P: ISSN NO.: 2321-290X RNI : UPBIL/2013/55327 VOL-6* ISSUE-6* February (Part2) * 2019
E: ISSN NO.: 2349-980X **Shrinkhla Ek Shodhparak Vaicharik Patrika**

Impact of Tehri Dam Reservoir on Geomorphology of the Area

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Abstract

The Himalaya forms the world's loftiest mountain with snowy peaks, river valleys, green flora and fauna and laboratory for the Geologists. Tehr**i** dam was constructed across Bhagirathi valley at old Tehri at the confluence of Bhagirathi and Bhilangana River in 2005. It has a height 260.5 meters and maximum power generation 2400 MW of which 1000 MW has been functioning in Ist phase. Due to construction of dam a huge lake of 42sq.km resulted along Bhagirathi and Bhilangana Rivers from Chinyalisaur to Ghansali. Geology, Geomorphology and structures are also responsible for slope instability. Large dam projects are developed in order to fulfil the basic human needs but such projects are often deleterious to the environment and to human welfare. The construction of Tehri dam and formation of huge reservoir inducing a variety of changes in the surroundings at micro and macro scale. The main impacts on surroundings are the mass movements changing in the slope stability, river terraces, etc. Present paper deals mainly slope instability in the form of landslides submergence of maximum terraces around reservoir rim and other landforms in the area Geologically the area falls in the lesser Himalayan block of the Himalaya. North Almora Thrust is the main structural feature and separate the rocks of inner lesser Himalaya from the outer Lesser Himalaya. Rocks of outer Himalaya comprises by Chandpur phyllite, Nagthat quartzites and Blaini, Infra krol, Krol and Tal series while inner lesser Himalaya by Rautgarha and Tejam formations.

Keywords: Tehri dam Reservoir, Landslides, Slope Instability, River Terraces,, North Almora Thrust.

Introduction

The Investigated area comes in the lesser Himalayan block between Chinyalisaur and Ghansali along Bhagirathi and Bhilangana river**.** Geographically investigated area lies between latitude 30^0 15^I to 30^0 45^I N and longitudinally 78^0 15^I to 78^0 45^IE in the Tehri and Uttarkashi district of Garhwal Himalaya around Tehri reservoir rim. Tehri dam was constructed at the confluence of Bhagirathi and Bhilangana River at old Tehri, which submerged in the reservoir. Tehri dam is the rock and earth fill type and was completed in 2005. It is the largest dam of 260.5 meters height of Uttarakhand. The dam and reservoirs world over have been playing dual role of harnessing river water for accelerating the socio-economic growth and mitigating the miseries of a large population of the world suffering from the vagaries of flood and droughts. Large dam projects are developed in order to fulfil the basic need but such projects are often deleterious to the environment and to the human welfare. Several studies made on the impact of reservoir impoundment on the proximate area. Increases the The construction of high dam and reservoir increases the mass movement especially in the Himalayan region.A significant landslide event was caused by the impoundment of the Vaiont Reservoir Italy(1963) Steven and Simon(2011)andZhang QianWei and Chen(2018)studied the slope stability zoning with multi numerical models along the three Gorges reservoir of China. Present paper also deals the impact of Tehri dam reservoir on the area around Tehri dam.

Methodology

For Geomorphological study, various geomorphological features were observed in the field and plotted on base map. For slope analysis the toposheet on scale 1;50,000 were used and slope angle was calculated as suggested by Wentworth(1930). The area was divided into 141 facets, each facet comprising of standard of contour spacing. Slope angle for each facet was calculated and all the facets were divided into 11 slope classes. River terraces of both river Bhilangna and Bhagirathi river were studied.

Landslides were studied around the reservoir rim. Attempt were made to impact of reservoir on these landforms and slope instability.

Aim of Study

Tehri dam was constructed in 2005 at the confluence of Bhagirathi river and Bhilangana river at old Tehri. Large reservoir of about 42 sq kms from Chinyalisaur to Ghansali was formed and large old Tehri town with numbers of villages submerged in the reservoir. Main aim of study is the impact of Tehri dam reservoir on the surroundings with special references to geomorphology. Before the construction of dam there were only few landslides but after formation of lake new landslides and slope instability problem increases frequently**.**

Geological Setting

Tehri dam Reservoir lies in the lesser Himalayan block of the Himalaya, which is bounded by main boundary thrust in the south and main central thrust in the north. The North Almora Thrust is the main structural feature and separate the rocks of inner lesser Himalaya from the outer lesser Himalaya.The NAT passes near Gadolia and along right bank of Bhagirathi river and crosses Bhagirathi river at Dharasu. The NAT(Heim &Gansser 1939) called Nalupani fault(Dhaundiyal & Ali 1967) Dharkot thrust(Saklani 1970). The different litho-stratigraphic units of the area record various metamorphic and deformational events of the Himalaya. The outer lesser Himalaya forms the Krol Nappe and comprises of Chandpur Phyllite, Nagthat Quartzite, Blaine, Infrakrol, Krol and Tals whereas inner comprises of Rautgarh and Tejam formations.

Number of geologists worked in this Himalayan blocks. Gansser (1964), Saklani and Pandey (1970), Jain (1971), Kumar and Agarwal (1973),Valdiya and Bhatia (1980), Valdiya (1984). Saklani and Doval(1981)recognised geologic and metamorphic characteristics of Ghuttu area..Schwan and Saklani (1991) took traverses around Tehri-NarendraNagar area of Tehri Garhwal. Gansser (1964) adopted that Mandhalis, Chandpur and Nagthat from top to bottom as Jaunsar series. Geological Successions was given in table (1) and geological map depicted in the figure-1.

Table-1

Litho-Stratigraphic Succession of The Area After Saklani1 (1972) And Valdiya (1980).

Group	Litho-Tectonic Unit	Stratigraphic Unit
Jaunsar gp	Nagthat Quartzites	Thickly bedded, grey coloured quartzites, sericite quartzites and schistose Phyllite intercalated.
	Chandpur Phyllite	thinly laminated greenish black Phyllite and greyish green quartzites.
	Laluri formation	C-Purple green slate B-Greyish green Phyllite, slate with quartzites A-Black non laminated slate and phyllitic slate
DharasuThrust Sheet	Dharasu formation	Olive green and greyish thinly laminated slates laminated Phyllite and massive greyish thinly bedded quartzites.
Pratapnagar Thrust Sheet	Pratapnagar formation (Berinag)	Massive white cream coloured quartzites.
Tejam Group	Mandhali formation Deaban formation	Grey variegated limestone and slate bhelunta limestone, bluish green limestonewith pink Dolomitic limestone
Damtha group	Rautgara formation	Bhainga slate, brownish grey slate Paturi quartzites, medium grained pink grey coloured Quartzites.

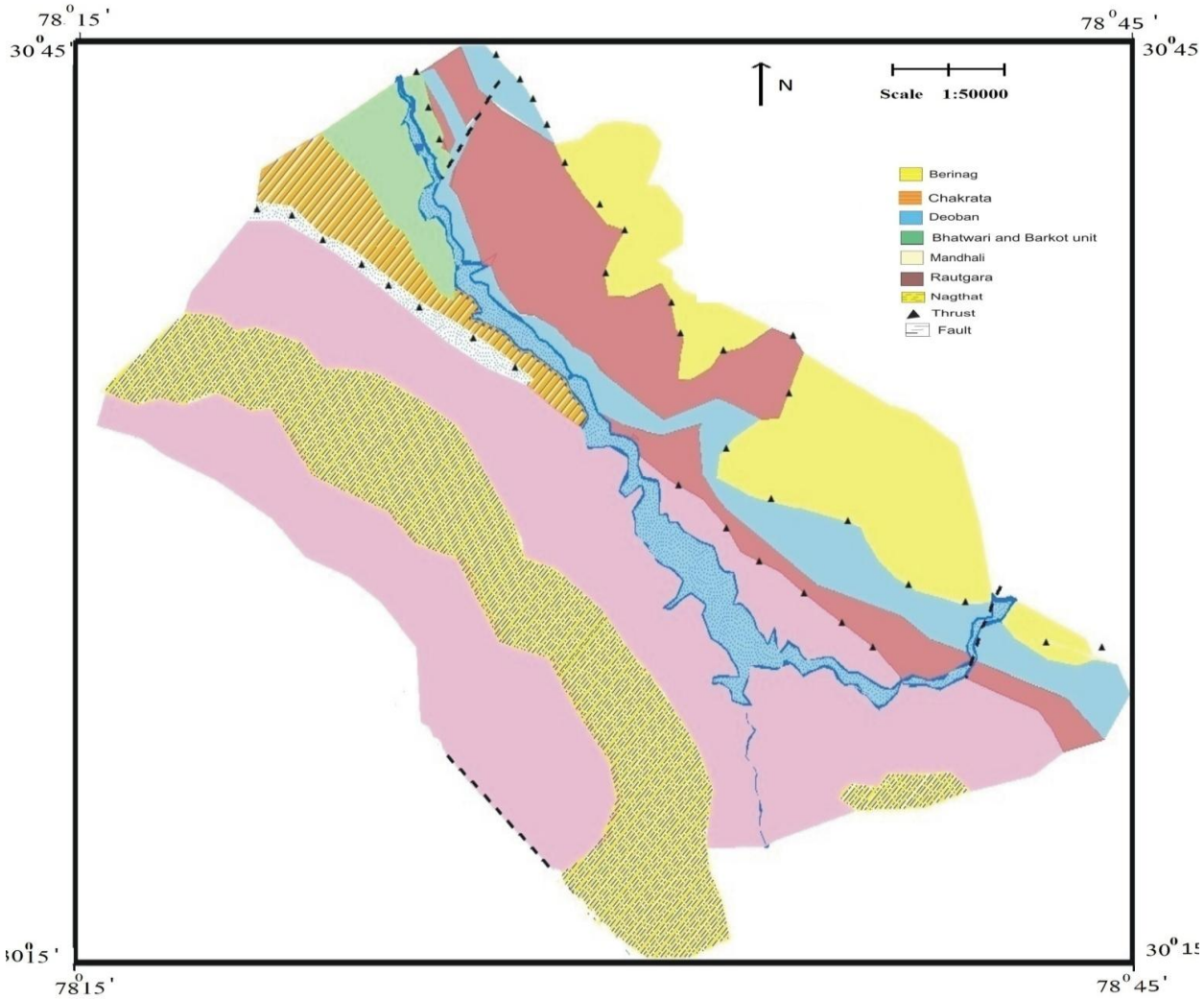


Figure -1 Geological Map of the Area

Geomorphology of the Area

The study area is characterised by rugged topography and steep valley side slopes at various places. At various places valley shows U shape in upper part and V shape in lower part suggests the previously valley was occupied by a glacier and V shaped carved out by river in later stage. Terraces development in the area show neo-tectonic activities in the area. Various landform features were identified and plotted on base map to prepare geomorphological map of the area. Help of Aerial photographs and remote sensing data were used in the identification of geomorphological features. Geomorphological map were depicted in Figure-2.

River Terraces

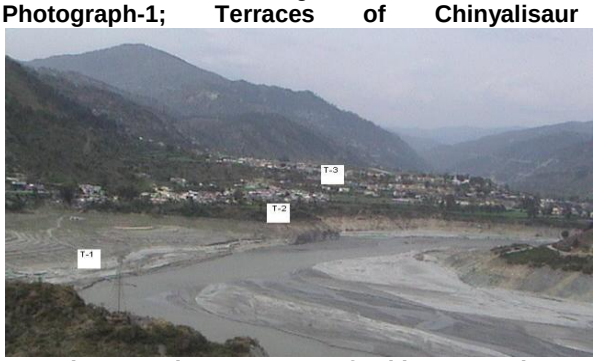
The quaternary sediments are developed in the form of terraces along Bhagirathi and Bhilangna river. Many of the terraces of old Tehri and Dobata have submerged in the reservoir and others are submerged during rainy season as water level increases in the reservoir. Terraces were categorised as T-1,T-2 respectively as T-1 is the youngest near the river valley and T-5 as oldest terrace on higher level. The terraces were divided into two groups;

Terraces of Bhagirathi River

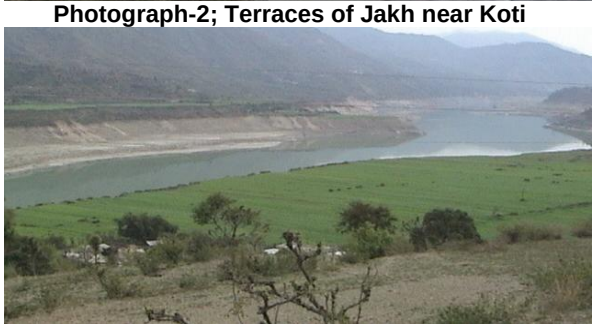
Along the Bhagirathi terraces are developed at Badethi, Chham, Chinyalisaur, while most of the terraces like Dobata and Tehri were submerged in the Reservoir. The terraces are mainly comprises of boulders, cobbles and pebbles embedded in silt and sands. In the Bhagirathi river Naithani (1992) observed 5 level of terraces similarly five level of terraces denoted around Chinyalisaur.T5 is the oldest terrace which is mainly comprises of clay horizon intermixed with boulder, cobbles and pebbles which are angular to sub angular may be of glacial origin. T4 terrace is less developed and is mainly comprises of gravels embedded in brown clay horizons, T4 terrace height is about 30 to 35 meters. T3 terrace is well developed and colony of hydropower project and scool and market is also well developed here.Terrace is mainly comprises of silty and sandy horizons with sub angular to subrounded cobbles and pebbles.T2 terrace is also developed in Chinyalisaur about 7-10 meter,mainly comprises of subrounded to rounded pebbles with coarse and fine sand layers. T1 terrace lie near the flood plain and is comprises of fine and

coarse sandy layer and generally submerged under water during rainy season. At Kandisaur T1,T2,T3 and T5 terraces are well developed but T3 is well developed and is about 800 mts length and 500 mts in width and is used for cultivation and human settlement. other are developed around Ratnogagad and Badethi and Jakh village near Koti.

Photograph-1; Terraces of Chinyalisaur



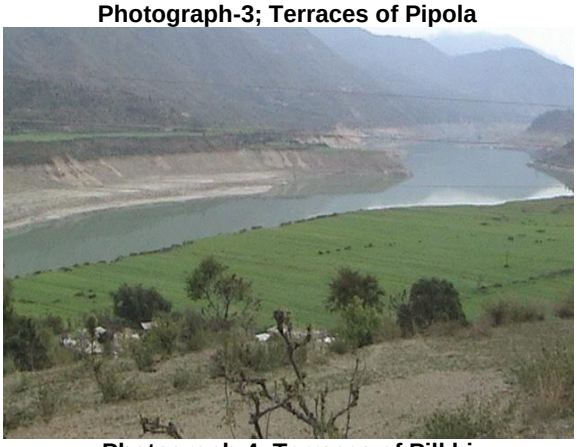
Photograph-2; Terraces of Jakh near Koti



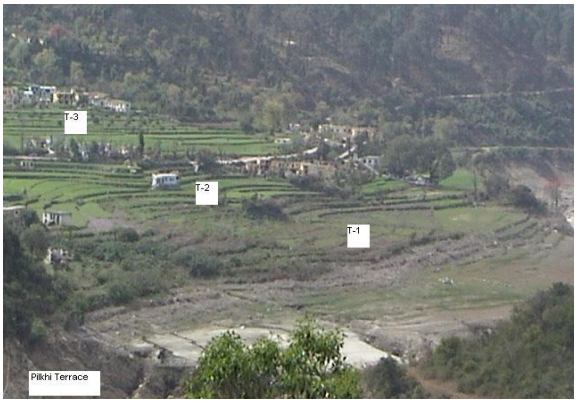
Terraces of Bhilangna River

In the Bhilangna river terraces are well developed at Pilkhi, Ppola, Asena, Gadolia, Nandgaon, Utthar and Chholgaon. In the investigated area only three level of terraces were observed around Pipola and Pilkhi the terraces are mainy unpaired.T3 terraces are mainly comprises of sub angular to surrounded pebbles and cobbles embedded in silty and sand layers height is about 15 to 20 meters T2 terraces are also developed in various parts and mainy comprises of pebbles with sand and silty layer sand and is main cultivated land of Pipola and Pilkhi.

Photograph-3; Terraces of Pipola



Photograph-4; Terraces of Pilkhi



Slope Analysis

The term slope is used to designate some small element or is of the land surface inclined from the horizon. A slope is an inclination of surface that form the part of landscape included between the crest of a hill and drainage line (Leopold 1964). Complicated geology and structural configuration together produce variation in slope (Pilgrim &Weat1968). Lithology, structure and geomorphic processes are responsible for the development of slope in the area. Slope classes were shown in Table-2 and slope map in figure-2.

Table-2
Frequency Distribution of Slope Values

Slope interval (Degrees)	Slope category	Frequency	% of total	% of cumulative frequency	Slope type
0- 5	**A**	**-**	**-**	**-**	Gentle to moderate
5- 10	B	1	. 32	.31	Do
11- 15	C	31	9.93	10.42	do
16- 20	D	100	32.05	42.29	do
21- 25	E	103	33.01	75.03	Moderately steep
25- 30	F	43	13.78	89.08	do
31- 35	G	15	4.80	93.88	do
36- 40	H	8	2.56	96.44	Steep
41- 45	I	5	1.60	98.04	do
46- 50	J	3	0.96	99.0	Very steep
51- 55	K	-	-	-	do
56- 60	L	1	0.32	99.32	D0
61- 65	M	1	0.32	99.64	Do
Total		312			

Landslides

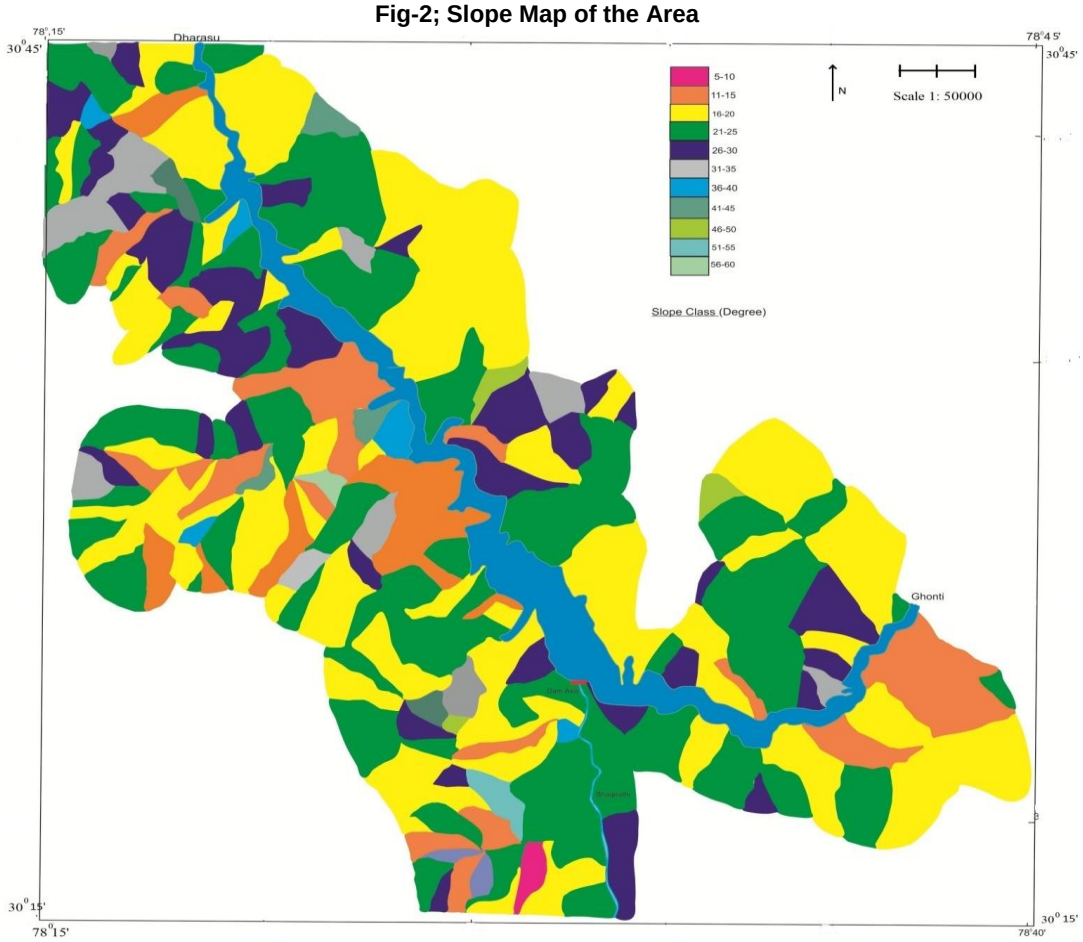
Landslide or mass movement is a term used for all kinds of movements which take place under the influence of gravity in rocks or in soils on slopes due to one or more causes. The movement could be of different shape, size, origin and type along one or more sliding plane (then it is called land slide) or within thick zone consisting of a system of partial sliding planes (Zaruba and Mincl, 1969). A part of hill when detached from the main mass and due to gravitational force moves downward, it is called mass movement. Every material has its own shearing strength but due to one or more reasons when this shearing strength is less than shearing stress, mass movement takes place, Mass movements and landslides may cause huge damages to engineering works, properties, lives and human activities. The study area consists of metamorphic rocks which have experienced folding, faulting, thrusting and shattering in successive phases of Himalayan orogeny. Landslides occur because the force creating the movement exceeds than those resisting it. A number of landslides have been observed in the study area. All around the rim area of the reservoir, landslides in minor scale are developed. It has been observed that among all the natural activities, the toe cutting by rivers by rivers/streams and slacking effect is the most prominent causes responsible for the occurrence of landslides throughout the study area.

Various forms of landslides observed in the study area are described as under-

Rock Fall

A rock fall is a fragment of rock detached by sliding, toppling, falling that falls along vertical or sub cliff, proceeds down slop (Varnes, 1978). An example of rock fall present in the area is Ghonti village, on the left bank of Bhilangana river.

Fig-2; Slope Map of the Area



Subsidence

It does not take place along a free surface but involves downward setting of material with little horizontal motion; the most common cause is the slow movement of material beneath the subsiding mass. (Willian d Thornbury, 1956). The recent subsidence activities can be seen near Bhagirathipuram , where due to heavy blasting, the rocks have loosened and consequently subsidence is taking place. Subsidence is also noticed in village Gaujana, near Pilkhi and also at Asena.

Screefall

They are generally associated with steep slopes of weathered rocks. Such falls have been observed along left slope of Bhagirathi near Dharasu bend, near Dharamghat along right slop of Bhaintogi nala near village Pangarkhaal and along bank of Bhilangana near village Ghonti.

Creep

It is the slow movement of earth's loose material. It is observed along Nagun gad, Chamba-Dharasu road, Pangarkhal village and in many other places too. Frost heaving is probably the most important contributory process to soil creep. Although heating cooling, wetting and drying of the mantle along with the wedging action of root growth also aid it. .

Important Landslide

In the study area many minor and major landslides are encountered. In order to understand the nature of landslides in the area, few major landslides having length greater than 80 metres are discussed as under.

Landslide of Nagun

Latitude 30°33'N
Longitude 78°20'E
Height 40 meters
Width 250 meters

Due to construction of road Chamba-Dharasu at the left side of downstream of Nagun gad (photograph-6). The active landslides were observed. It is about 250 mts in length and 40 mts in height. The bed rocks are highly jointed phyllites with overlying loose clay material. In both the places, widening and the construction of roads is the cause for slope failure.

Landslide of Lambgaon Band

Latitude 30°22'14"N
Longitude 78°33'30"E
Height 80 meters
Width 250 meters

The landslide is located at the right bank of reservoir rim near the lambgaun band 2 km ahead of Gadolia (photograph-5). The general topography of the slide is moderate to steep faces with the right face of the slide being moresteep. The upper part of the slide has thick shrubs and forest cover. The rocks are mainly phyllite mixed with unconsolidated clay with angular to subrounded boulders and cobbles overburden. It is an active debris slide.

Landslide at Madan Negi

Latitude 30°22'14"N
Longitude 78°33'30"E
Height 200 meters
Width 110 meters

The slide is located below the Madan Negi village. Rocks are mainly phyllite with overlying loose unconsolidated soil. The north Almora thrust is passes on right bank of down, stream side of Bhagirathi and Bhilangna river which plays important role in the mass movement. In comparison to toe part of the slide, the crown part is narrow with forest cover. As the slope of the affected area is steep, a small amount of precipitation in the area is enough to trigger the slide.

Landslide of Zero bridge

Latitude 30°21'N
Longitude 78°29'E
Height 200 meters
Width 155 meters

This slide is located near the zero bridge and is active in nature The slide has an irregular shape and is composed of loose soil, fragments of crushed phyllite material and rounded to semi rounded heterogeneous pebbles and boulders. During the heavy rainfall due to the pore water pressure, the soil and rocks slide down. The slide has a steep slop but has less forest cover which may aid the process of sliding. In the rainy season the road remain closed for few months.

Landslide of Bhaldgaon

Latitude 30°29'N
Longitude 78°24'E
Height 300 meters
Width 200 meters

The slide is located near Bhaldgaon on the left side of the reservoir rim. The slide has a steep face; the area over the crown part is covered with the trees and shrubs. The slide material is composed of small loose rock fragments and weathered material. It is an active debris fall slide and gets triggered with onset of precipitation.

Landslide of Baldogi

Latitude 30°31'N
Longitude 78°23'E
Height 200 meters
Width 180 meters

This landslide is located near village Buldogi on the left side of the reservoir rim(photograph-7). The slide has a clayey sandy matrix in which loose boulders and pebbles are visible .The upper part of the slide has a thick vegetation cover. The slide does not have a single failure plane instead multiple planes of failure exists for the sliding mass. As the photographs shows that there is a crack below Baldogi village and therefore it poses a serious threat for the village, during heavy precipitation the village may slide down in near future.

Landslide of Malogi

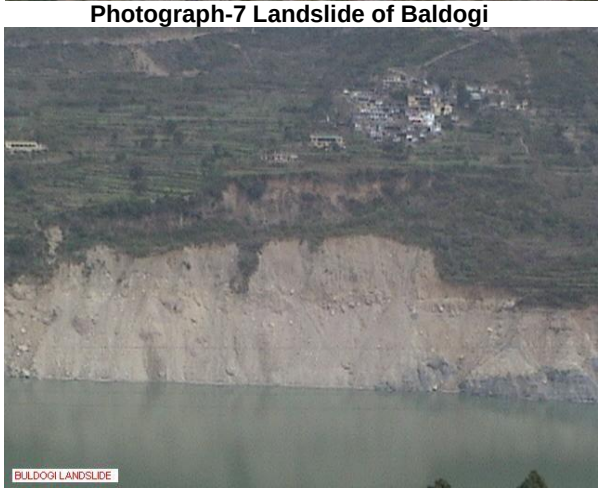
Latitude 30°22'N
Longitude 78°22'E
Height 500 meters
Width 300 meters

The slide is located near Malogi gad on the right bank of the reservoir rim (photograph-8) It has an irregular outline with moderate slop. The land upside of the slide is covered with thick forest cover. The slide material consists of loose soil debris and fragments of rock material.

Photograph-5; Landslide near Lambgoan Band

Photograph-6; Landslide of Nagungad

Photograph-7 Landslide of Baldogi



Photograph-8; Landslide of Malogi

Impact of Reservoir on Geomorphology

Landslides

Several studies illustrate the influence of reservoir impoundment on the proximate area. A significant landslide event was caused by the impoundment of the Vaiont Reservoir(Italy) in 1963 which triggered a sliding mass of 0.214 billion meter cube that slipped into the reservoir generating a tsunami affecting Lonagarone country (Matsui et al 1982).Huang and Li(1992) and Chen(1993) studied slope stability zoning with multi numerical models reservoir of China.

Due to the construction of dam the natural flow of river is obstructed thereby inducing variety of changes in the surroundings. The changes in the level of reservoir with changing weather conditions reduce the shear strength of the rocks thereby causing instability of the slope around the reservoir. The slacking effect is the main cause of slope instability.

Three basic types of landslides viz fall, slides and flow categorised on the basis of relationship between the nature of sliding mass and failure surface recognised in study area. In order to assess the impact of reservoir impoundment on the surrounding slopes of reservoir a comparative study of landslide activity and slope conditions for 2005 the beginning of Tehri reservoir impoundment, 2009 and 2011 is undertaken. Remote sensing imageries (Google image) are used to study the changes in the slope instability post impoundment of the reservoir. The following table -3 shows the temporal changes in the landslide activity along the rim of Tehri dam reservoir rim.

Table-3

The Temporal Changes in the Landslide Activity around the Reservoir Rim

Year	No of slide	Type of slide	Area (sq.mts)	Rock type
2005	54	Debris fall - 36 Screefall - 18	202781.9 87597.1	Phyllite, quartzite and limestone Quartzites &limestone
2009	65	Debris fall- 47 Screefall – 18	629172.7 74160.29	Phyllite,quartzite and limestone Quartzite & limestone
2011	81	Debris fall - 64 Scree fall - 17	902679.7 114019	Phyllite,quartzite and limestone Quartzite and limestone

Water rock interaction is the most active and important factor for a variety of geological disaster. Water rock interaction includes three aspects physical, chemical and mechanical effects. During the fluctuation of the reservoir water level the rock mass around rim the reservoir slopes are deteriorated in water-rock interaction of saturation-air dry cycles and it would further cause great damage to stability of the bank slope (Deng2011).

River Terraces

River terraces are well developed along Bhagirathi and Bhilangna river. Due to construction of 260.5 mts high Tehri dam important and fertile terraces of Tehri, dobata Chham submerged in the reservoir. Important terraces of Simlasu, Lampungri, Nandgaon Gadolia submerged in the reservoir. Due to formation of 42 sq.km lake several terraces of Bhairathi and Bhilangna river submerged while others are subjected to erosion.

As the North Almora Thrust passes near Gadolia and on the left bank of upstream of Bhagirathi river several new landslides reactivated.

Discussion and Conclusions

Before the construction of Tehri dam there were only few landslides around the reservoir rim and after the construction of Tehri dam the landslide activity increases.

1. In 2005 there were only 54 landslides around the reservoir rim. But increases in 2009 as 65 and in 2011 the total number of landslide increases upto 81 which is serious problems.Many villages rehabitated after construction of dam but landslide activity frequently increasing create problems to other villages. this is mainly due to slacking effect.
2. Water is the major factor producing slope failure. Near Baldogi, Lambgaon band, zero bridge and Nagun gad due to slope failure and slacking effect these villages sliding down,and villagers demands for rehabitation.
3. Most of the fertile land along Bhagirathi river and Bhilangna river submerged in the reservoir People rehabitated and their socio-economic environment changed. Fish ecology also changed. Although the tourist industry is growing due to the formation of Tehri lake.
4. As the NAT passes along the left flank of Bhagirathi river the landslides are maximum along the thrusts. Due to minor earthquake the loose debris mass moves downward as NAT thrust is the weak zone.

References

Aggarwa, N.C and Kumar. G(1973) : Geology of Upper Bhagirathi and Yamuna valley, Uttarakashi DistrictKumaon Himalaya Publ. in Himalayan Geology Volume 3, page 1-23.

Dhaundiyal, D.P.and Ali,K.N.(1967); General report of Geological Survey of India, Rec. Geo. Surv.Ind.98(1),29-30 in B.C.Roy,1968.

Gansser,A(1964); Geology of the Himalaya, Interscience Publication London,289p.

Heim. A and Ganseer. A (1939); Central Himalaya Geological Observation of the Swiss Expendition Mem.Sos.Holv.Nat,77(1):245

Jain A.K (1971) : Stratigraphy and tectonics of lesser Himalaya region of Uttarkashi, Garhwal Himalaya,Published in Him. Geol. Volume -1, page 25-38.

Jain, A.K. (1971);Stratigraphy and tectonics of Lesser Himalayan region of Uttarkashi,Garhwal Himalaya,Himalay.Geol.volume-1,25-57.

Naithani N.P. (1992); Study of Quaternary Sediments between Maneri and Gangnani area DistrictUttarkashi Garhwal Himalayan U.P unpublished thesis submitted to Garhwal University Srinagar.

Leopold,L.B,Waluman M.G and Miller, J.D.(1964) Fluvial process in geomorphology Eurasia publishing House New Delhi.

Naithani N.P. and Mala Bhatt (2011); Geo-Environmental Hazards around Bhatwari area, publ in International Journal of Current Research Vol-3 Issue-4 pp 200-205 April 2011.

Saklani,P.S(1970);Metamorphism in rocks of Garhwal Nappy of Garhwal Himalaya, centre. Adv. stud.Geol.Punjab Univ.Chandigarh7, 115-118.

Saklani,P.S and Pandey, I.C. (1970); Geology of Pratapnagar area, Tehri Garhwal, Uttar Pradesh ,Bull. Ind. Geol. Association, Chandigarh. 3(182)13-18.

Saklani,P.S.and Doval(1981);Ghuttu Garhwal Himalaya;Geologic and metamorphic characteristic,Metamorphic Tectonics of the Himalaya in Saklani,P.S,ed.15-20,Today and Tomorrow.Publisher New Delhi.

Singh,S.B(1976)Slope Catagories(Wentworths Methods) and slope development in the shimla hills.Himalayan Geology volume 6,page 409-422

Steven N Ward and Simonj Day(2011); The 1963Landslide and flood at Vaiont Reservoir Italy. A tsunami ball simulation Ital. J .Geosci .(Boll.Soc.Geol.It) ,vol.130, NO.1 (2011) .PP 16-26, 9FIG .(DOI;10,3301/IIG2010.21)

Thornbury,W.D.(1964): Principles of Geomorphology John Wiley and Sons

Valdiya K.S. (1978); Outline of the Strucutre of the Kumaon Himalaya pub. In P.S. Saklani, Edited Tectonic Geology of the Himalaya Today and Tomorrow, Published in New Delhi.

Valdiya,K.S and Bhatia (1980);Stratigraphy and correlation of Lesser Himalayan formation,published by Hindustan Publishing corporation. India Delhi110007.

Valdiya,K.S. (1997).;High dams in central Himalayain context of active faulta,seismicity,etc.published in journals of geological society of India,volum.49(479-494)

Wentwortrh, C.K. (1930) ;A simplified method ofdetermining the average slopeof landsurfaces, Americon journal of Sciences,sweries 5,vol20.pp 184-94..

Zhenhua Zhang,Mingming Qian,Song wei andJuxiang Chen(2018);Failure Mechanismof the Qianjiangping slope in three gorgesReservoirArea China, Research article published in volume 2018/Article ID3503697/https//doi.org/10.1155/2018/3503 .