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Rockfall at Siyar Baba Waterfall, Tehsil and District Reasi, Jammu and Kashmir (UT)

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Abstract: ***The Siyar Baba Waterfall located in Reasi District of Union Territory (UT) of Jammu and Kashmir is famous for its beauty and tourist attraction. The occurrence of rockfall/ landslide on 15th July 2018 adjoining the waterfall caused casualty of more than 07 visitors which led to reduction in flow of tourists. Accordingly an attempt has been made to determine nature and structure of rocks, topography and drainage pattern in the area to ascertain the causes of rockfall/landslide and to work out preventive measures thereof. Geologically the area under study is a part of Reasi Inlier and comprises of rocks consisting mainly of cherty/non-cherty, grey to creamy white and pale to brown, dolomitic limestone bands belonging to Sirban/ Trikuta/ Reasi Limestone Formation of Proterozoic Age. The rocks in and around the waterfall are affected by numerous fractures and joints due to proximity of the area to Reasi Thrust (M.B.F). The general trend of the rocks in the area are NE - SW with dips inside the hills having angle of inclination from 21^0 to 57^0 due North and North-West. The present investigation reveals that the major factor involved in triggering rockfall in the area are mainly, nature and structure of rocks which are highly jointed and fractured, percolation of surface as well as rainwater in the joints and fractures, presence of minerals in the rocks having differential thermal expansion and toe cutting by falling water at the plunge pool and toe erosion by Siyar Nalla. To minimize the incidence of occurrence of landslide for the safeguard of the visiting tourists in the area some precautionary measures may be taken up like: construction of a concrete wall below the waterfall and along the bank of Siyar nalla adjoining the hill, by raising of a permanent railing about 25-30 meters in front of the waterfall, by constructing small check dams across the stream at the catchment area of the waterfall, gentle offloading of hanging mass, plugging of major crevices, rock bolting and raising of Rockfall Protection Structures (RPS).***

Keywords: Siyar Baba, Waterfall, Himalaya, Rockfall, District, Reasi and Jammu & Kashmir

1. Introduction

The States and Union Territories in the Himalayan region are familiar with the adverse impact of extreme events like excessive rainfall, snowfall which leads to occurrence of flash floods, landslides, Rockfalls, debris flow, subsidence, avalanches, etc. in the shape of disasters. Among them the Jammu and Kashmir UT is most susceptible to occurrence of landslide/Rock fall/subsidence/ avalanches since it is located in the young mountain ranges of North Western Himalayas. It has been grouped in the seismic zones IV and V by the Seismology Division, Government of India, New Delhi. The landslide occurrences in an area mainly depends upon its Structural Manifestations, Lithological set up, Geomorphology, Drainage, Vegetation, Topography, besides Water regime. The Water among other stated factors alone plays significant role in triggering landslides. Most failure of the rock slopes are related to planner weakness with unfavourable orientation. Landslide/Rockfall occurs when the shear resistance of slope is exceeded by shear stress which causes downward displacement of rock debris along the slope. It may be slow or fast depending upon the variety of Geological characteristics and surrounding environment. Thus the landslides are understood by assessment of both the initial structure and the whole trigger process which have pivotal role in the origin of geological structures like folds, faults, joints, fractures, crevasses, springs, lakes, waterfalls besides so many other structural features which have an important role to depict the geological importance of a particular area from beauty as well as its development point of view.

The **Siyar Baba Waterfall area is** located in Reasi District of Union Territory (UT) of Jammu and Kashmir and was visited to study the occurrence and determine the causes of rockfall/landslide due to which casualty of more than 07 people took place. Waterfalls are the source of tourist attraction in many countries over the Globe and play major role to boost tourism Industry. In India, waterfalls are believed to be sacred and it is common faith that taking bath under waterfalls purifies one's body and soul. In Jammu and Kashmir there are some waterfalls such as Siyar Baba waterfall, District Reasi, Noori Chammb waterfall District Poonch, besides many more which has yet to be explored in interiors like Padder District Kishtwar, Bhaderwah, District Doda, Bani area of District Kathua, in Jammu region, besides interiors of Kashmir Division and many virgin areas of UT of Laddakh. In Jammu Division Siyar Baba waterfall is one of the famous waterfall located at an altitude of around 570 m (top) on the Sirban/Great Limestone cliff in District Reasi (Fig- 1). It has been categorized the status of one of the largest waterfall of Northern India having height more than 100 m (top to bottom). It has religious importance since a large number of devotees visit there for paying obeisance to the ancient Idol of Siyar Baba in the temple adjacent to the waterfall. It is belief of the devotees and the tourists that the water of the waterfall has medicinal characteristics. It is well understood that the origin of the waterfalls takes places along the fault plane i.e. weaker plane of the rocks in an area where chances of occurrence of landslide/rockfall are expected to large extent. It is to mention that the District Administration Reasi conveyed to the Department of Geology and Mining regarding the incident of landslide/ Rockfall which took place at Siyar Baba waterfall on 15th July 2018 where a huge block of rock mass fell down over the tourists and devotes taking holy dip and claimed 07 precious lives. It is to mention that intermittent incident of occurrence of Landslides/Rockfalls

have also been reported at the Siyar Baba waterfall earlier causing loss to mankind.

2. Location and Approach

The area under investigation is depicted in Survey of India Toposheet No: 43 K/16 and is bounded between Latitude N 33^0 06' 30" to N 33^0 07' 45" and Longitude E 74^0 46' 08" to E 74^0 47' 30". It is located about three km away from Reasi – Pouni National Highway - 144 and is adjoining Salal Dam Road (Fig. 2). The area lies on the right bank of the mighty Chenab River near Talwara Town of Reasi District and is about 90 km away from Jammu which is easily approachable by all-weather Jammu- Reasi-Pouni National Highway-144 and also via Jammu- Bhamla-Pouni-Reasi an all-weather road.

Figure 1: Panoramic view of the Siyar Baba Waterfall, District Reasi, UT of Jammu and Kashmir.

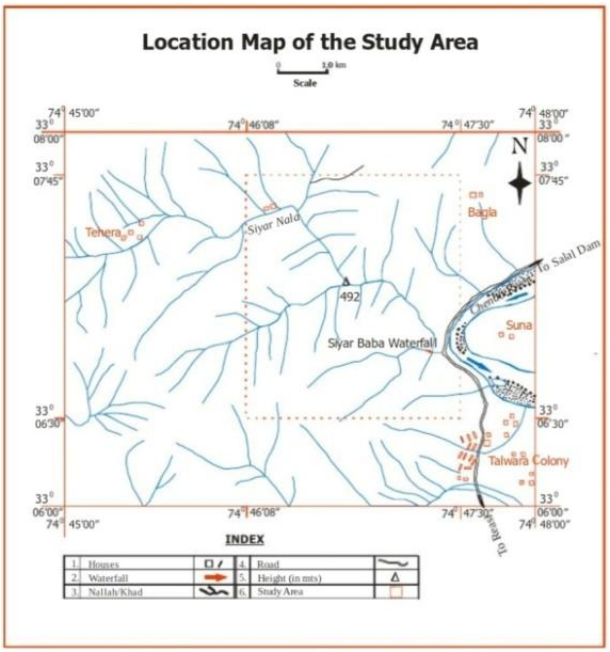

Figure 2: Location map of Study area, showing location of waterfall and drainage pattern

Topography, Vegetation, Climate and Drainage:
The topography of the area under investigation is rugged, having moderate to low forest cover. The abrupt change in the elevation in the area under study have been noticed wherein a number of well-defined ridges dissected by deep narrow ravines, (Fig. 3). The prominent ridges present adjoining the study area are Bagla Dhar and Bida-Kundwara Dhar. Aggarwal and Bhattacharya (1981) classify this area into geomorphic unit of Structural Hills of High Relief. The Chenab River is the main source of drainage in the area which is confluenced by various perennial as well as seasonal nallas/khads forming dendritic type of drainage pattern wherein Siyar Nalla flowing NE-SW is among them which flows along the waterfall (Fig. 3). The affected area under study adjoining Siyar Baba waterfall experience hot summers whereas winters remains severe cold and sometimes the temperature even goes below zero degree centigrade. The area receives high rainfall during summer monsoon period whereas prolonged showers/drizzles take place in winters which play an effective role in triggering landslides and occurrence of Rockfall. Scarce to medium vegetation comprising of pine trees, thorny bushes and green grass have also been noticed in and around the area under study during the field visit.

Figure 3: Satellite view of the Siyar Baba Waterfall area depicting Waterfall, Drainage System, High Peaks and Watershed area with enlarge view of waterfall (NTS).

General Geology of the area

The study area falls in the Reasi Foreland Thrust belt, which is comprised of Siwalik, Murrees and Subathu Group of rocks of Tertiary age besides the Sirban/Great Limestone of the Proterozoic Age. Sirban/Great Limestone and Siwaliks are two distinct Groups of Rocks exposed in and around the area under study where the Sirban/Great Limestone is unconformably overlain by Siwaliks near Talwara. The rocks of Subathu Formation, the Murree Group and the Siwalik Group are unconformably overlying the Precambrian Sirban/Great limestone. The base of the Subathu Formation is highly obscure and rarely exposed and where exposed, the rock rests unconformably on Pre-Tertiary formations (Bhandari and Aggrwal, 1966). The Sirban/Great Limestone in the area is part of Reasi inlier, the largest inlier in Jammu region; having length about 40 km and width about 12 km which extends from Chedai Muttal District Udhampur to Chapperwari village of District Reasi (Hakku et al., 2011) Singh et.al (2005) and Kumar (2020). It forms high ridges against the Siwalik foothills towards south and the Murrees towards north and west. The Sirban/Great Limestone is the Oldest Formation comprising mainly of cherty and non-cherty dolomitic limestone bands which are generally grey to creamy white in colour. At places the limestone is thick and massive in nature. The general strike of the beds is North East - South West dipping North West. Faults of variable geological characteristics have also been noticed in the area where deep gorges have been formed along the fault plane. The Sirban/Great limestone is highly jointed and fractured over which the Siyar Baba waterfall is located. Earlier workers like Wadia (1928,1931), Karunakaran & Ranga Rao (1979), Raiverman et al. (1994) has confirmed the presence of Main Boundary Fault (M.B.F) known as Reasi Thrust, passing through the Reasi near Talwara area. The rocks present in and around the area under study also exhibit generation of multiple folds. The limestone possess buggy, inter- and intra-granular, fracture, inter- and intra-layer porosities. The joints and fissures in the Sirban Limestone are penetrated by various dykes and irregular masses.

Geological set up in the area:

The Geological set up present in the area under study worked out by various researchers is given here under:

Group	Formation	Lithology	Age
	Alluvium	Clay, Silt, Sand, Pebbles and Boulders	Sub-Recent to Recent
Siwalik Group	Upper Siwalik	Sandstone, Mudstone, Pebble beds and Boulder, Conglomerate	Pliocene to Pleistocene
	Middle Siwalik	Sandstone with interbeded Mudstone	Late Miocene
	Lower Siwalik	Sandstone, mudstone, conglomerates with Red clay	Middle Miocene to Late Miocene
Murree Group	Upper Murree	Soft brown and buff sandstones, red and purple Shale/Mudstone with nodular Clays	Mid – Eocene to Early Miocene
	Lowe Murree	Fine grained, indurated and dark Sandstones, red and purple coloured splintery shale and Siltstone	
Subathu	--	Varigated shales with Coal and Nummulitic Limestone	Late Palaeocene to Middle Eocene
	Bauxite	Pisolitic to Non- Pisolitic Bauxite and Kaolinite	?
Sirban/Great Limestone		Cherty to non-cherty grey/ creamy white/pale dolomitic Limestone	Proterozoic

Alluvium comprised of boulder, cobbles, sand, silt and clay of Sub-Recent to Recent age have been noticed in the area under investigation. The rocks exposed at the site under study consists of Sirban/Great Limestone comprised of cherty to non-cherty limestone of grey to creamy white colour. Slate band has also been encountered in the area under investigation.

Structure:

The structural characteristics of the Sirban/Great limestone remains controversial and different opinion were given by earlier researchers like Middlemiss (1928) described Sirban/Great Limestone as dome, whereas Audan (1944) described it as synclinal Dome, Wadia (1937) described it as anticlinal structure. Gupta and Dhal (1962) were of the opinion that Sirban/Great limestone is a doubly plunging anticline faulted near the axis of fold. Gupta and Sharma (1978), Sharma (1985) and Pandita et. al. (2002) of Geology and Mining Department of J&K Government have also carried out work on the different aspects of Sirban/Great limestone deposit of Udhampur and Reasi District of Jammu Province. The authors have worked in the area under discussion which is located near the Main Boundary Fault (M.B.F) also called as Reasi Thrust and is one of the important Geological factors in aggravating the occurrence of landslides in the area which is evident by the presence of above specified structures besides joints, fractures, slickenside, etc. in the rocks. The general strike of the Sirban/Great limestone is North East to South West having dips due North and North West.

3. Observations and Discussion

Reconnaissance Survey was conducted in and around the affected area and various observations were made. Geologically the rock in the area under study is Sirban/Great Limestone forming a part of Reasi inlier, which consists of cherty/non-cherty, grey to creamy white and pale to brown flaggy, dolomitic limestone bands. The rocks exposed at site and adjoining waterfall have strike North East - South West with dips inside the hills having angle of inclination from 21^0 to 57^0 due North and North West. The dolomitic limestone in the area is affected by numerous fractures and joints (Fig. 4) with considerable orientation having moderate to wide fresh spacing between joints have been observed (Fig. 4&5). The orientation of the joints varies from few millimeters (mm) to centimeters where the dominant deformation has taken place. The rock has been shattered into small rhomb shaped fragments due to deformation by the impact of the nearby active Main Boundary Fault. (Fig. 5).

Figure 4: The joints in Sirban Limestone near the landslide having variable Orientation

Figure 5: The rocks shattered into small rhombs adjacent to the Siyar Baba waterfall.

Another landslide (slope failure) has occurred at about 80-100 m southeast of the Siyar Baba waterfall due to the wedge failure caused by the intersection of two set of joints. The one set of joints along the bedding plane whereas other one across to the bedding plane (Fig. 6 & 7). The occurrence of joints in the rocks present in the area may be due to the proximity of the Reasi Thrust (M.B.F) which passes near Talwara (Aggarwal and Bhattacharya 1981). The Reasi Thrust (M.B.F.) is the most significant from Geology point of view in the area and is neo-tectonically active (Auden 1944) and (Gansser 1964). Raha (1984) has identified a prominent joint plane dipping at 40^0 North East at up section just near the road linking Siyar Baba waterfall. Due to the proximity of the Main Boundary Fault (M. B. F.) the rocks are more susceptible to displacement/movement which is also considered one of the major causes of the occurrence of joints of variable orientation/spacing and condition.

Figure 6: A Landslide occurred earlier southeast of Siyar Baba Waterfall

Figure 7: Close view of the joints which have major role in triggering landslide

At the Siyar Baba waterfall a huge block of rock fell down from the cliff area of the top point of the waterfall on the Devotes/Tourists on 15th July, 2018 as narrated by the locals present at site during the visit. During the Reconnaissance Survey, the debris of the rock fall has not been witnessed at the point of fall as the same might have been removed during the rescue operation for the affected tourists at the time of incident whereas a fresh pile of scree has been seen at the base of waterfall (Fig. 8). At top most point of the waterfall two prominent depressions have been observed which indicate that the rock mass (Block) might have displaced recently which is evident by the presence of concave scars (Fig. 9). One depression adjacent to the waterfall appears fresh indicating that huge block of the rock may have fallen down on Devotes/Tourists taking bath. The role of unfavorable joints to weaken the rock at source with the influence of water seepage adjoining waterfall cannot be ruled out to trigger the movement of the rock mass. It is imperative to mention that the mineral content of the rocks having different thermal expansion coefficient respond differently with the impact of rainwater/surface water and temperature fluctuations on over saturation of the rocks present in the area of study.

Figure 8: A fresh rockfall (depicted by arrows) adjacent Siyar Baba waterfall.

Figure 9: Depressions created after fall/ displacement of the rock mass.

At the point source of waterfall along the left side a deep crevices has been observed pointing increase in its width upward where some plants have also been noticed (Fig. 10 a&b). The roots of the plants too have exerted pressure on the bed rock and played major role in origin of the joints/fractures. The rocks at the right side of the waterfall are also affected by joints as well as folding and at places weathered fragments have tumbled down from the cliff under the influence of gravity. The joints and crevices become deeper and wide due to surface weathering, pore pressure on oversaturation besides modification of weathered sediments by the fluvial action especially during flood season. Thus the wedges caused the rocks to fall due to the presence of the roots of the trees by exerting tremendous pressure to weaken the rock strength at source to displace from its place of deposition (Fig.10-a&b). The concentric as well as elongated depressions have developed in the rocks at the middle and lower part adjoining the waterfall from where limestone band has eroded due to the continuous expansion and contraction of the mineral present in the bed rock and existence of numerous joints/fractures. The joints are so deep which are clearly visible. The recession of point of waterfall is clearly depicting that the bed rock at the point of the waterfall either has been eroded or a block of it has been displaced which is evident by the geomorphic features at site (Fig. 10-a&b).

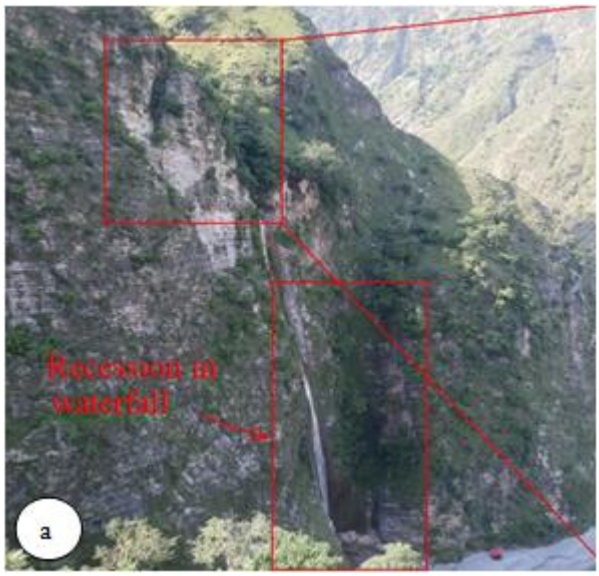

Figure 10 (a): A deep crevice developed at the left side of the waterfall widening upward due to growth of vegetation. The lower part shows waterfall area recede due to weathering and erosion.

Figure 10 (b): Enlarge view of the Crevice developed at site shown in figure 10-a.

The susceptibility of rock fall along the waterfall is due to the unfavorable pattern of joints and fractures where the flowing water and precipitation has also played effective role, since mass movement of rock debris is aggravated with the influence of flow of water. The percolation of water in fractures and joints in the bedrock can build up pore pressure which leads to its shattering and fall from cliff faces under the influence of gravity. The daily temperature fluctuations and extreme weather causes rock mass to become unstable because different minerals present in the rocks have different coefficients of thermal expansion. It plays key role to weaken the actual strength of the bed rock resulting in displacement of produced scree/blocks of the parent rock. The steam spray generated due to waterfall from such a height is full of water vapours which will definitely affect the rocks and exert pore pressure in the rocks adjoining the waterfall resulting in occurrence of landslide and fall of rock debris/ huge block

The water released through the cascades does not fall straight. Initially it hits the rocks at top where it deflects towards right side and then has straight fall up to the base (Fig. 11). The rocks which come in spade of jet of waterfall are also subjected to erosion causing further displacement of sediments downward. The impact of falling blocks of rocks from the cliff to dislodge rocks adjoining the waterfall is clearly evident due to the presence of fresh depressions and scars at left side of the waterfall (Fig.11). Similarly the percolation of water in the jointed rocks in the watershed area also have important role in weakening them as there are many small springs located in the catchment area of the waterfall (Fig. 12) which are feeding water to the nalla/khad which is the main source of water in the origin of Siyar Baba Waterfall. The first order streams in the catchment area having high gradient have significant role in depositing huge sediments in the main nalla of waterfall.

Figure 11: Deflection in the waterfall and presence of depressions in the waterfall area

Figure 12: A spring located in the watershed area of Siyar Baba waterfall

The first order streams are comparatively broad at its origin but as it flows down, the gradient as well as size of rock boulders along with the width of the nalla decreases which is depositing pebbles, grit, sand and silt/clay as small braided bars and natural levees (Fig.13&14). The deposited material is further modified during floods in rainy season which is either eroded or a part of that is deposited at point source of the waterfall. By the passage of time it is either eroded gradually by the nalla water or deposited at the waterfall point and due to impact of Neo-tectonisim suddenly falls

down since the area under study is still active due to impact of the nearby main boundary fault. The first order streams at such topography having high bed gradient have ability to carry abundant sediment load resulting in cutting of bed rocks into deep gorge and its banks since streams have a tendency to carry sediments ranging from clay, silt, pebbles, cobbles, or even boulders which may erode stream beds resulting in the deepening of stream channel and scouring of the rock bands located on the banks of nalla.

It is imperative to mention here that the water velocity increases in the nalla as it approaches source point of waterfall which also escalates the erosion of the deposited rock debris by weathering of eroded material during the period when flow remains very low. Due to which deep gorges in three steps (cascades) have been formed just above the main water fall which is about 2-3 meter wide and 3-5 meter deep followed by small plunge pools. The possibility of rolling of big boulders from the source with normal water flow is low but the possibility of movement of big boulders during the flash floods cannot be ignored.

The sediment as well as water topple over the waterfall creates a hollow beneath it categorized as plunge pool. The crashing flow of the water may also create powerful whirlpools which has a great role to erode the rocks of the plunge pool beneath it. Sometimes it creates hollow, a cave-like structure known as "rock shelter". Eventually, the rocky ledge (called the outcropping) may tumble down, sending boulders into the stream bed and plunge pool below which causes the waterfall to "recede" upstream. The waterfall erosion process thus started again helps in breaking down the boulders of the former outcrops resulting in the recession of waterfall area (Fig. 10). The Siyar Nalla forms a meander at the base of waterfall causing erosion of the rocks adjoining waterfall as the tendency of rivers to erode outer bank at the meander and deposit the eroded sediments along the inner side and scouring of the rocks at the foot of waterfall by the Siyar Baba nalla is also one of the causes of occurrence of rock fall in the same.

Figure 13: Presence of boulders and cobbles in the nalla upstream of the Siyar Baba waterfall

Figure 14: Pebbles, Grit and Sand in the form of small braided bars levees upstream of the Siyar Baba Waterfall

4. Remedial Measures

The area under study is adjacent to the Main Boundary Fault (Reasi Thrust) and is tectonically active. There are some measures which may be helpful to minimize the occurrence of landslide in the area are given here under:

1) The rocks at the source, crest and adjoining the waterfall can be treated by adopting latest Engineering Techniques i.e. gentle offloading and plugging of major crevices.
2) The erosion created by jet of water at the base of waterfall and by Siyar Nalla along the right bank can be minimized by constructing a concrete wall below the waterfall and along the bank adjoining the hill.
3) Gravels and sand carried by the water increases erosion which causes the waterfall to carve deeper into bed rock as well as ridge above it. If small check dams are constructed at the catchment above the waterfall within the main nalla upstream at a specific interval and feeding channels near the confluence with main nalla can play effective role to restrict further transportation of the material from the source.
4) The Rockfall Protection Structures (RPS) can also be raised to reduce the risk of rock fall to an acceptable level but they cannot be relied upon to eliminate risk in complete. Regular check up to ensure their performance in accordance with the intended design is mandatory.
5) Rock Bolting is another viable option to control the fall of rocks which may be planned under the expert advice of Structural/Civil Engineers thereby reducing the risk of mishap in future.
6) A permanent railing may be raised about 25-30 meters in front of the waterfall and adjoining the right bank of Siyar Nalla for the safe guard o the tourists and devotees.
7) For bathing of the visitors/devotees a pool can be constructed at the left side of the Siyar Nalla near stairs which may be safe for taking bath and to attract more and more tourists and devotees.
8) The area may also be brought under the control of Shri Mata Vaishnoo Devi Shrine Board for its development and control since it is located in between Mata Vaisnoo Devi Caves at Katra and Shiv Khori caves of Lord

Shiva in the district Reasi as it may become one of the most important tourists hub.

9) The visitors should be made aware by putting sign board that the area adjacent to waterfall and hill side is not safe due to rock fall so avoid taking bath directly under the waterfall.
10) All the measures suggested above require periodical checkup and maintenance thereof to avoid occurrence of any such incident untoward in near future for the safe guard of the visiting tourists in the area.

5. Conclusion

On the basis of the observations made during the Geological Reconnaissance Survey of the affected area and perusal of the data recorded, it has been concluded that the rocks present in area belong to Sirban/Great Limestone of Proterozoic Age which are fractured and highly jointed which may be due to the proximity of the area to Reasi Thrust (M.B.F). The surface as well as rainwater percolation in the joints and fractures exert pore water pressure which plays crucial role to weaken the rocks. The minerals present in the rocks having differential thermal expansion coefficients exert internal pressure on the rock units which leads to breakdown and fall or slide down of rock debris/material under the influence of gravity leading to occurrence of landslide and rockfall. The toe cutting by falling water at the plunge pool and by Siyar Nalla has also played a pivotal role in triggering of the landslide/rockfall. Keeping all the factors in consideration the area in and around the Siyar Baba Waterfall is prone to rockfall/landslide and will be safe for tourists only after accomplishment of the remedial measures suggested above.

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