1. Introduction

The kingdom of Nepal has an area of 147,000 km^2 and stretches from the Terai in the south with elevation around 100 m to the Great Himalaya in the north with elevation exceeding 8,000 m a.s.l.. This contrast in elevation occurs within a width of around 200 km. Precipitation is concentrated in a relatively short period of approximately three months in the monsoon season from mid-June to mid-September. The 70 to 85 % of annual precipitation, which is estimated at about 1,400 mm over Nepal, occurs in this season. The considerably steep topographical condition, the sharp concentration of precipitation and well developed glacierized areas are peculiar natural characteristics of Nepal. These natural conditions lead to almost all kinds of natural hazards derived from mass movement, such as snow/rock avalanches and landslides, debris flows, mud flows and collapses on the steep mountain slopes. Floods as well as erosion and sedimentation in river channels occur especially in the monsoon season. The natural disasters from the mass movement has been quite natural in the leveling processes of high mountains owing to weathering.

The Great Himalaya provides a sub-polar climate and an appropriate condition for a stable existence of cryosphere covered by snow and glaciers. Snow is brought in the areas above 3,000 m in winter and above 6,000 m even in summer monsoon season ; glaciers develop in the areas above 4,000 m. Some of these glaciers have glacier lakes. The formation of such lakes seems to have been accelerated in recent times. Many glacier lakes were born during the last half century in the Himalaya. The recent formation of glacier lakes is believed to be visual evidence of the *Global Warming*.

Almost all of the glacier lakes in the Nepal Himalaya are formed on the glacier terminus dammed by a moraine. The moraine-dam is not consolidated well enough to become a stable structure. A slight disturbance can break the balance of the structure. It results in an abrupt release of a great amount of water and generates a tremendous flood. Serious damages are caused to infrastructure, to the inhabitants and also eco-system and environment along the flood path downstream in the Himalayan regions. This phenomenon is called Glacier Lake Outburst Flood (*GLOF* in short). GLOF explicitly appeared in Nepal only three decades ago. The GLOFs happened not only in Nepal but also in Bhutan, India, Pakistan and Tibet. The GLOF phenomena are quite common phenomena in the glacierized areas of Asian high mountain regions.

Large area of the cryosphere and rich precipitation provide abundant water resources in the country. In addition to having abundant rainwater, Nepal possesses substantial reservoir of water stored in the form of snow and glaciers. The main water discharge systems such as Sapta Kosi, Narayani, Karnali and Mahakali (see thick dotted lines in Fig. 3) originate from the Great Himalaya and are fed by meltwater from snow and glacier ice. While liquid precipitation (rain) is directly discharged through river channels in a relatively short period, solid precipitation (snow) is first accumulated on the ground and/or on glaciers and melts gradually. The meltwater from snow and ice contributes significantly to the sustained base flow in the dry season. This flow is important for planning and management for the utilization of water resources. The rivers having sustained flow provide promising potential for their utilization for hydropower generation, irrigation, industry

as well as drinking.

This abundant water mass provides rich hydropower potential in the country. There are no other valuable energy resources such as coal, petroleum or natural gases. The annual amount of discharge through all river channels is estimated at approximately 200 billion m^3. It is estimated that 42,133 MW of hydropower energy could be developed commercially and technologically from the theoretical hydropower potential of 83,000 MW. The amount already developed is only 254 MW (WECS Report, 1994).

As the development of water resources has been gradually expanding up to the Himalayan regions, Nepal has encountered severe disasters caused by GLOF. Only a decade ago, when a GLOF occurred at Dig Tsho glacier lake on 4 August, 1985 in the Khumbu region of East Nepal, the destructive GLOF impact was first recognized by the concerned officials, engineers and planners of His Majesty's Government of Nepal. Now it is known that the most careful attention should be paid to control this hazard to the development of water resources in the vicinity of glacierized areas in the Himalaya.

To prevent or to mitigate GLOF disasters, one has to obtain enough information and knowledge on the glacier lake itself as well as the background of its formation process and mechanism. Very little is, however, known on this phenomena in the Himalaya. This publication aims to present knowledge and situations of glacier lakes and GLOF in the Nepal Himalaya. Descriptions will be made of present circumstances surrounding GLOF in Nepal, formation processes of a glacier lake, the distribution of glacier lakes, the outline of potentially dangerous glacier lakes, the results of detailed investigation of the typical and the most dangerous looking glacier lake, Tsho Rolpa, located in the Rolwaling Himal, East Nepal. The possible countermeasures against GLOF will be suggested. The future studies of GLOF as well as the Himalayan cryosphere are recommended.