# LANDSLIDE INVESTIGATION NEAR BHAKRA DAM : AN INTEGRATED APPROACH OF REMOTE SENSING AND GIS

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## ABSTRACT

*Bhakra is one among earliest constructed large dams in India after independence. It was constructed in 1963 near village Bhakra in the state of Punjab. It is a 225.55 m high concrete gravity dam. Geologically it is hosted in Siwalik Group of rocks. Geomorphologically, two distinct morphological units are observed in the area, one is structural hills and valleys and another is fluvial landform. The trends of the structural hills are of NW-SE and the slope varies from 15° to 42°. Drainage pattern is Sub-trellis to trellis with high concentration of first order streams.*

*With the help of remote sensing data IRS Resourcesat 2 LISS IV imagery, PSLV-C40 CARTOSAT-2 and google images, it was observed that total 50 nos. of landslide were present in the Gobind Sagar reservoir area. Geologically Siwalik Group of rocks mainly covers the area rather than Sirmour and Shali Group of rocks.*

*After integration of GIS techniques it is found that landslides are very small, small, medium and large scales occupied by 50 sq. m to 1000 sq. m; 1001 sq. m to 5000 sq. m; 5001 sq. m to 10000 sq. m and more than 10001 sq. m respectively. The number of landslides belonging to the very small, small, medium and large are 6, 22, 10 and 12 nos. the concentration of landslides are more near road connecting Bhakra to Naina Devi as analysed through GIS indicating that they are largely related to post road construction reworked slopes rather than reservoir induced. It has also been observed that 1st order streams are more influencing the landslides along with the heavy continuous rainfall in the study area.*

## 1. INTRODUCTION

Landsliding is a natural phenomenon in the hilly terrain, caused due to improper management of vulnerable slopes. Risk and losses of animal life, road, railway, tunnel, major constraction and agricultural land affected directly and indirectly due to landslides.

Present landslide study deals with the landslide present near Gobind Sagar reservoir, mainly presented nearer to the dam axis (Fig. 1). The study area is bounded by latitude 31°15'-31°37′ N and longitude of 76°20′-76°45′ E, covers 570 sq. km., parts of the districts of Bilaspur, Hamirpur and Una of Himachal Pradesh. Satluj River is the prime river flowing through the study area and is fed by tributaries such as Karhwin *Khad*, Lunkhar *Khad*, Seer *Khad*, Matla *Khad*, Gambher *Khad*, Gambrola *Khad,* and Ali *Khad*.

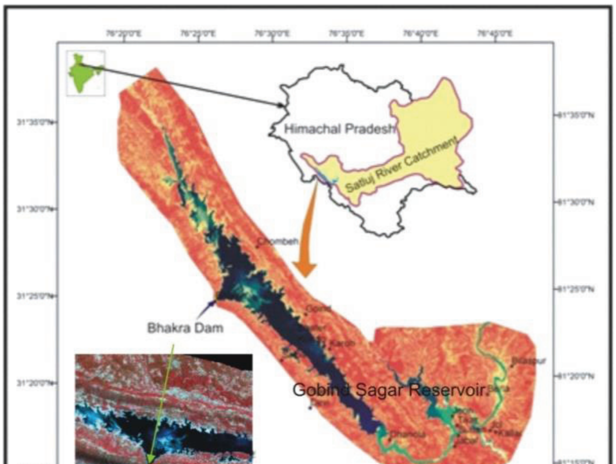


**Fig. 1** : Location map of study area

## 2. GEOLOGY AND GEOMORPHOLOGY

The rocks exposed in the Gobind Sagar reservoir rim area can be put into three classes, i.e. Siwalik Supergroup, Sirmour Group and Shali Group. These rocks are characterized by their distinct lithological characters. Shali Group is the oldest rocks exposed in the area overlain by Sirmour Group. These two groups are rocks separated from Siwalik Supergroup by Main Boundary Fault (MBF).

The general litho-stratigraphic sequence based on *Unpublished Report, GSI, FS 2016-17* of the studied area is as follows:

**Table 1** : Stratigraphy of the study area.

| Age | Group/ Supergroup | Sub-group | Formation | Lithology |
|---|---|---|---|---|
| Pliocene to Pleistocene | Siwalik | Upper Siwalik | Pinjor | The alternating sequence of pebbly conglomerate and sandstone with intermittent thinly bedded, subordinate clay beds (65:35) |
| Miocene to Pliocene | | Middle Siwalik | Mohargarh | Massive/multistoried, coarse, micaceous sandstone with randomly oriented small pebbles and subordinate grey-earthy mudstone (70:30). |
| | | | Dewal | Fine to medium grained, rather compact, greyish sandstone and grey to reddish mudstone (almost 50:50). |
| Miocene | | Lower Siwalik | Nahan | Alternate fine, compact, hard, grey-white micaceous/flaggy sandstone and reddish-brown-greyish mudstone (40:60). |
| Eocene to Miocene | Sirmaur ≡ Dharamshala | | Dagshai | Purplish brown sandstone and red clay, purple and chocolate shale with minor sandstone. |
| Palaeocene to Eocene | | | Subathu | Olive green carbonaceous shale, shale, marl, fossiliferous limestone |
| Meso-Proterozoic | Shali | | Parnali | Cherty dolomite, quartzite and limestone. |
| | | | Makri | Purple pale greenish and grey shale, slate, quartzite and cherty dolomite |
| | | | | (Unpublished Report, GSI, FS 2016-17) |

Parnali Formation consists of Cherty dolomite, quartzite and limestone and Makri Formation (GSI 2002) consists of Purple pale greenish and grey shale, slate, quartzite and cherty dolomite of Shali Group of rocks are present in the study area and as of Meso-proterozoic in age. In the Sirmour Group Purplish brown sandstone and red clay, purple and chocolate shale with minor sandstone of Subathu and Purplish brown sandstone and red clay, purple and chocolate shale with minor sandstone of Dagshai formations are present. Lower Siwalik Sub-group of Miocene age, Middle Siwalik Sub-group of Miocene to Pliocene and Upper Siwalik Sub-group of Miocene to Pliocene age are present in this area. Dewal Formation consists of fine to medium grained, rather compact, greyish sandstone and grey to reddish mudstone (almost 50:50) and Mohargarh Formation consists of massive/multistoried, coarse, micaceous sandstone with randomly oriented small pebbles and subordinate grey-earthy mudstone (70:30) are the two main formations observed in the middle Siwalik Sub-group. Pinjor Formation (alternating sequence of pebbly conglomerate and sandstone with intermittent thinly bedded, subordinate clay beds (65:35)) and Nahan Formation (Alternate fine, compact, hard, grey-white micaceous/flaggy sandstone and reddish-brown-greyish mudstone (40:60)) are the only formation present in the Upper Siwalik Sub-group and Lower Siwalik Sub-group respectively.

The lower Siwalik rocks exposed near dam site, which strike N-S and NNW-SSE with dip value of 35°-45°. Four different joint sets $J_0$*: 220°/25°→310°,* $J_1$*: 210°/70°→120°,* $J_2$*: 130°/70°→40°* $J_3$: 350°/80°→260° are observed in the left bank of the reservoir. Main Boundary Thrust (MBT), Barsar Thrust (BT) and Gambhar Thrust (GT) pass through the area. BT and GT are parallel to each other and trend NW-SE. Barsar Thrust dip towards the west while Gambhar Thrust dip towards east. Main Boundary Thrust, locally named as Bilaspur Thrust is more prominent near the Swarghat area. Upper, Middle and Lower Siwalik are repeatedly appearing in the reservoir area due to anticlinal and synclinal folding. One fault has been observed in the southern part of the reservoir near Naina Devi area. Changar Talai anticlinal axis, most prominent anticline, trending NW-SE, parallel to the Barsar Thrust passes in the Changar Talai area.

Structural hills-valleys and fluvial landform are the two main geomorphological unit (Fig. 3) present in study area (Srivastava et al., 1967, Gautam, 1992 and Gautam et al., 2002). Structural hills, in this area are of three different types, highly dissected hills, moderately dissected hills and low dissected hills. The trend of structural hills is NW-SE with varying between 15° to 42°. The crests of the hills are sharp to round. Development of steep escarpment usually along

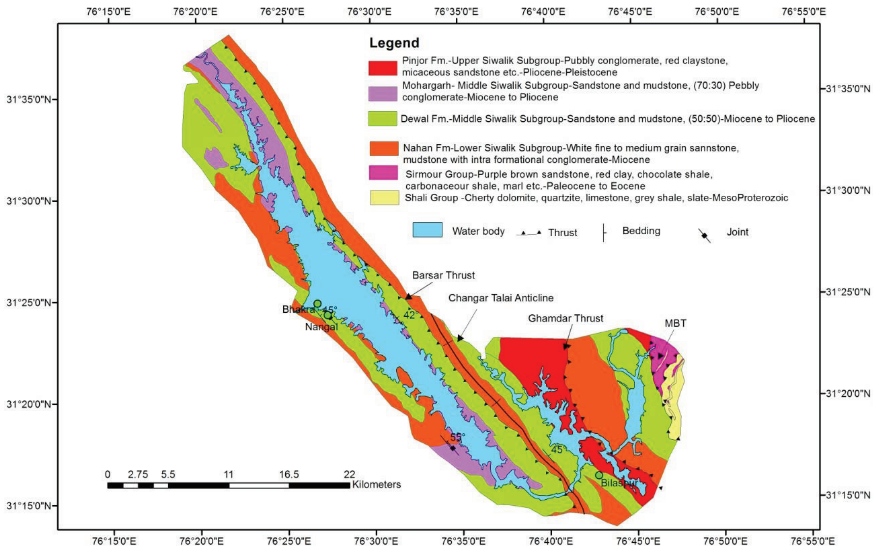


**Fig. 2** : Geological map of the study area.

the eastern side of the central main ridge has been observed. Sub-trellis to trellis drainage pattern is observed in the area. Satluj River and its tributaries Sarhyali *Khad* and Sir *Khad* flow mainly along NW-SE direction but towards south-east, Satluj River takes turn and flows along NE-SW direction. The flanks of the hills are moderately dissected by sub-parallel to parallel drainage. Narhal Khad, a tributary of Seer Khad drains a broad valley around Bala. Development of badland around Bala due to intense gully erosion indicates the rejuvenation of Satluj river system.

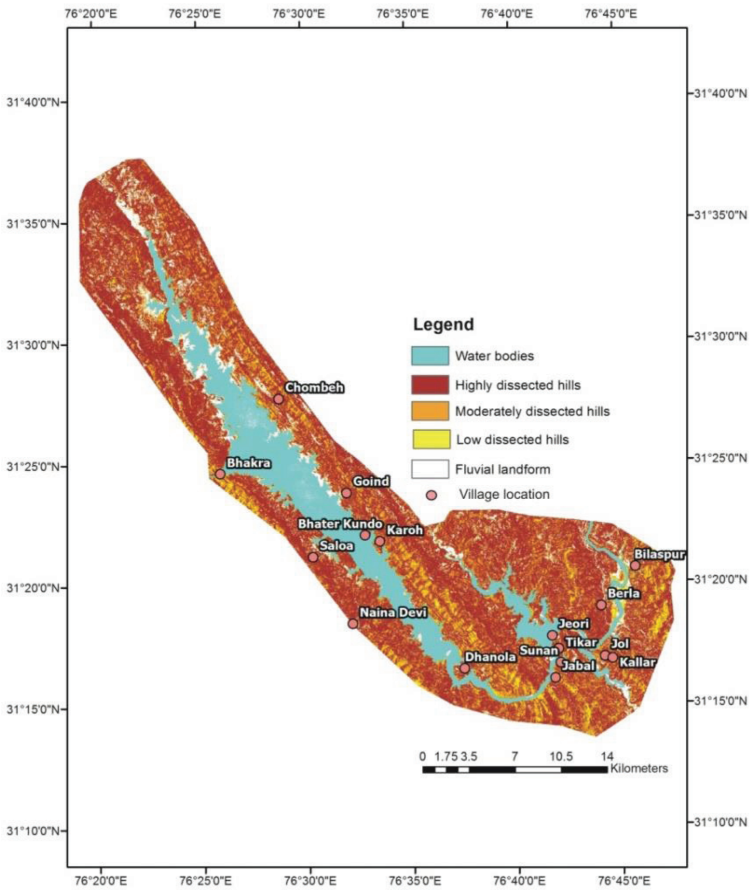


**Fig. 3 :** Geomorphological map of the study area.

## 3. RESULT AND DISCUSSIONS

Four sets of CARTOSAT -2 data of 2014 and 2015, one set of IRS Resoursesat-2 LISS IV data for the year 2015 and google images were used for preparation of landslide incidences and landslide zone map under supervised and unsupervised classification methods. Landslide affected area have been digitized based on supervised classified map. Drainage map also prepared with the help of above images by digitisation. LISS IV data has 5.8m 4.5 resolution and Cartosat data have 2.5m resolution. Both the data used for the resolution merge images and prepared RGB image of 2.5m resolution, with the help of image enhancement techniques (Rawat et al., 2015 and Singh et al., 2014) in ERDAS imagine software. The drainage morphometry (Fig. 4) and the thematic maps were prepared in the ARCGIS software.

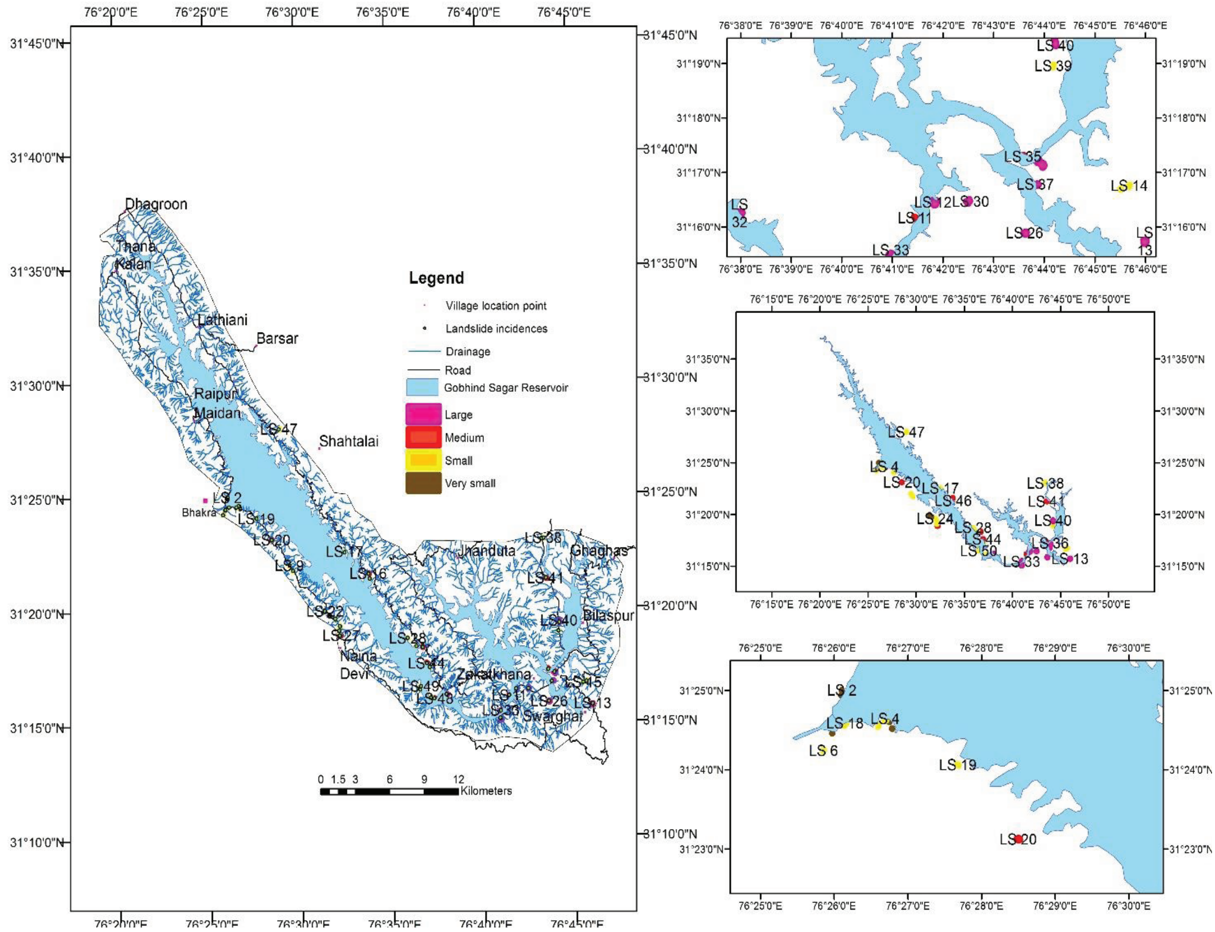


**Fig. 4** : Drainage map along with the landslide incidence point and area of landslide

Based on the interpretation of the satellite data, total 50 landslide incidences have been identified and marked on the map. The inventory data of 50 landslides, which were presented in the year 2018 given in the table no. 2 and the entire prepared landslide inventory, were validated through field checks. The areas of the landslides are classified into four distinct categories for better understanding of the size of the landslides. The categories are very small, small, medium and large and classified according to the area occupied by them, as 50 sq. m to 1000 sq. m are very small; 1001 sq. m to 5000 sq. m are small; 5001 sq. m to 10000 sq. m are medium and more than 10001 sq. m are large respectively (Table 2). The number of landslides belonging to the very small, small, medium and large are of 7, 24, 9 and 10 nos. It was also observed that the concentration of landslides are more near road connecting Bhakra to Naina Devi developed due to the past road construction rather than reservoir induced. It has also been observed than 1st order streams are more influencing the landslides along with the heavy continuous rainfall in the area.

**Table 2** : Landslide inventory along with physical properties and classifications.

| Name of the landslide | Latitude | Longitude | Type of Material | Length | Width | Height | Area (sq. m) | Perimeter (m) | Classification of Landslide |
|---|---|---|---|---|---|---|---|---|---|
| LS 1 | 31°24'56.8" N | 76°26'05.8" E | Debris | ±11m | ±10m | ±10m | 53 | 29 | Very small |
| LS 2 | 31°25' 00" N | 76°26'06" E | Debris | ±23m | ±31m | ±20m | 591 | 99 | Very small |
| LS 3 | 31°24'27.60"N | 76°25'58.30"E | Debris | ±25m | ±21m | ±21m | 354 | 72 | Very small |
| LS 4 | 31°24'37.38" N | 76° 26'41.54" E | Debris-cum-rock | ±20m | ±200m | ±18m | 2859 | 209 | Small |
| LS 5 | 31°24'33.70"N | 76°26'35.40"E | Debris-cum-rock | ±10m | ±70m | ±08 | 1333 | 155 | Small |
| LS 6 | 31°24'14.37"N | 76°25'51.11"E | Debris Slide | ±52m | ±37m | ±31m | 1541 | 151 | Small |
| LS 7 | 31°24'31.23"N | 76°26'47.15" E | Debris Slide | ±25m | ±24m | ±32m | 548 | 92 | Very small |
| LS 8 | 31°24'36.15"N | 76°26'44.90"E | Debris-cum-rock | ±12m | ±150m | ±10 | 825 | 144 | Very small |
| LS 9 | 31° 21'59.06" N | 76° 29'28.03" E | Debris-cum-rock | ±12m | ±75m | ±05 | 2697 | 199 | Small |
| LS 10 | 31°19' 06.04" N | 76° 32'09.02" E | Debris-cum-rock | ±25m | ±120m | ±18 | 2764 | 235 | Small |
| LS 11 | 31°16'9.84"N | 76°41'26.21" E | Debris-cum-rock | ±15 | ±60 | ±10 | 7096 | 357 | Medium |
| LS 12 | 31°16'27.31"N | 76°41'48.56"E | Debris-cum-rock | ±80 | ±260 | ±35 | 32961 | 974 | Large |
| LS 13 | 31°15'45.00"N | 76°46'0.00"E | Debris-cum-rock | ±100m | ±80m | ±80 | 17676 | 524 | Large |
| LS 14 | 31°16'44.78"N | 76°45'40.68" E | Debris-cum-rock | ±150m | ±105m | ±80 | 4231 | 242 | Small |
| LS 15 | 31°16'41.61"N | 76°45'30.54" E | Debris-cum-rock | ±120m | ±100m | ±85 | 2630 | 188 | Small |
| LS 16 | 31°21'34.88"N | 76°33'47.25"E | Debris | ±110m | ±150m | ±85 | 7248 | 479 | Medium |
| LS 17 | 31°22'32.50" N | 76°32'30" E | debris-cum-rock | ±20m | ±50m | ±22 | 3031 | 220 | Small |
| LS 18 | 31°24'34" N | 76° 26'11.2" E | Rock-cum-debris | ±50m | ±40m | ±45 | 4676 | 282 | Small |
| LS 19 | 31°24'04.10" N | 76° 27'40.80" E | Debris/mud | ±15 | ±50 | ±10 | 1769 | 179 | Small |
| LS 20 | 31°23'6.78"N | 76°28'30.13"E | Debris/mud | ±13 | ±45 | ±8 | 5368 | 275 | Medium |
| LS 21 | 31°21'45" N | 76° 29'39.30" E | Debris | ±7 | ±100 | ±5 | 1275 | 134 | Small |
| LS 22 | 31°19'57.96"N | 76°31'22.26"E | Debris | ±10 | ±50 | ±8 | 896 | 133 | Very small |
| LS 23 | 31°19'45.97" N | 76° 31'37.25" E | Rock | ±25 | ±50 | ±18 | 873 | 140 | Very small |
| LS 24 | 31°19'37.14"N | 76°31'56.73"E | Rock cum debris | ±17 | ±45 | ±10 | 4493 | 347 | Small |
| LS 25 | 31°19'17.80" N | 76° 32'11.15" E | Debris | ±18 | ±80 | ±12 | 1755 | 175 | Small |
| LS 26 | 31°15'52.80"N | 76°43'36.25"E | Rock cum debris | ±45 | ±120 | ±30 | 12236 | 428 | Large |
| LS 27 | 31°18'52.58"N | 76°32'11.01"E | Rock cum debris | ±13 | ±60 | ±8 | 6719 | 435 | Medium |
| LS 28 | 31°18'44.16" N | 76° 35'53.68" E | Rock cum debris | ±75 | ±60 | ±55 | 1982 | 210 | Small |
| LS 29 | 31°18'20.26" N | 76°36'43.05"E | Rock cum debris | ±150 | ±150 | ±120 | 6191 | 308 | Medium |
| LS 30 | 31°16'28.27"N | 76°36'33.08"E | Debris cum rock | ±150 | ±200 | ±120 | 13316 | 602 | Large |
| LS 31 | 31°16'6.18"N | 76°37'6.97" E | Rock | ±110 | ±100 | ±85 | 4393 | 298 | Small |
| LS 32 | 31°16'14.96"N | 76°37'59.25"E | Debris cum rock | ±100 | ±140 | ±85 | 15400 | 500 | Large |
| LS 33 | 31°15'30.14" N | 76° 40'58.09" E | Debris cum rock | ±80 | ±120 | ±58 | 16287 | 571 | Large |
| LS 34 | 31°15'10.90"N | 76°40'55.58"E | Debris cum rock | ±150 | ±250 | ±50 | 49251 | 1077 | Large |
| LS 35 | 31°17'17.10"N | 76°43'35.48"E | Debris cum rock | ±40 | ±80 | ±20 | 9021 | 363 | Medium |
| LS 36 | 31°17'09.99" N | 76° 43'55.41" E | Rock cum debris | ±40 | ±150 | ±15 | 38657 | 980 | Large |
| LS 37 | 31°16'45.57"N | 76°43'46.49"E | Debris cum rock | ±30 | ±120 | ±12 | 20026 | 696 | Large |
| LS 38 | 31°23'2.34"N | 76°43'25.64"E | Debris cum rock | ±15 | ±80 | ±12 | 2965 | 252 | Small |
| LS 39 | 31°18'58.22" N | 76°44'10.64" E | Debris cum rock | ±20 | ±140 | ±19 | 2716 | 274 | Small |
| LS 40 | 31°19'19.90" N | 76° 44'13.90" E | Debris cum rock | ±22 | ±140 | ±18 | 15882 | 655 | Large |
| LS 41 | 31°21'17.10" N | 76°43'31.80" E | Debris cum rock | ±18 | ±100 | ±12 | 9113 | 467 | Medium |
| LS 42 | 31°23'0.97" N | 76° 43'18.52" E | Debris cum rock | ±20 | ±80 | ±10 | 2886 | 222 | Small |
| LS 43 | 31°17'26.79"N | 76°37'5.50"E | Debris cum rock | ±50 | ±120 | ±40 | 4498 | 277 | Small |
| LS 44 | 31°17'37.42"N | 76°36'55.75"E | Debris cum rock | ±85 | ±220 | ±75 | 9134 | 422 | Medium |
| LS 45 | 31°18'22.48"N | 76°36'22.47"E | Debris cum rock | ±50 | ±150 | ±38 | 3709 | 281 | Small |
| LS 46 | 31°21'21.91"N | 76°33'51.13"E | Rock cum debris | ±50 | ±100 | ±42 | 2861 | 238 | Small |
| LS 47 | 31°27'57.79"N | 76°28'57.74"E | Rock cum debris | ±130 | ±250 | ±80 | 2992 | 259 | Small |
| LS 48 | 31°16'4.95"N | 76°37'22.06"E | Rock | ±110 | ±100 | ±85 | 8768 | 417 | Medium |
| LS 49 | 31°16'36.68"N | 76°36'35.67"E | Rock cum debris | ±130 | ±150 | ±80 | 3880 | 330 | Small |
| LS 50 | 31°16'27.08"N | 76°36'29.50"E | Rock cum debris | ±137 | ±43 | ±82 | 4868 | 312 | Small |

In the Bhakra to Goribnath area 2 landslides Ls2 and Ls 3 are present but they are small in size (591 sq. m and 354 sq. m). on the other hand three landslides Ls 4, Ls 5 and Ls 18 (Fig. 5) are present in the road connected to the Bhakra to Naina Devi area are also small in size but larger than Ls 2 and Ls 3, 2859 sq. m, 1333 sq. m and 4676 sq. m respectively, though they are small in size but their presence in the nearer to the dam axis may directly or indirectly hamper the life of the dam.

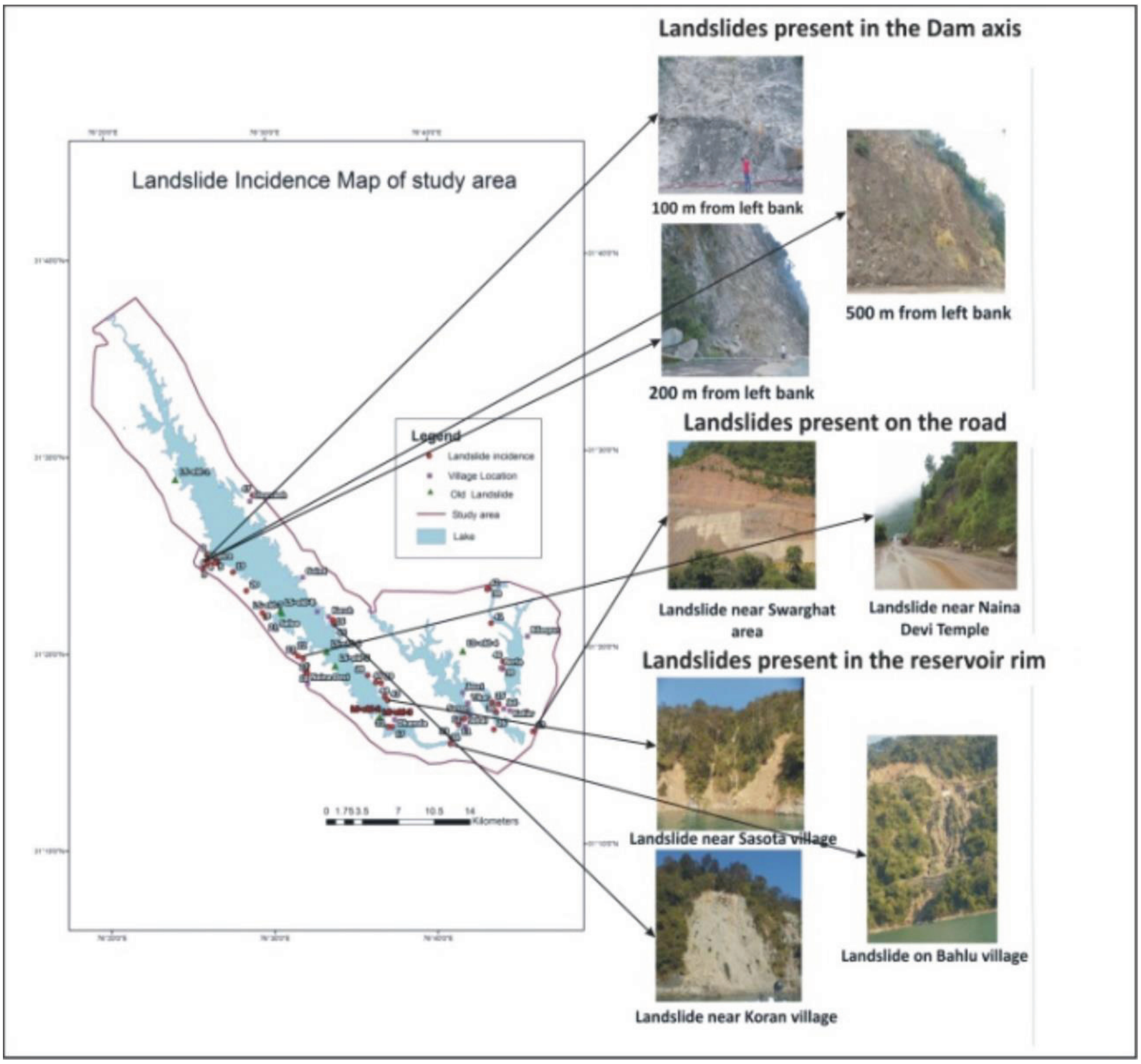


**Fig. 5** : Landslide incidence map along with field photographs.

## 3. CONCLUSION

With the overall study if can be concluded that Remote Sensing and Geographic Information System are the best tool for landslide investigation along with the limited field checks (Zhang et al., 2010) . It was observed that out of 50 landslide total 10 landslide are large in size but they are away from the dam sites are not vulnerable. But three landslides which are present in the Bhakra dam, road connecting from the Bhakra to Naina Devi area are vulnerable though they are small in size. So it is recommended that these three landslides may be taken for detailed investigation for the safety of dam.

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