains does not allow the particles to roll freely past each other. Sands and gravels typically have a friction angle of 30 to 35 degrees. The friction angle is also the natural angle of repose of the soil with zero cohesion. When processed gravel is stacked off a conveyor at a mine it can be seen that the pile forms a uniform cone that maintains a constant slope between 1.5 and 2 to 1. The slope of a friction angle of 30 degrees is also 1.732 to 1

Cohesion is the shear strength of soil, the glue that binds the grains together. Cohesion can stem from many sources. If water is added to the above sand sample, it can be moulded in intricate shapes such as sand castles often seen at the beach. The surface tension of the water provides a weak bond between the sand grains. The moisture present in most soils provides a significant cohesion. Often a gravel bank will safely stand on a 1 to 1 cut bank for a short duration. As the bank surface dries it will ravel to a 1.5 to 1 slope. Natural minerals that have been leached into the soil, such as caliche and salts, can provide a very strong cohesion. Heat fusion and long term overburden pressure will tend to fuse the soil grains together, producing significant cohesion.

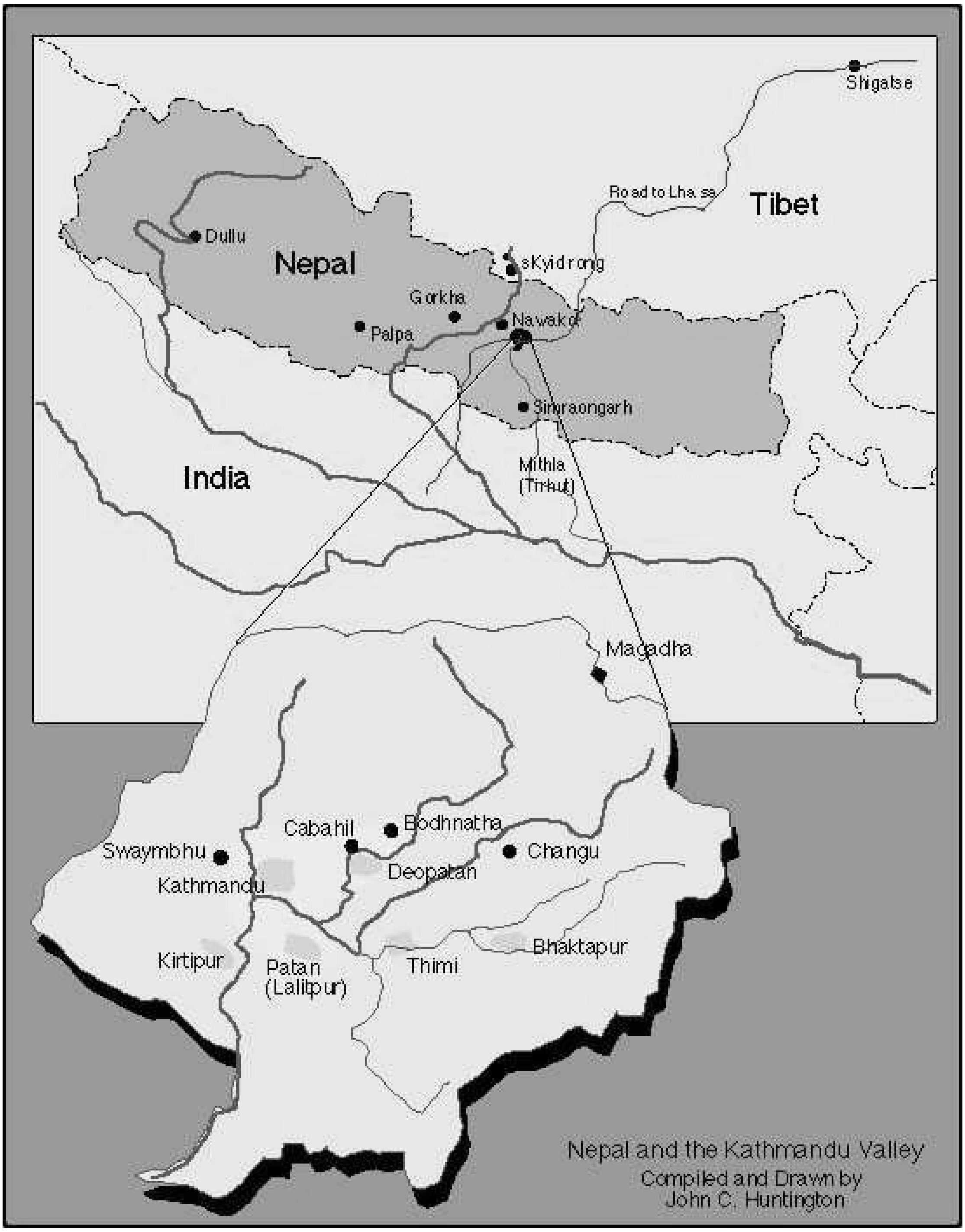
Below is the fundamental friction angle diagram. The critical failure plane is assumed to be a circle arc. The weight of the soil mass between the circle failure plane and the exterior surfaces of the bank provides the impetus for slippage along the critical circular failure plane. The soil mass is a vertical vector passing through the center of gravity of the enclosed soil mass. The slippage is resisted by the passive soil support below the critical plane and the cohesion along and tangential to the critical failure plane. The passive soil support force is always applied as a vector passing at a distance of the slip circle radius focus times the sine of the Internal Friction Angle. The cohesion is a vector placed at the center and tangential to the failure plane arc. Statics dictate that all three forces of weight, reaction and cohesion must intersect at a single common point. Note that the intersection point is not shown on the arc.



SLIP CIRCLE DIAGRAM

W = Soil gross weight including moisture inside the slip plane and the ground surface plus any live load surcharge.
P = The passive weight reaction.
C = The soil total cohesive resistance (shear).
R = The slip circle radius.
X = The distance from the slip circle focus to the centroid of the total weight (W).
F = The soil internal friction angle.
H = The Bank Height
L = The sip circle setback from the top of bank slope
S = The slope of the bank excavation.

ANNEX 3: Location of the Kathmandu valley in Nepal



ANNEX 4: Godamchaur Demonstration Site Development Conceptual Framework

Godamchaur Demonstration Site Development Conceptual Framework

Prepared by:
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Babar Mahal, Kathmandu
November 2005

Godamchaur Demonstration Site Development Conceptual Framework

Background

Department of Soil Conservation and Watershed Management (DSCWM), its district level offices and projects have been using various soil conservation techniques and watershed management measures mainly developed in other parts of the world to implement soil conservation and watershed management (SCWM) programs in Nepal, since its establishment. There have been successful soil conservation interventions to meet departmental objectives and failures as well. Based on experience, DSCWM has realised the need of research and demonstration in the fulfilment of the departmental objectives. Consequently, a section has been created in the Department to deal with technology testing, research and demonstration. In the past, Technology Development and Promotion Section followed by Research Section conducted SCWM research and demonstration activities. Now, Technology Development Section of the Department is responsible for technology testing, research and demonstration.

One of the strategies of the department is to achieve its objectives by developing appropriate technology and expanding the service to the rural areas of the country through extension. To develop the appropriate technology, various technology testing, research and demonstration become utmost. Technology Development Section is mainly mandated with these responsibilities. Therefore, the section is focusing on appropriate soil conservation technological package development through testing, research and demonstration.

In this background a soil conservation demonstration site is planned to develop in Godamchaur VDC of Lalitpur district.

Objective

The general objective is to develop and disseminate appropriate soil conservation technological packages through testing, research and demonstration.

Specific objectives are:

- to develop appropriate soil conservation technological packages through testing and research., and maintain data base.

- to rehabilitate heavily eroded or degraded site and convert it into a productive area with simple/low cost techniques, which can be replicated by the District Soil Conservation Offices and local people.
- to disseminate the technology through demonstration, training, seminars, workshops and study tours.

Rationale

Recognition of soil erosion, mass movement and land degradation related problems, and demonstration of technological packages to solve these problems is one of the first steps in SCWM. To do this, establishment of demonstration site is of immense importance. Test and Demonstration sites or areas are very effective means of data generation, teaching, educating and creating awareness for conservation as per the principle "seeing is believing". People who visit demonstration site will observe/learn the conservation techniques applied to solve the problems and they may be able to replicate appropriate technological package in other problematic areas.

Considering these facts, DSCWM had established Demonstration Centres in Subbakuna of Surkhet, Kulekhani (Burrow-pit) of Makawanpur, Panchkhal of Kabhre and Pipaltar (Trisuli) of Nuwakot districts in the past. All these Demonstration Centres have been closed since 2002. Therefore, establishment of a new demonstration site is deemed necessary.

Demonstration Site Selection

Following points were considered for demonstration site selection:

- Site having heavy erosion and land degradation problems (like surface erosion, gully formation, shallow landslide, over grazing, depleted vegetative cover etc.)
- Represent a typical and frequently occurring problem in the region
- Accessible
- Suitable to test and demonstrate different conservation techniques
- Possibility of collaborative implementation with the District Soil Conservation Office and local community based organisation.

Based on these considerations, Ratmate landslide area in Godamchaur VDC of Lalitpur district was selected.

Ratmate landslide area locally known as Ratmate Khaulo located inside the Godamchaur Community Forest in Godamchaur VDC ward No. 1 and its micro-watershed, where heavy erosion and land degradation problems were observed, is selected to develop as demonstration site. The site is about 20 km south from Babarmahal which covers approximately 0.3 ha of landslide area and nearly 3 ha of its micro-watershed area.

The steep hanging scarp of landslide collapse every year during the heavy monsoon rain, rills and gullies develop on loose slipped mass and drainage at the toe part erodes the loose soil moved from the scarp. Red soil mining from the landslide area by the local people further aggravates the problem. The eroded red soil is transported by drain water that goes to an irrigation channel (Kulo) which is used by local people to irrigate their more than 100 Ropani paddy field in the down stream. Ultimately, soil eroded from the landslide area deposited in the farmers' field which adversely affects land's fertility and crop production.

Proposed demonstration site has been visited many times by all the officers and mid-level technician of Technology Development Section (DSCWM), one officer and one mid-level technician from District Soil Conservation Office (DSCO) Lalitpur and two experts from ICIMOD. A meeting has been arranged with Godamchaur Community Forest User Group's Executive Committee Members including President for the first time. Godamchaur CFUG Ex. Com. has expressed interest and commitment for active people's participation. Prior to formal agreement with DSCWM and DSCO Lalitpur, Godamchaur CFUG Executive Committee has called general assembly of Godamchaur CFUG and first meeting's decisions were endorsed by the assembly. Then mapping and preplanning works were carried out to prepare a broad five year plan. Detail survey, design, and cost estimation of all activities to be implemented in each Fiscal Year (FY) will be carried out in the beginning of each FY.

Observed Problems

Following soil erosion related problems were observed in the site:

1. Toe cutting by drainage
2. Run-off concentration from upstream on the main scarp of the landslide
3. Shallow landslide expanding upstream and north western part
4. Rills and gullies developed on slipped accumulated mass
5. Cracks developed above scarps in Northern and southern part
6. Red soil mining from bottom of the vertical scarps
7. Sparse vegetation

Conservation Activities to be Implemented in 5 Years Period

1. Toe/supporting wall construction
2. Conservation pond construction for run-off water collection
3. Diagonal hedge rows plantation above main scarp
4. Slope correction
5. Crack filling
6. Fascine, Palisade, brush layering and brush wood check dams for rill and gully control
7. Stone filled gabion check dams in deep gullies and drainage
8. Safe drain
9. Grass seed sowing and plantation
10. Live fence around demonstration site

Although tentative plan is prepared for five years, funding source for this demonstration site's development and management is uncertain. Therefore, work to be done in each FY will be determined in the beginning of the FY based on available budget for this activity.

Potentiality of Testing and Demonstration

1. Construction of conservation pond for run-off water collection- location, design etc.
2. Hedge row plantation for diversion of upstream run-off water (safe drain)- plant species, location, design, timing or season
3. Fascine, Palisade, Brush layering and Brush wood check dams for rills and gullies' control- sprouting plant species, size of vegetative part, orientation in the ground, timing or season
4. Grass seed showing and plantation on exposed surface of slipped mass- species, regeneration technique, timing or season
5. Some important chemical and physical properties of the soil

Activity Implementation and Demonstration Site Management Strategy

Since Technology Development Section is staffed with only two officers including head of the section and one mid-level technician, and budget allocation for Demonstration Site development and management is very limited, it is viewed necessary to work in collaboration to fulfil the objectives. Therefore, collaborative work with the District Soil Conservation Office Lalitpur will be carried out. Technical and limited financial support will be provided by Technology Development Section of DSCWM and DSCO Lalitpur. Godamchaur CFUG will be responsible for people’s participation to implement the activities and protection of the site. An agreement has been signed by all the stake holders involved before starting implementation.

Expected Outcome

The demonstration site will be instrumental to generate data, maintain database, disseminate appropriate technological package for conservation and sustainable development of the land resource. It will help local people to stabilize their land, to improve their land use system and to reduce soil erosion. Local people will be aware of how conservation measures can be applied effectively and can be replicated in other places.

ANNEX 5: Assessment of the area of one hexagonal cross section of the gully "central" in Godamchaur.

This annex explains how the formulas used to assess the area of the cross sections measured for the assessment of the volume of eroded soil in the gully central in Godamchaur have been calculated.
Figure A6.1 is the complete sketch of a cross section and additional constructed features which allows understanding all calculations.

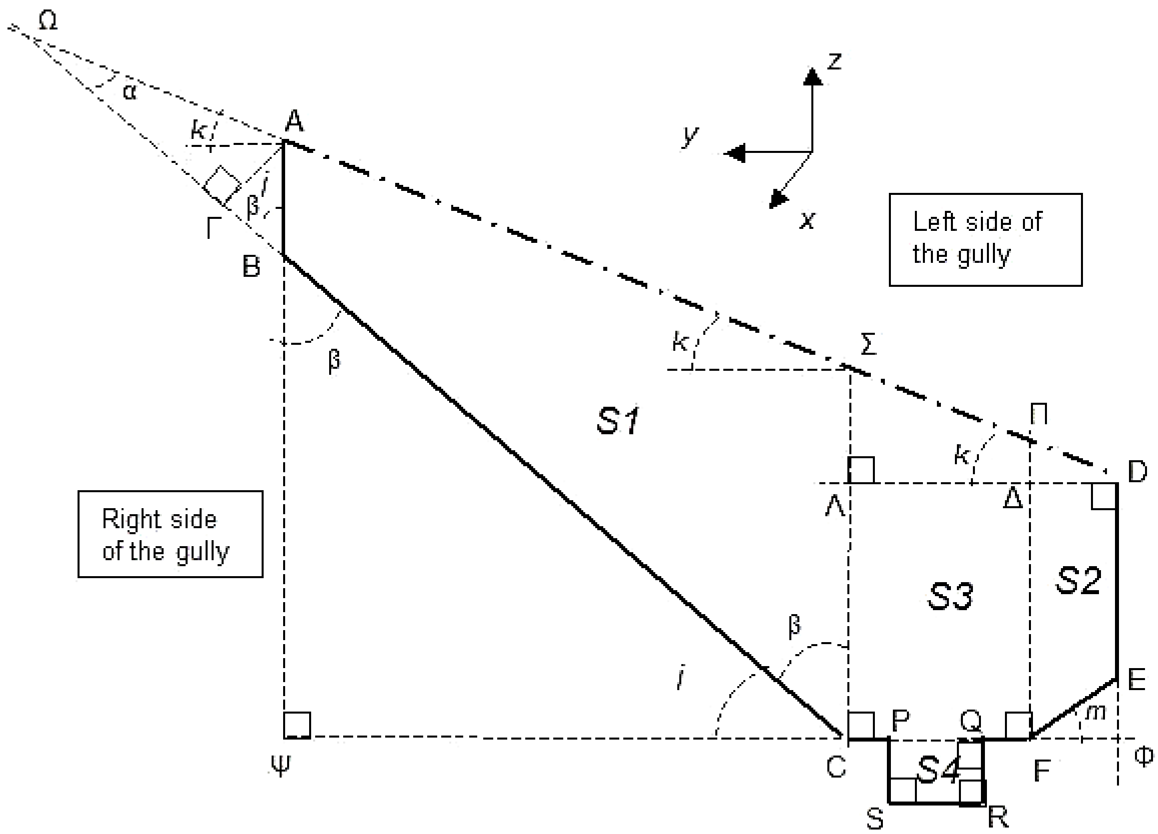


Figure A6.1: Sketch of one given cross section and associated parameters to derive the calculation formulas (source: N. Dolidon)

Latin letters indicate easily measurable/localizable parameters, Greek letters indicate parameters useful for calculation but impossible to measure on a simple way in the field. In both alphabets, capital letters indicate points, lower-case letters indicate angles.

Here are the explanations for the "real" parameters. The ones described with a Greek letter are not detailed, since the sketch presents all their geometrical features.

A: Top of the scarp above the slide	*D*: Ridge, head of the cliff on the left bank
B: Foot of the scarp upslope/ head of the sliding slope	*E*: Foot of the cliff downslope / head of the left bank of the gully
C: Right side of the bottom of the gully	*F*: Left side of the ground of the gully
P, Q, R, S: corners of the ditch at the ground of the gully.	*j*: slope of the landslide, on the right bank of the gully
k: former hill slope angle	
m: slope angle of the left bank of the gully	*S1*, *S2*, *S3* and *S4* are sub-areas which can be calculated

Notes:

–the ditch *PQRS* does not always exist. Sometimes P = C and/or Q = F. When it exists, it is considered as a rectangle. This is an assumption which is very close to the reality.

–(BA), ($C\Sigma$), ($F\Pi$) and (DE) are assumed vertical and thus parallel.

The total area of the polygon ABCPSRQFED, called S, is the sum of $S1 + S2 + S3 + S4$. It is an assessment of the real area of the given cross section. The aim is to express the areas $S1$, $S2$, $S3$ and $S4$ only as functions of parameters indicated by Latin letters, which can be measured on the field.

1/ Expression of the area *S1*

By definition of the area of a parallelogram:

$$S1 = \frac{1}{2}\left(AB + \Sigma C\right) \times C\Psi \qquad (1)$$

$$S1 = \frac{1}{2}\left(AB + \Sigma\Lambda + DE + E\Phi\right) \times C\Psi \qquad (2)$$

By definition in the triangle $\Sigma\Lambda$ D:

$$\frac{\Sigma\Lambda}{\Lambda D} = \tan k \Rightarrow \Sigma\Lambda = \Lambda D \times \tan k \qquad (3)$$

And we know that:

$$\Lambda D = C\Phi = CF + FE\cos m \qquad (4)$$

(3) and (4) lead to:

$$\Sigma\Lambda = \left(CF + FE \times \cos m\right) \times \tan k \qquad (5)$$

Thus (2) and (5) lead to:

$$S1 = \frac{1}{2}\left[AB + \left(CF + FE \times \cos m\right) \times \tan k + FE \times \sin m + ED\right] \times BC \times \cos j \qquad (6)$$

This equation seems satisfying because it contains only Latin letters; it means that necessary parameters can be measured quite easily in the field, by one single person and with little material. However, it implies measuring the distance BC, which complicates a lot the field work. Indeed, in some places the distance BC is longer than the measuring tape (50 m), which could lead to measurement mistakes. Moreover, it is necessary to measure it to walk up on the slide, which takes a lot of time and destabilizes the already fragile bare soil. For all these reasons, the equation (6) will be changed in order not to use the parameter BC.

But in order to better understand the calculations, the respective areas of $S2$ and $S3$ will be first calculated and the change to (6) will be explained at the end.

2/ Expression of the area of S2

Following the same principle than previously:

$$S2 = \frac{1}{2}\left(F\Pi + ED\right)\times F\Phi$$

$$S2 = \frac{1}{2}(\Phi E + ED + \Delta\Pi + ED)\times FE\times \cos m$$

As in section 1, (calculations for *S1*) it can be demonstrated that: $\Delta\Pi = FE\times \cos m\times \tan k$

Hence:

$$S2 = \frac{1}{2}\left[FE\times \sin m + 2\times ED + \left(FE\times \cos m\times \tan k\right)\right]\times FE\times \cos m \qquad (7)$$

All parameters of equation (7) are measurable on the field with simple means and by only one person. Thus it is the equation which has been used to assess the area *S2*.

3/ Expression of the area of *S3*

By definition

$$S3 = \frac{1}{2}(C\Sigma + F\Pi)\times CF$$

The calculations made previously for *S1* and *S2* allow replacing immediately $C\Sigma$ and $F\Pi$ as follows:

$$S3 = \frac{1}{2}\left[FE\times \sin m + ED + (CF + FE\times \cos m)\times \tan k + FE\times \sin m + ED + FE\times \cos m\times \tan k\right]\times CF$$

$$S3 = \frac{1}{2}\left[2\times \left(FE\times \sin m + ED\right) + \tan k\times \left(2\times FE\times \cos m + CF\right)\right]\times CF \qquad (8)$$

All parameters of equation (8) are measurable on the field with simple means and by only one person. Thus it is the equation which has been used to derive the area *S3*.

4/ Expression of the area *S4*

Since *PQRS* is considered as a rectangle, the area *S4* can be written as:

$$S4 = PQ\times PS$$

5/ Expression of the distance *BC*

It will not be demonstrated in the general case that 7 parameters are enough to describe the whole figure, instead of the 8 *AB*; *BC*; *CF*; *FE*; *ED*; *j*; *m* and *k*. But it has been chosen to express *BC* as a function of the 7 other parameters, because of the reasons explained above (section 1). This is the aim of following calculations:

5.1. Expression of the angle *α*

By construction, with all parameters in degrees:

$$\alpha + \beta + k + 90 = 180$$

and $\beta = 90 - j$

Hence: $\alpha = j - k$ (9)

5.2. Expression of *ΩB*

$$\Gamma B = AB \times \sin j \qquad (10)$$

$$\tan\alpha = \tan(j - k) = \frac{A\Gamma}{\Omega\Gamma} \Rightarrow \Omega\Gamma = \frac{A\Gamma}{\tan(j - k)} \qquad (11)$$

$$A\Gamma = AB \times \cos j \qquad (12)$$

(11) and (12) $\Rightarrow$ $\Omega\Gamma = \dfrac{AB \times \cos j}{\tan(j - k)}$ (13)

$$\Omega B = \Omega\Gamma + \Gamma B$$

Thus, (10) and (13) lead to:

$$\Omega B = AB \times \left(\frac{\cos j}{\tan(j - k)} + \sin j \right) \qquad (14)$$

5.3. Expression of BC

According to the Thales' theorem in the triangle ΩCΣ, since (*AB*) and (*ΣC*) are parallel:

$$\frac{\Omega B}{\Omega C} = \frac{\Omega B}{\Omega B + BC} = \frac{AB}{\Sigma C}$$

$$\Omega B + BC = \frac{\Sigma C \times \Omega B}{AB} \Rightarrow BC = \Omega B \times \left(\frac{\Sigma C}{AB} - 1 \right) \qquad (15)$$

According to (14) and (5) and considering the features of the figure, (15) can be written as:

$$BC = AB \times \left(\frac{\cos j}{\tan(j-k)} + \sin j \right) \times \left(\frac{(CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED}{AB} - 1 \right)$$

$$BC = \left(\frac{\cos j}{\tan(j-k)} + \sin j \right) \times \left((CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED - AB \right) \quad (16)$$

6/ Writing of the calculation formula of S1 without the parameter *BC*

By replacing BC in (6) with the result of (16), S1 can be expressed as:

$$S1 = \frac{1}{2}\left[AB + (CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED\right]$$
$$\times \left(\frac{\cos j}{\tan(j-k)} + \sin j \right) \times \left[(CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED - AB\right] \times \cos j \quad (17)$$

(17) has the form $x = (a - b) \times (a + b) \times c$, which can be simplified as $x = (a^2 - b^2) \times c$

Where

$x = S1$

$a = \left[(CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED\right]$

$b = AB$

$c = \frac{1}{2} \times \left(\frac{\cos j}{\tan(j-k)} + \sin j \right) \times \cos j$

Hence it can be written as follows:

$$S1 = \frac{1}{2} \times \left(\frac{\cos j}{\tan(j-k)} + \sin j \right) \times \cos j \times \left(\left[(CF + FE \times \cos m) \times \tan k + FE \times \sin m + ED\right]^2 - AB^2 \right) \quad (18)$$

(18) is more complicated to write than (6), but does not imply measuring *BC*, which would have been a major constraint for the field work and may have lead to bigger imprecision. Thus it is the expression of *S1* which has been used to assess the area of all measured cross sections.

7/ Calculation of the whole area *S*

The area of the model cross sections has been calculated by adding *S1*+*S2*+*S3*+*S4*.

It has not been deemed necessary to display the whole formula, since it is very long, complicated, and has not been used. This result is an assessment of the actual area of these model cross sections.

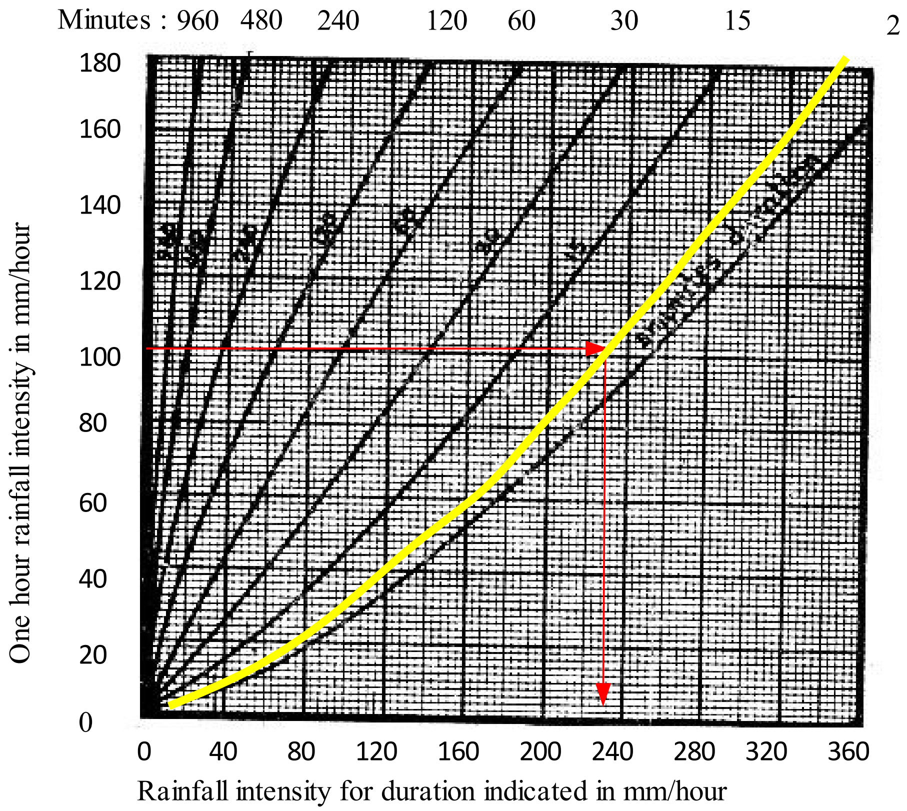
8/ Measured parameters on the field

All the parameters of these formulas are easily measurable on the field. This explains the choice of the parameters which have been used to derive the area of each measured cross section. Thus, the parameters collected on the field to assess the volume of the eroded soil were following ones:

1. number of the ***x*** axis used (***x1***...***x6***)
2. number of the section
3. distance to previous measured section on the same axis ***dx*** (m)
4. height of the scarp above the landslide **AB** (m)
5. height of the cliff above the left bank of the gully **DE** (m)
6. length of the left bank of the gully **EF** (m)
7. width of the bottom of the gully **CF** (m)
8. slope of the left bank of the gully ***m*** (degrees)
9. slope angle of the landslide or of the right bank of the gully ***j*** (degrees)
10. former hill slope angle ***k*** (degrees)

ANNEX 6: Assessment of the intensity corresponding to a given concentration time : I_{TC}

Graph used for the determination of I_{TC}.



The black curves are standard ones, for different times of concentration. The yellow one corresponds to the time of concentration of a rain with 10 years return period in gully "central" : 3.5 minutes. The rainfall intensity of a rainfall with 10 years return period is 100 mm/hour in one hour. In 3.5 minutes, according to the graph, the intensity of a 10 years return period is about 235 mm/hour.

Abstract:

Landslides are soil or bedrock movements which can lead to important damages to natural or man made elements of interest, such as natural habitats, infrastructures, industries, agricultural land, dwellings and even human lives. They are of concern throughout the globe and constitute an issue tackled by several international organizations, including FAO. Gullies are another erosion process which constitute a threat to livelihoods of people living in mountain areas of the world. Gullies can eventually lead to landsliding.

Slope stability is an issue embedded in a broader system including human lives and activities, linked to natural phenomena. Based on a global literature survey and a field study in the Mid-Hills of Nepal, the present document aims to give an integrated approach of the risks related to landslides and gullies, as well as some key components for their mitigation. The complementary roles of vegetation, soil and water management are of highest importance. The emphasis is put on the high interest of the watershed scale approach to best address these issues and the study highlights upstream-downstream linkages.