Chapter

Risks of Glaciers Lakes Outburst Flood along China Pakistan Economic Corridor

Muhammad Saifullah, Shiyin Liu, Muhammad Adnan, Muhammad Ashraf, Muhammad Zaman, Sarfraz Hashim and Sher Muhammad

Abstract

The China-Pakistan Economic Corridor (CPEC) passes through the Hunza River basin of Pakistan. The current study investigates the creation and effects of end moraine, supra-glacial, and barrier lakes by field visits and remote sensing techniques along the CPEC in the Hunza River basin. The surging and moraine type glaciers are considered the most dangerous type of glaciers that cause Glacial Lake Outburst Floods (GLOFs) in the study basin. It can be concluded from the 40 years observations of Karakoram glaciers that surge-type and non-surge-type glaciers are not significantly different with respect to mass change. The recurrent surging of Khurdopin Glacier resulted in the creation of Khurdopin Glacial Lake in the Shimshal valley of the Hunza River basin. Such glacial lakes offer main sources of freshwater; however, when their dams are suddenly breached and water drained, catastrophic GLOFs appear and pose a great threat to people and infrastructure in downstream areas. This situation calls for an in-depth study on GLOF risks along the CPEC route and incorporation of GLOF for future policy formulation in the country for the CPEC project so that the government may take serious action for prevention, response to GLOFs, and rehabilitation and reconstruction of the areas.

Keywords: glaciers, GLOF, CPEC, climate change, lakes

1. Introduction

The high altitudes of the China Pakistan Economic Corridor (CPEC) region encompass glaciers as frozen reserves of water which act as an important natural resource by supplying fresh water to millions of people living the mountainous and downstream areas. The water released from the glaciers acts as a perennial source for most of the Himalayan Rivers [1]. The rivers and streams originating from these glaciers not only serve as power generation from hydroelectric power plants but also irrigate the agricultural lands in the command area during summer and also provide water for industrial purposes. Like this, these glaciers control the socio-economic activity in this part of the CPEC region. Therefore, the meltwater from the snow and glaciered region is of high importance for the runoff in the Indus River [2]. There is a lack of exact facts and figures about the exact contribution of flow in the region

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due to rugged mountains and the limited data availability because there is a highly different precipitation rate due to the settings and steep topography. Similarly, there are extremely different ablation rates due to aspect and variable debris cover on the glaciers. However, an extensive field study was conducted by the Snow and Ice Hydrology Project (SIHP) of Water and Power Development Authority (WAPDA) with the collaboration of Canadian University during the 1980s. It was reported that the maximum precipitation occurs at the elevation of 4500–5100 m.a.s.l. Moreover, Hewitt [3] reported that about 80% of flows in the Upper Indus River derives from the glaciered region above 3500 m.a.s.l. Recently, researchers have tried to assess the spatial distribution of precipitation by inversely inference of precipitation for glacier mass balance [4] snow cover variation [1, 5] using remote sensing data, Geographical Information System (GIS) techniques, and runoff modeling approaches. Adnan et al. [5] reported that the expansion in snow cover in the Hunza River could be attributed to the surge activities in the basin. Many researchers [6–10] have reported the surge events in the region. Studies on glaciers also indicate the slightly reduced mass balance in the region. However, most of the glaciers have gained the mass in the nourishment zone and loss in the ablation zone. These findings suggest the increase in the slopes of the glacier that could cause increased glacier velocities and the probable advance of glaciers in the future. However, in this chapter, we have presented the existence of glaciers and glacial lakes in the Hunza basin through which the CPEC route passes and is a heavily glaciered region. Many GLOF events and surges have been reported in the basin, especially, along the CPEC route. Moreover, glaciers are sensitive indicators of global climate change because they remain sensitive to global temperature conditions as specified by their continuous retreat which has been witnessed in many parts of the world including the Hindu-Kush Karakoram Himalaya (HKH) region especially CPEC route [9, 11]. After the industrial revolution, the rapid glaciers melting and its associated retreating trend left a major concern to the scientists and managers in the region. The substantial glaciers melting not only decrease the rivers discharge in the long run but also bring the high sediment load which causes flash floods in downstream areas and has a direct posture on the life of hydropower projects and socio-economic consequences for the local people and those living in downstream areas.

1.1 Glacial Lake Outburst Floods (GLOFs)

Terminal moraines and glacial lakes have been exposed in these high mountains as a result of surging, substantial melting, and retreating of glaciers. GLOFs have become a matter of concern for social and economic stability in the river valleys because of the rapid addition of meltwater in those glacial lakes adjacent to receding valley glaciers and may lead to sudden breaching of the unstable debris dam. Thus, it is very important to understand the state and fate of these glaciers and lakes as well for long-term development and planning in this region [12, 13].

During the last half-century, a large number of glacial lakes development have been witnessed in the CPEC region, and at the same time, several GLOFs have been reported, especially, in the eastern part of the CPEC region. Probably, remote glacial lakes are under risk and they may impact the downstream inhabitant as a result of GLOFs. These GLOFs may have devastating effects on the population as well as property and infrastructure [14–16].

The understanding that GLOFs can significantly surpass design floods of Hydropower Plant (HPP) under the threat of destruction or complete non-functionality is based on few case studies [17–19] but a clear picture of regional GLOF exposure remains vague. The previous glacial lake inventories to identify future GLOF sources have neglected their impacts on downstream areas [20]. However, hydrodynamic modeling may encounter such kinds of impacts but it requires a detailed analysis of high-resolution Digital Elevation Models (DEMs) and high computation facilities so that simulations of possible outbursts are existing for only a handful of lakes [12, 21, 22]. This research gap has been filled by linking a glacial lake inventory with both flood propagation and a dam-breach model to assess potential flood magnitudes for a sample of operating, planned, and currently built hydropower plant in the CPEC region [23–25].

Regional predictions of peak discharges as a result of GLOFs are difficult because of the unavailability of data on the geometry of glacial lakes and the moraine dams. The current field visit as well as different researchers provided an alternative solution to this problem and use the range of the simulated peak discharges at each HPP as a measure of uncertainty of GLOF exposure. For our flood propagation model, the volume and the resulting distributions of peak discharges for each lake have been used as the initial conditions during the field visit.

2. Hunza River basin

CPEC is in the interest of both the countries China and Pakistan; it will develop connectivity between west China and south China; and it is an integrated part of the "One Belt One Road" initiative policy. The establishments of China and Pakistan have agreed to complete the CPEC route from Kashgar (China) to Gwadar (Pakistan) by the end of 2030. The Chinese government is providing necessary support in terms of finance and logistics to build the infrastructure along the CPEC route. The CPEC is not only important for both the countries but also will prove beneficial for the surrounding countries. This project will strengthen the economic growth of Pakistan and it is the right initiative for both the countries. This corridor is considered a sign of peace, prosperity, and development. Even though this economic corridor is challenging but it will open new horizons of development in the future for both the countries. In the past, the lack of the right decision and insufficient opportunities have always remained a hurdle in the way of Pakistani peoples but CPEC will have transformational impacts on the state and the prosperity Pakistani nationals. The Chinese president Xi's visit in April 2015 and the announcement of $46 billion-plus for various CPEC projects drew the world's attention to this region because new development and growth of the economy will benefit both of the countries under the umbrella of this economic corridor. In the meeting called by the Prime Minister of Pakistan, all political parties have supported the CPEC and project and warmly welcomed the Chinese investment. This project will bring a revolution in the lives of over 3 billion people in this region. It will improve the strategic and economic location of Pakistan through trade and investment and exploration of mineral resources. Alternatively, according to China's perspective, this is a "flagship project" because it provides the shortest route to the Middle East, Africa, and Europe, which will boost up its economy. This corridor is passing through the Northern part of Pakistan.

The northern part of Pakistan is mostly consisting of a mountainous region, which is rich in glaciers and glacial lakes. The source of water in the river is glacier melting and rainfall. The population living downstream is under high risk due to the melting of glaciers and GLOFs [26–28]. International Center for Integrated Mountain Development (ICIMOD's) published an inventory in 2005, which comprised of 2420 glacial lakes in 10 major river basins of Hindukush Karakoram Himalayan Region of Pakistan [29]. The different river basins have glacial lakes such as Gilgit (614), Indus (574), Swat (255) Shingo (238), and Hunza (110). The Gilgit River basin comprised of 614 glacial lakes and 380 lakes out of 614 were identified

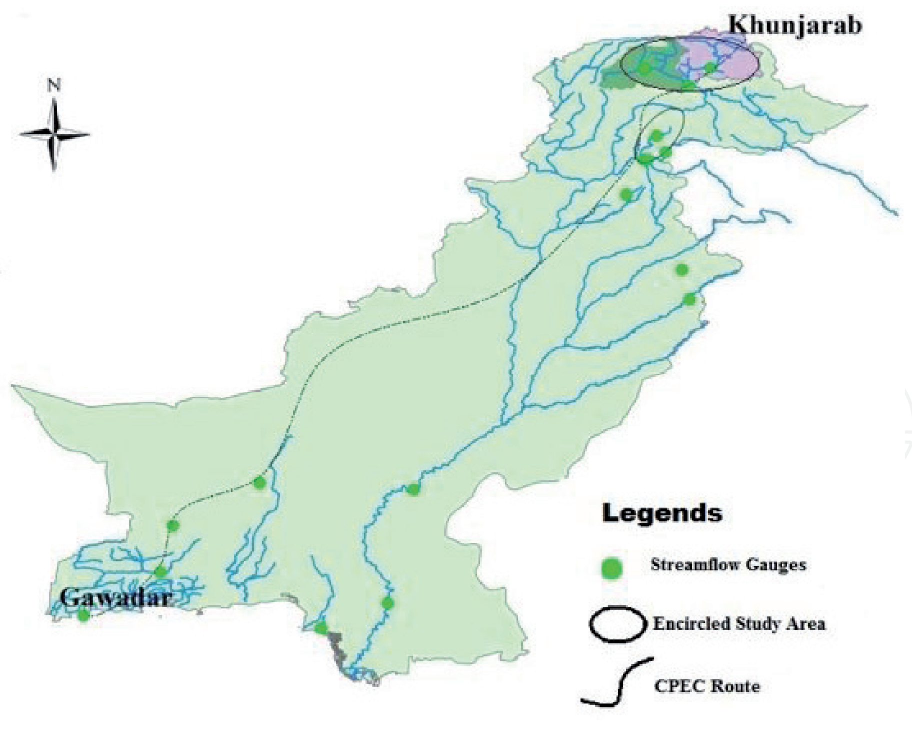

Figure 1.
Study area of China Pakistan economic corridor.

as major lakes, which contribute 62% of the total lakes. These major lakes form 93% of the lake area of the basin. New glacial lakes also formed due to glaciers thinning and retreating of this region. These lakes are categorized according to risk, 52 glacial lakes identified in this region. Passu lake has experienced historical GLOF events, which lie in the Hunza River basin [6]. The location of Passu lake is 38 km away and directed to the East-West of Passu glacier in the HKH region (**Figure 1**). The climate of Hunza is moderate, which have minimum and maximum temperature of 16 and 35.9°C, respectively. The annual average rainfall in this region is 136.2 mm with a minimum (2.1 mm) and maximum (283.2 mm) in November and April, respectively [30].

3. Materials and methods

3.1 Glaciers along CPEC route

The CPEC route passes through the Hunza River basin which is a glaciated region of Gilgit Baltistan. The route starts from China to Pakistan through the Sost border which lies in the Hunza River basin. Approximately, 28% of the Hunza basin area is covered by glaciers, and Passu, Batura, and Ghulkin are some known glaciers that exist along the CPEC route (**Table 1**), which have an established history of GLOF events. The Karakoram Highway and other roads in Shimshal and the Nagar River basins have been damaged many times because of GLOF events from the glaciers.

3.2 Assessment of GLOF using remote sensing data and GIS

Rugged mountain conditions make it difficult to investigate the glacial lakes for the whole region. However, the end moraine and the lakes in the blocked river valleys (e.g., Khurdopin glacial lake) were investigated with physical visits. However, the area's calculations and the causes of surging were made through remote sensing data and GIS

River basins	Glaciers			Glacial lakes		
	no.	Area (km^2)	Ice reserve (km^3)	No.	Area (km^2)	Potential danger
Swat	233	223.55	12.221	255	15.86	2
Chitral	542	1903.67	258.817	187	9.36	1
Gilgit	585	968.1	83.345	614	39.17	8
Hunza	1050	4677.34	808.794	110	3.21	1
Shigar	194	2240.08	581.27	54	1.09	0
Shyok	372	3547.84	891.8	66	2.68	6
Indus	1098	688	46.38	574	26.06	15
Shingo	172	36.91	1.009	238	11.59	5
Astore	588	607.03	47.931	126	5.52	9
Jhelum	384	148.18	6.943	196	11.78	5

Table 1.
Summary of glaciers, glaciers lakes, and potentially dangerous lakes in CPEC region [31].

techniques. The Landsat satellite images for May and June 2017 were downloaded from the website; http://earthexplorer.usgs.gov/ to explore the formation of newly developed lakes due to river blockage caused by the surging of Khurdopin glacier. The formation of the newly developed lakes was identified from the visual interpretation of the images in the ArcGIS tool, whereas Temporal Geodetic mass balance is employed to compute the vertical changes in glaciers by using remote sensing data of that region. The potential GLOF lakes were identified base on the following criteria and physical conditions [24]:

The rise in water level in glacial lakes, which creates the condition to breach the lake.

The lakes form on the glacial surface, which produces the combined effect with a group of lakes. It became potentially dangerous lakes.

The valley lake also becomes the potential GLOF lake due to short distance from mother glaciers tongue and the size of lake also plays an important role.

A lake several times breaches and damages the downstream. These types of lakes filled again and breach again.

The physical conditions of the surrounding of the lake also play a vital role to identify the potential dangerous glacial lake.

There is still no standard to identify the potential glacial lakes. The above mention criteria and condition decide the potential dangerous glacial lakes.

3.3 Field investigations for GLOF events

Remote sensing and field investigations are two basic methodologies used to assess the GLOF events (**Table 2**) and their credible effects. The number of glacial lakes, their areas, and geodetic mass balance for surging glaciers have been estimated through remote sensing techniques; whereas, field investigations help to assess the severity of the GLOF event. Moreover, the possible disaster from the potential hazard lake can be investigated through field investigations in terms of barrier strength, discharge conditions, and depth of the lake.

Pakistan Snow and Ice Hydrology Project (PSIHP) of WAPDA in collaboration with a Canadian University studied the Khurdopin glacier for precipitation input. They also did field visit of Batura glacier and Passu lake through the collaboration of Joint Venture of National Science Foundation of China, under the umbrella of the institute of international Rivers and Eco-security, Yunnan University,

Year	Event date	Glacier	River	Influencing factors
1973	—	Batura	Hunza	—
1974	—	Batura	Hunza	—
1977	—	Balt Bare	Hunza	—
1978	September	Darkot/Barados	Gilgit	—
1994	July	Sosot/Gupis lake	Gilgit	—
1999	6 August	Khalti/Gupis	Gilgit	Moonsoon rainfall
2000	10 June	Shimshal	Hunza	High temperature
2000	27 July	Kand/Hushe	Indus	Moonsoon rainfall
2005	July	Sosot/Gupis lake	Gilgit	
2007	5 April	Ghulkin	Hunza	Western disturbance
2008	6 January	Passu	Hunza	Western disturbance
2008	2 April	Ghulkin	Hunza	Western disturbance
2008	22 May	Ghulkin	Hunza	Persistent rainfall
2008	24 May	Ghulkin	Hunza	Persistent rainfall
2008	14/15 June	Ghulkin	Hunza	Heat wave
2009	26 March	Ghulkin	Hunza	Western disturbance
2018	17 July	Barsuwat glacier	Immit	Heat wave
2019	23 June	Shishper	Hunza	High temperature
2020	29 May	Shishper	Hunza	High temperature

Table 2.
History of major GLOF events in CPEC region.

Kunming, China, and ICIMOD. The remote sensing and field observations analysis of Khurdopin glacier provides up to date evidence about glacier surge and its possible impacts on the downstream populations because of the newly developed lake.

4. Results and discussion

4.1 GLOF events in Hunza basin

Glacial lakes formation depends on the type of glacier, its slope, and geological settings. For example, a supraglacial lake creates on the surface of glaciers when its slope is less than 2%. Similarly, surging glaciers block the river valley and cause the formation of the lake. Moreover, moraine-dammed lakes develop due to the advancement or recession of valley glaciers. Overall, these GLOF events depend on the physical and topographical conditions and the nature of damming materials. The severity of damages increases as the elevation and the volume of the glacial lakes increases. The type of moraine-dammed and the surging glaciers are the most dangerous types that block the valleys and cause GLOF events in the basin. In this regard, the type of GLOF event for the glaciers in the Hunza Basin is also not the same for example; Passu glacier caused damage due to outbursts of the end-moraine dammed lake, supra-glacial lake outburst occurred from Ghulkin and Hispar glaciers, valley blocked by Khurdopin glacier. GLOF from these glaciers bring rocks and the mudflows in the glacial streams, for example, significant mudflows released from Batura glacier.

4.2 GLOF events associated with surging of glaciers

The surging activities of the glaciers in the Hunza Basin have also been interpreted by earlier studies [14, 32, 33] from a stable or slightly increasing trend of snow cover for the Hunza River basin [1, 25]. It has been reported recurrent surges for several glaciers of the Hunza Basin [6]. For example, Bolch et al. [20] and Quincy and Luckman [34] have comprehensively reported the surge history of Khurdopin glacier. The glaciated area of Khurdopin glacier is 115 km^2 which is situated in Shimshal River, a tributary of the Hunza River. The first surge has been reported in 1979 and the second surge event occurred in 1999 and both surge events occurred in the summer season. The latest surge was observed during the summer season of 2017 [35]. These events suggest the return period of the surge event for Khurdopin glacier is about 20 years. No significant change has been observed in the debris cover Hispar and Shimshal glaciers of the Hunza basin for the period of 1977–2014 [36]. It was determined that this might be due to balanced glacier budgets during this period. Type of glaciers and their areas are given in **Table 1**.

The surging of Khurdopin glacier has resulted in the formation of the medium-sized ice-dammed lake at an elevation of 3454 m a.s.l and it lies at latitude-longitude of 36°21′007″ N and 75°27′51.2″ in the Shimshal River valley of the Hunza basin. Khurdopin lake started to surge in the first week of May 2017 and it has been greatly expanded in terms of size and depth and it became vulnerable to breach as witnessed by the local people. Due to the short distance between the glacier and opposite hard mountain resulted in the rise of river bed and glacier as well as triggering the creation of Khurdopin lake. The velocity of the flow was reduced by the damming of water behind the barrier and this phenomenon also raised the river bed and blocked the river (**Figures 2** and **3**).

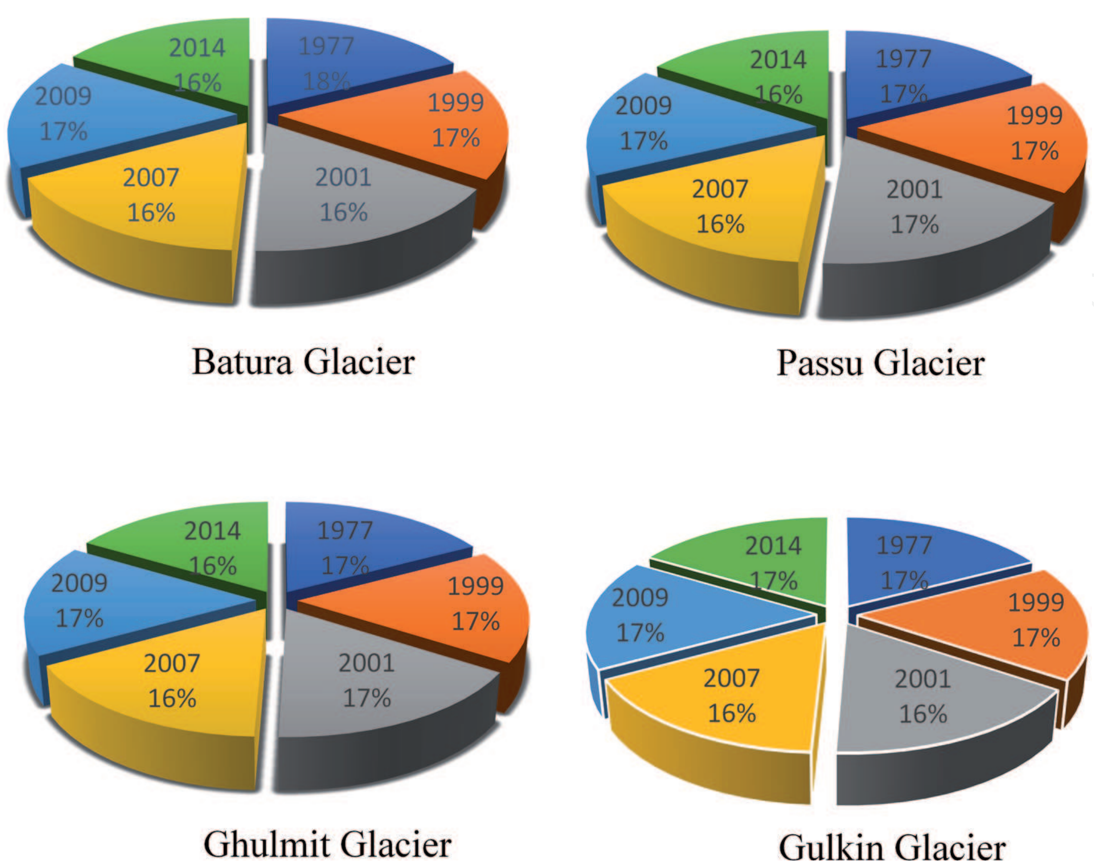

Figure 2.
Comparison of different glaciers area loss during the period of 1977–2014.

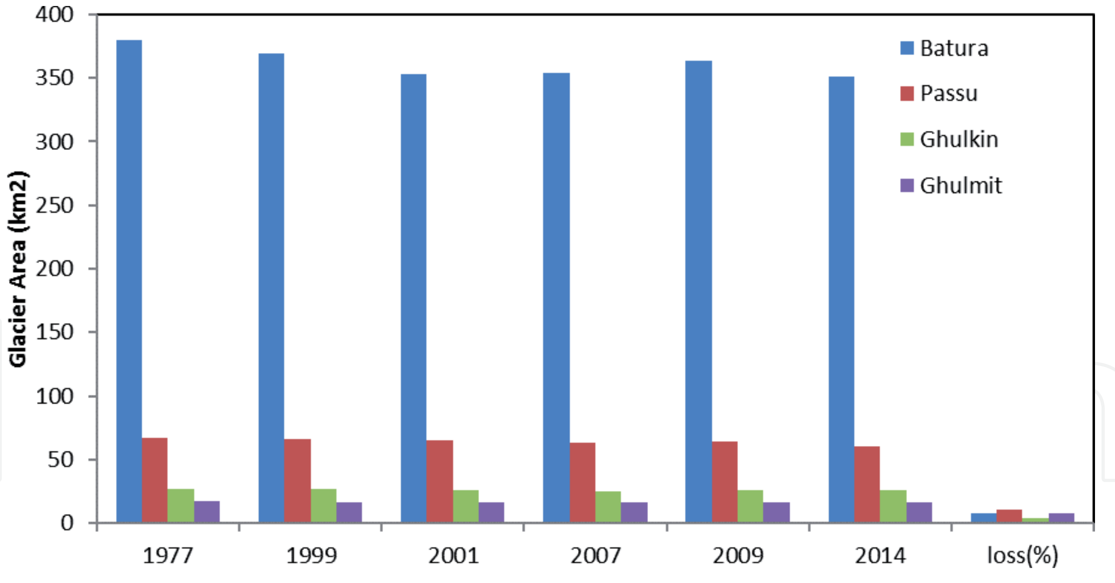

Figure 3.
Temporal variation in areas of different glaciers along CPEC.

The glacier areas of different glaciers were compared, which mostly thinned in terms of area or remain constant during the different periods. The area of Batura glacier was 380 km^2 in 1977 as compared to 351 km^2 in 2014, respectively. The loss of the area was 7.63% during this period. However, the glacier area loss was observed about 4.69% between 1999 and 2014. The glacier area was reduced to 369 km^2 till 1999 and lost 2.89% of the glacier area as compared to 1977. The loss in glacier area was increased by up to 7% in 2014 as compared to 1999. The increment of a 4% loss in glacier area was due to an increase in temperature. During 2001 and 2007, the loss of glacier area was consistent, but it was observed 4.2% in 2009 as compared to 1977. Passu glacier area loss observed 10% from 1977 to 2014. The loss of the area was less than 1% for 1999 as compared to 1977. The rate of loss of the glacier area increased in 2001 and reached up to 3% but this rate reached up to 7% in 2007. The lake formation also fluctuated during this period. The number of GLOF and historical events was also observed during this period. Ghulkin glacier also lost its area up to 4% due to global warming from 1977 to 2014. Earlier 2000, Ghulkin glacier lost the area less than 1.5%. After 2 years, the loss of the glacier area was 6%. From 2001 to 2007, the melting of glacier and loss of its area remained constant but the rate of glacier area loss was reduced up to 4% in 2009. Ghulmit glacier lost its area about less than 2% before 2000. The loss of the glacier area in 2001 was 4% but it increased up to 5% in 2007. This glacier area was reduced to 3% in 2009 as compared to 2007 (**Table 3**).

4.3 Drifting mechanism of glaciers

Due to differential movement of glaciers, crack or rift is produced in the glaciers having connected snout. A rift was formed along the left part of the Khurdopin glacier due to collapsing and crushing of glacier all together. The Yukshin Girdan glacier played a role of strong obstruction, produced massive frictional forces, and initiated the glacier ice to break down at the rift area into pieces of ice bergs that were seen floating on the newly formed lake. During this process, the Khurdopin glacier was forced by the Yukshin Girdan glacier to move toward the right side because of the unavailability of an obstacle to the opposite mountain. The elevation of the glacier at the rift area was about 3558 m a.s.l. The glacier was covered by a huge amount of debris during 2015, and after this surge, the debris began to falling

Sr.#	Glacier name	Glacier type	Area (km^2)
1	Batura	Debris cover	236
2	Passu	Debris free	51
3	Barpu	Surge type	90
4	Hispar	Surge type Debris cover	345
5	Yazghil	Debris cover	99
6	Khurdopin	Debris cover Surge type	115
7	Vijerab	Debris cover Surge type	113
Whole region			2868

Table 3.
List of selected glaciers and their types in Hunza basin [20].

and sliding into the crevasses and impacted the sub-glacial water movement and that may further result in the formulation of a new sub-glacial lake [25, 34].

The meltwater released from the Vijerab glacier was blocked by the Khurdopin glacier and it was muddy because of high sediment load coming from the glaciated area. A large amount of water was flowing through the newly developed crevasses due to the presence of barriers and ultimately outflowing through the cave type snout of Khurdopin glacier. The phenomenon of ice block falling in the stream of Vijerab glacier and on the supra-glacial lakes was also perceived. Because of surging effects, glacier deforms and results in the formation of huge crevasses. Three main types of crevasses developed in Khurdopin glacier are listed below: irregular crevasses, longitudinal crevasses, and transverse crevasses. Due to the demolishing action of glaciers, most of the crevasses were found to be irregular in shapes. Due to glacier advancement, large numbers of crevasses were developed all over the glacier. The width of the crevasses was variable at different locations and mostly, it ranged between 1 and 2.0 m [20, 35].

4.4 Geodetic mass balance of surging glaciers

The heterogeneous behavior and close-to balanced budgets are not a recent phenomenon in Hunza Valley (Karakoram). We have observed that the geodetic mass budgets computed from the 1973 KH-9 and 2009 ASTER DTMs are in covenant with the results of the individual periods 1973–1999 and 1999–2009 without indefinite radar penetration correction: since the 1970s, the glaciers in this region underwent slight and insignificant mass loss. Though, the differences may exist in individual glaciers for the two studied periods. Overall, we can confirm that the surge-type and non-surge-type glaciers are not significantly different with respect to mass change inferred from the 40 years observations of glaciers in the Karakoram (**Figure 4**).

One can easily assess the flood damages from recently developed lakes if it bursts based on watermarks of previous flood events. Besides, the bursting mechanism and the volume of flood events can give us an insight into the damages in the downstream areas. The water level in the lake can provide us information about the GLOF impacts on downstream infrastructure. The GLOF will have devastating impacts on the infrastructure including homes, lands, schools, etc. The settlement along the river site could be adversely affected as a result of GLOF (**Figure 5**).

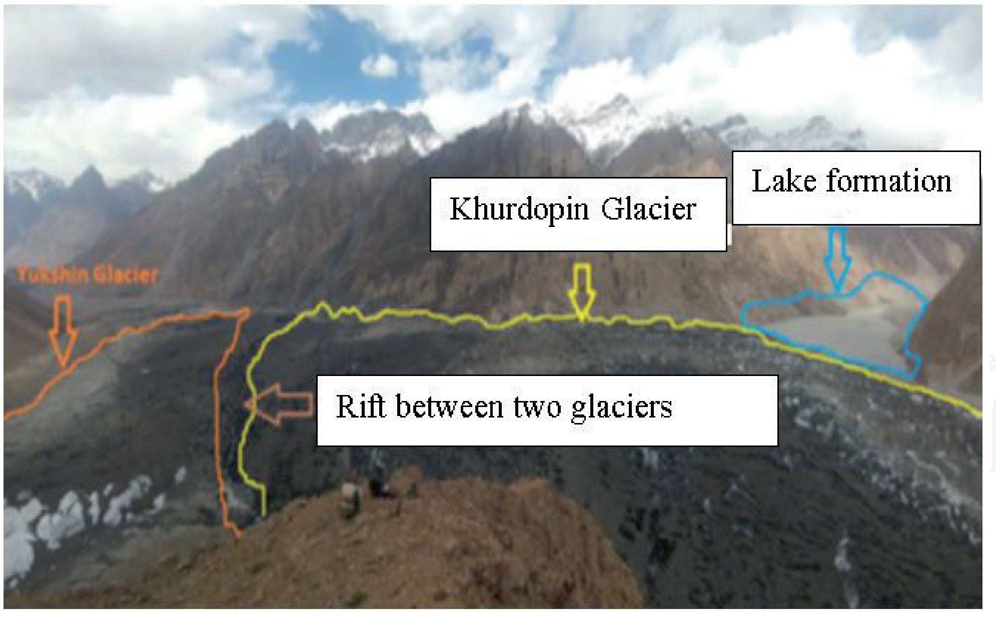

Figure 4.
Khurdopin Glacial Lake formation.

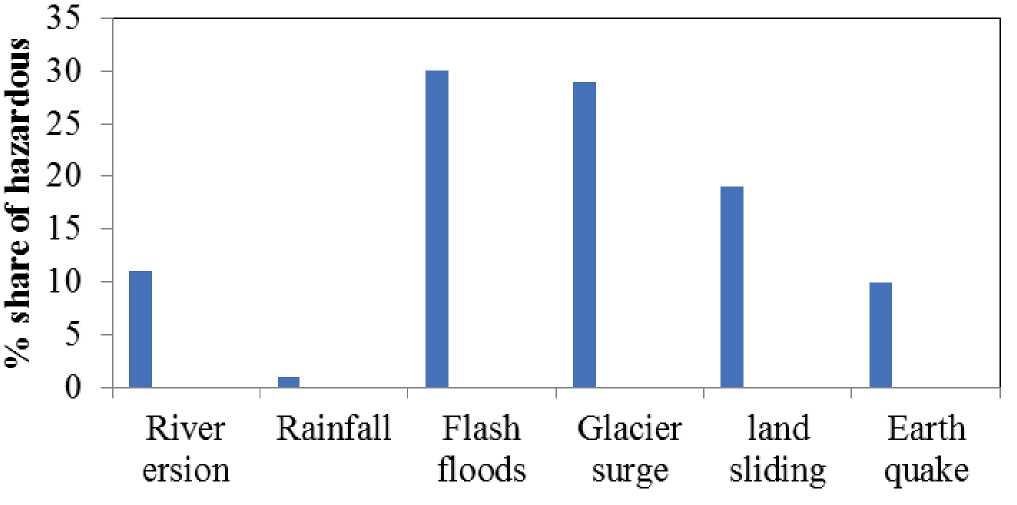

Figure 5.
Contribution of hazardous share in different glaciers along CPEC.

4.5 GLOF events associated with end-moraine dammed lakes

During 2001, the total numbers of lakes in Gilgit were 614. The total area of these lakes was 39.2 km^2. Out of 614 lakes, 380 were major and 8 were potential GLOF lakes. There were 110 glacial lakes in the Hunza basin, which have a total area of 3.2 km^2. Out of 47 glacial lakes, only one lake was potential GLOF, that is, Passu lake which has a potential threat to CPEC (**Figures 6** and 7). In the past, this lake had busted many times during the flooding period as given in **Table 2** and **Figures 6** and 7.

Amongst the end moraine dammed lakes of Hunza Basin, six were identified as potentially hazardous lakes for the CPEC route (**Figures 6** and 7). The major lakes were valley type and superglacial lakes. Passu lake was observed as a hazardous lake, which is near to Passu glacier. The surface area of this lake was 0.12 km^2, length 26 km, and thickness of about 173 m. The population of the Ghulkin, Hussaini, and Passu villages are 1133, 621, and 863 persons, respectively. During the July 2007 and April 2008, heavy flooding occurred, this damaged the CPEC route.

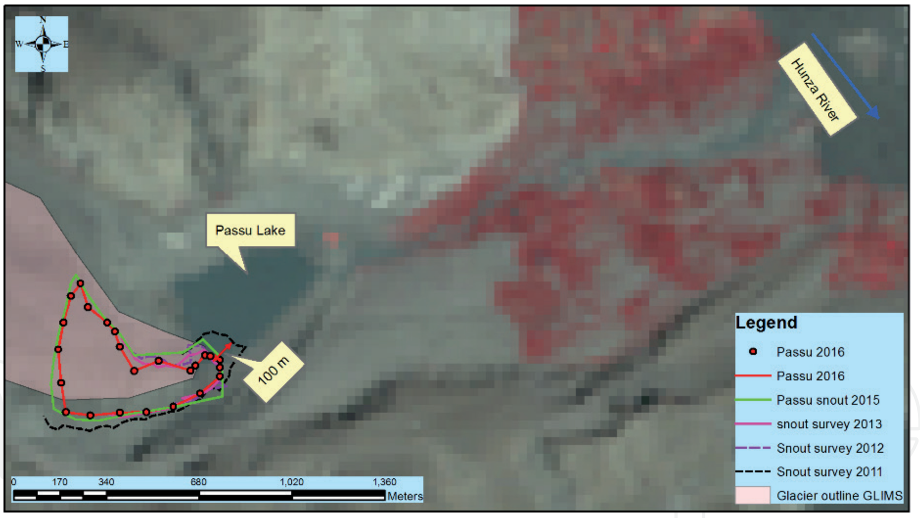

Figure 6.
Retreat of Passu glacier caused expansion in the glacial lake.

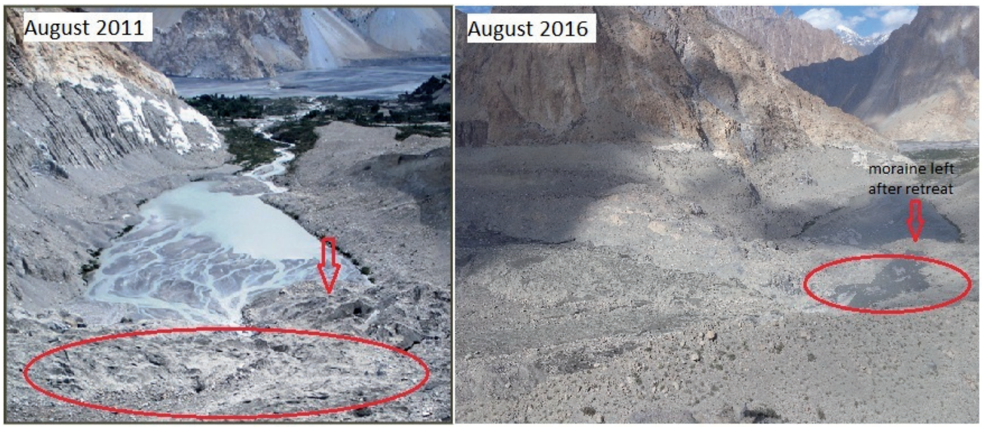

Figure 7.
View of the Passu glacier during 2011 and 2016 shows the expansion in lake area.

Basin	Number of lakes	Lake area	Major lakes	GLOF lakes
Gilgit	614	39.17	380	8
Hunza	110	3.22	47	1

Table 4.
Summary of glacial lakes in two major glaciered river basins along CPEC [20].

In July 2007, the lake was outburst with heavy flooding and another event was observed in April 2008. These events damaged the Karakoram Highway, hotels, and houses of the Passu village. This lake was breached several times in the past. Passu village is under high risk due to GLOF of this lake. There is a need to install the proper monitoring system to reduce the risks of glacier lakes outburst as well as local community protection in the downstream area (**Table 4**).

Although this lake is hazardous for the nearby communities of the Passu village and after the creation of a large land-slide dammed lake (Attabad lake) at Attabad during February 2010, the villages along Hunza River up to Gilgit and downstream became highly vulnerable of GLOF hazard. Early warning systems and proper monitoring can reduce the risk of damage to the CPEC route, infrastructures, and community. The different lakes of Gilgit have different rates of expansion such as 1.2, 0.4, and 0.3 ha/year during 2001 and 2013, respectively (**Figures 8–10**).

Figure 8.
Field observation of Passu glacier and lake.

Figure 9.
Impact of high flow of Batura glacier on CPEC bridge.

5. Conclusions

The rugged topography and remoteness of the study area is a hurdle in the way to study the detailed processes and reasons behind the creation of glacial lakes along the CPEC. However, remote sensing techniques along with field surveys helped us to study the remote lakes along the CPEC route in the Hunza River basin. It was inferred from the analysis that the glaciers and glacial lake dynamics are interconnected to each other. The glacial lake dynamics is a complex phenomenon along CPEC. Gradually, lake dynamics has increased the risks of vulnerability along CPEC. Many potential lakes in the study area have the capability to damage the infrastructures as well as routes. Several GLOF events have been reported, especially, in the eastern part of the CPEC region during the last 50 years. Recently, Shisper Glacier damaged

Figure 10.
(a) Shisper glacier and its recent impact on CPEC route; (b) view of Passu glacier and CPEC route alignment.

the CPEC route and blocked it (**Figure 10a**). In the same way, the repeated surging of Khurdopin and Passu glaciers also resulted in the formation of high altitude glacial lakes in the Hunza River basin. We found that the type of GLOF event for the glaciers in the Hunza River basin is not the same. The aerial expansion of these glacial lakes increased due to global warming. Several glaciers are retreating in this region; this retreating will result in reduced river flows which in turn will affect the available run-off for irrigation and power generation. Moreover, the history of Khurdopin glacier's surge events revealed that the thermal phenomenon causes these surges. Moreover, it was perceived that the Passu Glacial Lake expansion is due to the retreat of the glacier (**Figure 10b**). However, the structure of the glacier surface suggests that its advancement is due to an increase in slope. A maximum increase in lake area was observed below 3500 m elevation, exhibiting a situation favorable for water resource management. The climate and hydrodynamics also influence the glaciers and glacial lakes. The CPEC initiative will bring a revolution in the lives of over 3 billion people in this region. Being the shortest route to the Middle East, Africa and Europe, it will benefit all partner countries and will boost their economies. However, there is a need to study climate change impacts on glaciers dynamics and lakes formation in the vicinity of CPEC to secure the route from future vulnerabilities and disasters.

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Conflict of interest

There is no conflict of interest.

Author details

Muhammad Saifullah[1,2], Shiyin Liu[1*], Muhammad Adnan[1,3], Muhammad Ashraf[4], Muhammad Zaman[5], Sarfraz Hashim[2] and Sher Muhammad[6]

1 Institute of International Rivers and Eco-Security, Yunnan University, Kunming, China

2 Department of Agricultural Engineering, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan

3 State Key Laboratory of Cryospheric Science, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences (CAS), Lanzhou, China

4 Department of Agricultural Engineering, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan

5 Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan

6 International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal

*Address all correspondence to: shiyin.liu@ynu.edu.cn

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