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Climate change impact on glacier lakes in Panjshir province of Afghanistan

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ABSTRACT

The upper portion of the Panjshir River watershed consists of steep mountain valleys in the Hindu Kush mountain range, which reaches over 6,000 meters above sea level and remains snow covered throughout the year. The Glacier Lakes there pose a potential flood risk to the Panjshir valley. As the weather is warming globally, the increasing temperatures accelerate the melting rate of the glacier, causing the mountain ice caps to melt and create numerous lakes. Over the last decade, two of these lakes ruptured, leaving dozens of deaths, many hectares of land farm washed out, and hundreds of houses destroyed. This study looks at the potential impact of climate change on villagers in the province. Hydro-meteorological data (wind, temperature, precipitation, and runoff) from five meteorological stations over the last decade were analyzed with satellite imagery. Discharge data at the outlet of this sub-basin over ten years were also analyzed with remote sensing data for higher accuracy and validity. Rising regional climate temperatures have resulted in faster snow and glacier melting, causing more discharge, high evapotranspiration, and higher water demand. Although precipitation decreased between 2008 and 2018, discharge increased from melting glaciers. Satellite imagery reveals 234 lakes in the valley; 66 lakes have potential or high potential risk to the six districts of this province, and Paryan district is at most risk.

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1. Introduction

The climate change has caused a continuous glacier recession and emergence of glacial lakes behind the newly exposed unstable moraines in most of the glaciated regions of the world, two types of glacial lakes are recognized, (i) proglacial lakes and (ii) supraglacial lakes. The upper portion of the Panjshir River watershed consists of steep mountain valleys in the Hindu Kush mountain range, which reaches over 6,000 meters above sea level and remains snow covered throughout the year [1]. The proglacial lakes often grow downstream of steep glaciers, where water is collected behind former moraines [2]. In the context of global change, many glaciated areas below 5000m asl have been uncovered, his development bears multiple consequences, such as emerging hazards from unstable moraines, ice and rocks changes in erosion and sedimentation rates, as well as spatiotemporal alterations in both quantity and quality of mountain water resources. As a result of glacier shrinkage, many high mountain lakes are currently developing [3].

Glacier Lake Outburst Floods (GLOF) are worldwide threats in high plateau regions. In total, over 200 glacier lake outbursts have been recorded in the Alps [4]. In the Panjshir province of Afghanistan, a flash flood occurs every five years, leaving many casualties and losses in its wake. Recent investigations reveal these floods are GLOF; these floods produce a large amount of water that is out-of-control and strikes without warning. In 2018, another catastrophic flood caused by the failure of the Glacier Lakes dam smashed on the upper hills of the Pishghor valley destroying 500 houses, flooding hectares of arable land, and killing ten people. Floods damaged tracts of land, with associated impacts on agriculture and livestock farming. Transport has been affected by floods due to damage caused to roads, bridges, and associated infrastructure [5]. Lakes play a pivotal role as regulators, sentinels, and integrators of climate change, The glaciers act as a water storage tower and provide fresh water to almost 1 billion people in South and East Asia [6].

2. Case study

The economics and the livelihoods of most people living within Panshir, which is located within the Hindukush-Himalayan (HKH) countries are extremely water dependent, and agriculture accounts for nearly 90% of all water withdrawals [7], Panjshir province is located 120 km northeast of Kabul within the valley of the south Hindu Kush where the tributaries of the Panjshir River join the main stream. The elevation of the province is 1600 meters above sea level (asl), but the high plateau reaches 5200 m asl. The length of the valley from the Dalan Sang to Anjuman pass is 125 km. The Panjshir watershed plays a vital role in the surface runoff, and groundwater flows in the Kabul River Basin and supplies the desired water to downstream hydropower dams like Naghlu and Sorobi [8]. The Panjshir catchment area is around 3770 km^2 and located between 69.24°-70.03°E longitude and 35.07-35.89°N latitude. There are nine hydro-meteorological stations in this sub-basin for the data collection [1].

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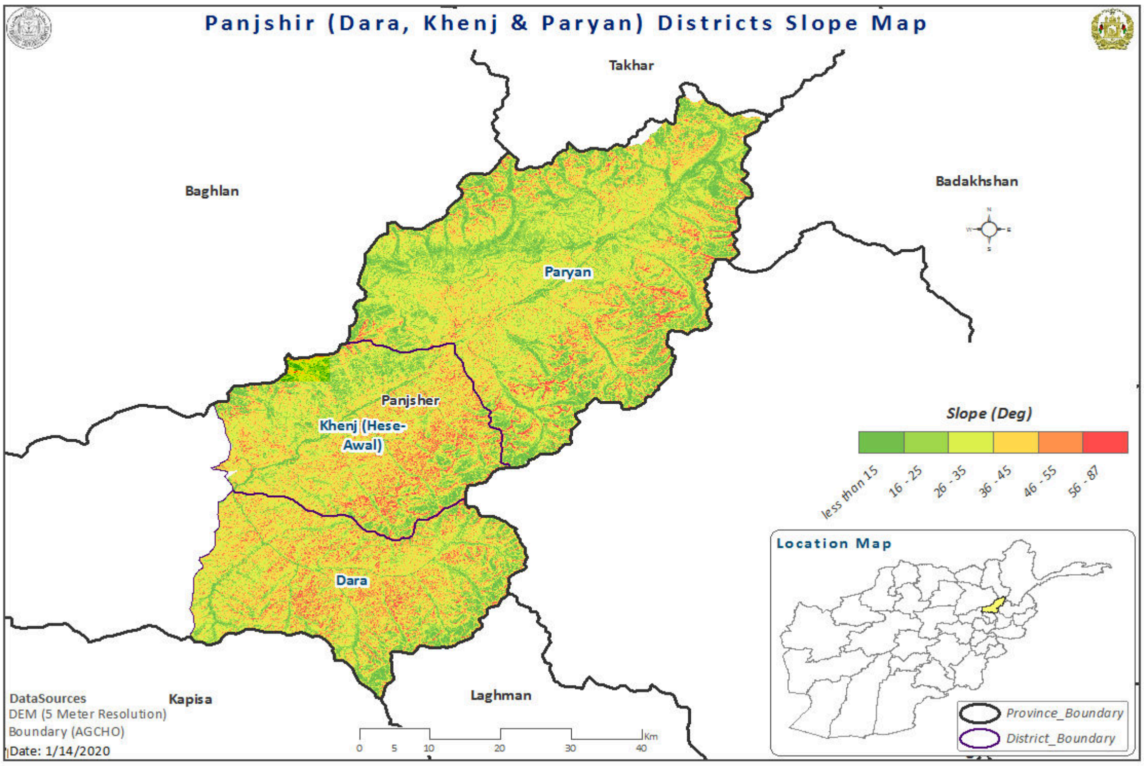

Figure 1. *Slope map Dara, Khenj, and Paryan Districts* [9].

Figure 1 shows the lowest slope in Panjshir Provence is less than 15 degrees, and the highest slope is between 56-87 degrees.

Table 1: Dara, Khinj and Parian district topography.

No.	Province Name	District Name	Area Sq-Km	Max Slope	Mean Slope	Min Elev	Mean Elev	Max Elev
1	Panjshir	Dara	711.69	84.57	33.28	2008.05	3726.33	5099.67
2	Panjshir	Parian	1419.31	86.56	28.79	2342.65	3956.07	5768.88
3	Panjshir	Khenj (Hes-e- Awal)	666.37	85.96	33.32	2005.99	3529.96	5066.10

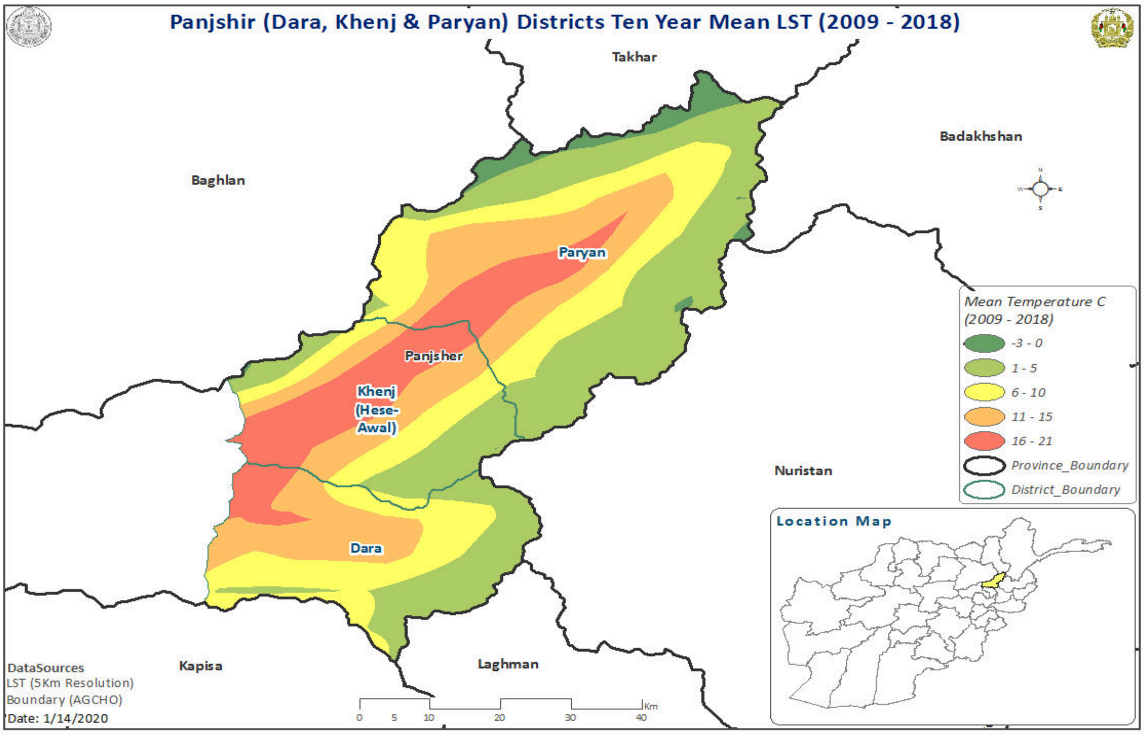

Figure 2. Mean land surface temperature (2009-2018).

Figure 2 shows the lowest mean temperature in Dara, Khenj, and Paryan is between 0 and -3 degrees and the highest about 16-22 degrees C.

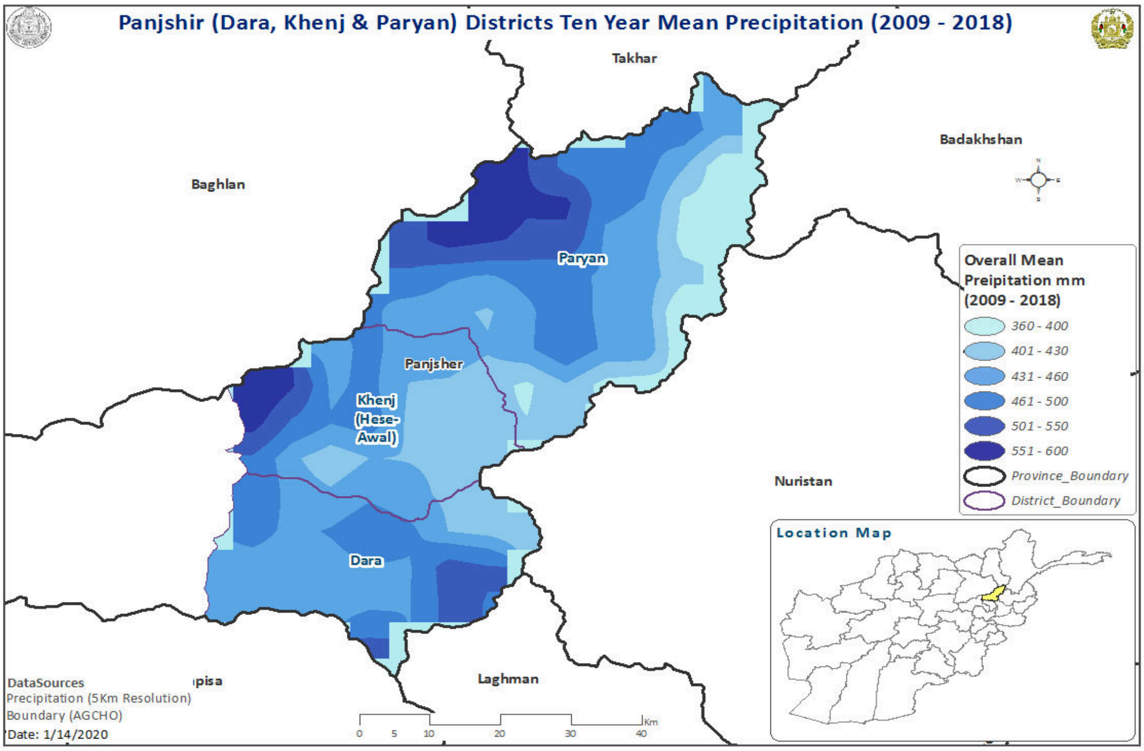

Figure 3. Mean Precipitation in Dara, Khenj, and Paryan (2009-2018).

Figure 3 shows the lowest mean precipitation in Dara, Khenj, and Paryan is 600-551 mm; the highest is about 360-400 mm.

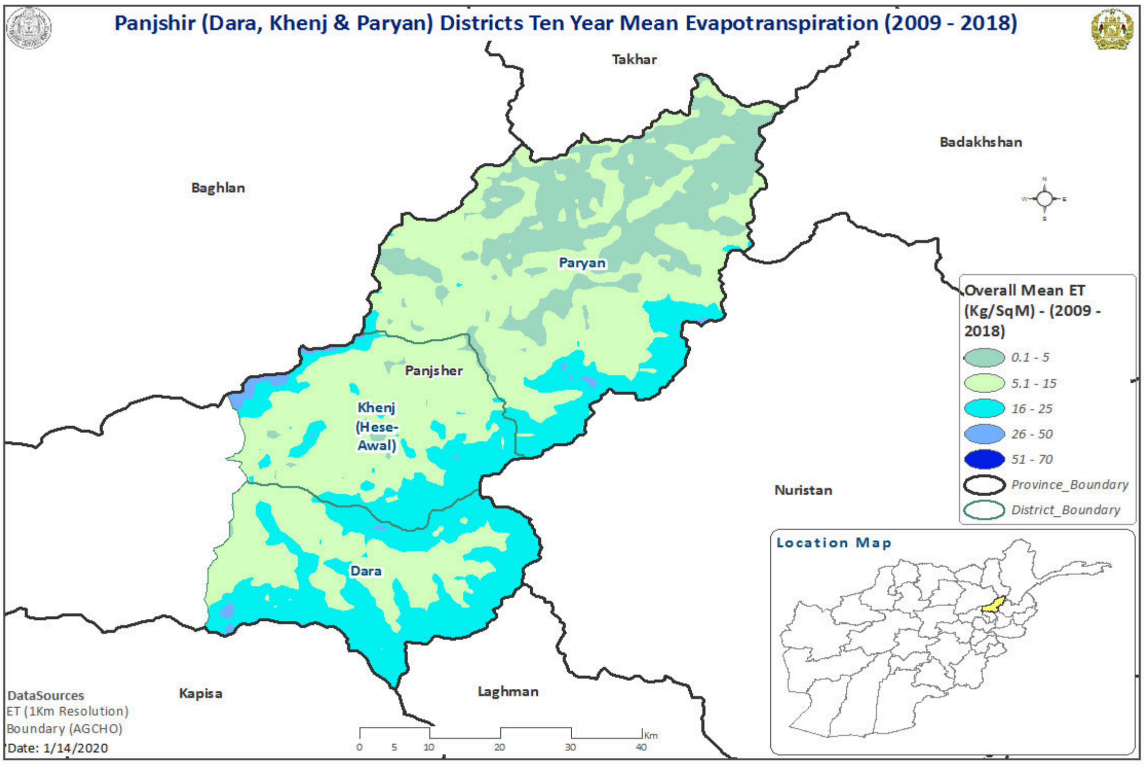

Figure 4. Mean evapotranspiration (2009-2018).

Figure 4 shows the lowest mean evapotranspiration in Dara, Khenj, and Paryan is 0.1-5 kg/Sqm; the highest is about 51-70 kg/Sqm. Data collection includes assessing sources, conducting surveys, and performing analyses. Since climate change is a global issue, it impacts every person, studying all aspects, would be complicated and time-consuming. We focus on the impact of GLOF in the study area.

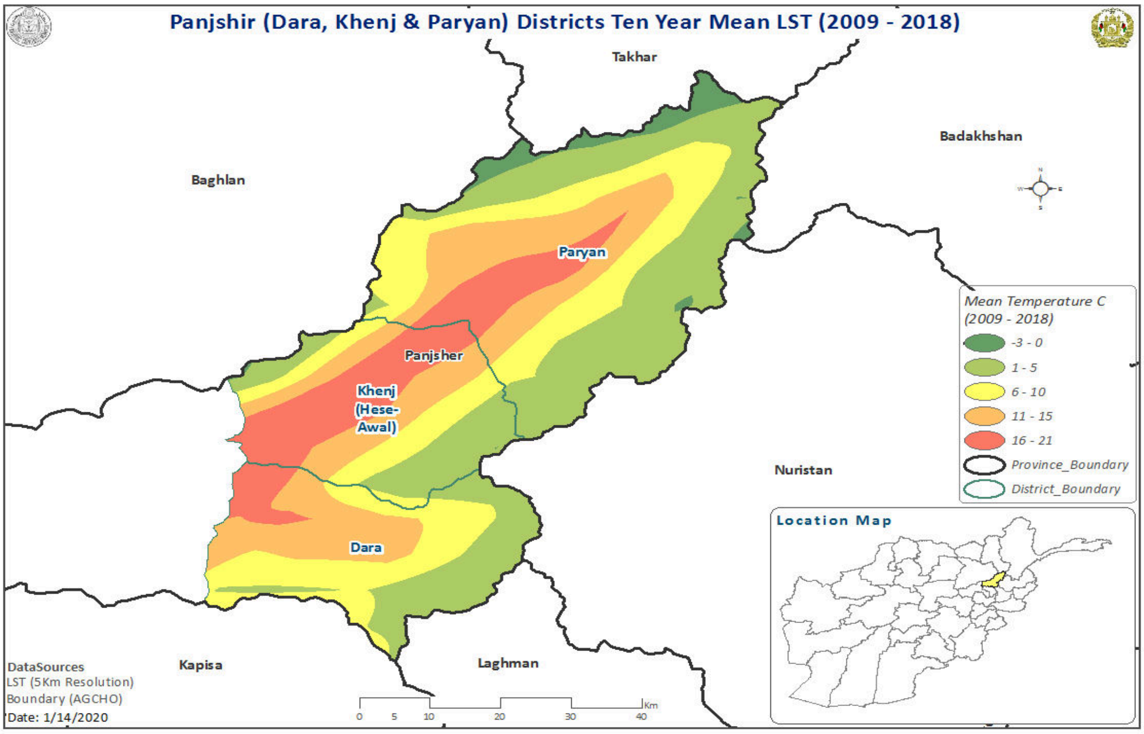

Figure 5. Mean land surface temperature (2009-2018).

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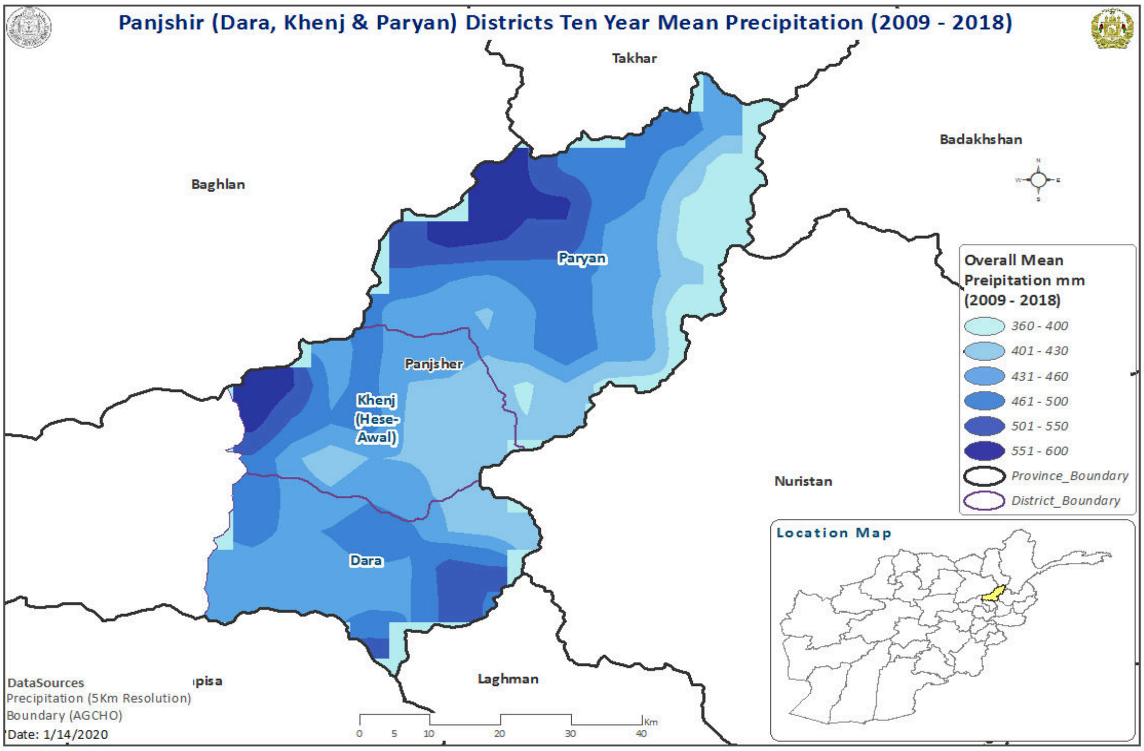

Figure 6. Mean Precipitation in Dara, Khenj, and Paryan (2009-2018)

Figure 3 shows the lowest mean precipitation in Dara, Khenj, and Paryan is 600-551 mm; the highest is about 360-400 mm.

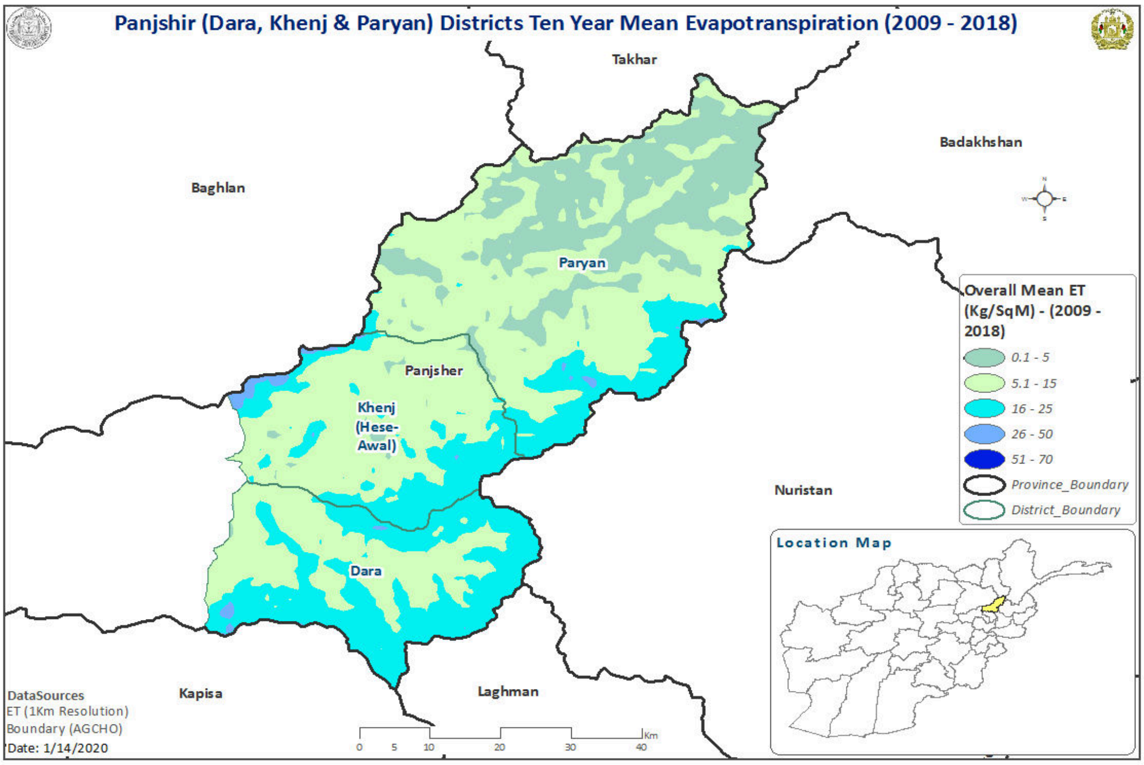

Figure 7. Mean Evapotranspiration (2009-2018).

Figure 4 shows the lowest mean evapotranspiration in Dara, Khenj, and Paryan is 0.1-5 kg/Sqm; the highest is about 51-70 kg/Sqm.

A literature search included books on floods, climate change, articles, websites, Google Earth, and aerial photos. The software was used for data collection, data managing, mapping, visualization, and data analysis like ArcGIS 10.7.1, ERSDAS Imagine 2020, GEE, PCI – Gematica 2019, and IBM SPSS 26.

The raw data of temperature and precipitation were organized and evaluated daily, monthly , and yearly. The maximum and minimum discharges are determined to draw the periodic hydrographs; the same procedure was applied to the temperature and precipitation and compared with graphs created by remote sensing tools.

3. Result and discussion

The mean annual GLOF rate in the Himalayas and its seven subregions from remote sensing-based analyses covering the past three decades is 23-45 [10]. Data from the automatic weather stations installed in the Panjshir Valley (Tang-i-Gulbahar, Doabi, Keraman, Omarz, Nazdik-i-Khawak, Shamal Khawak) show that climate change has impacted water resources. As precipitation has changed in time and volume, temperature has increased, and discharge is not aligning with rainfall trends.

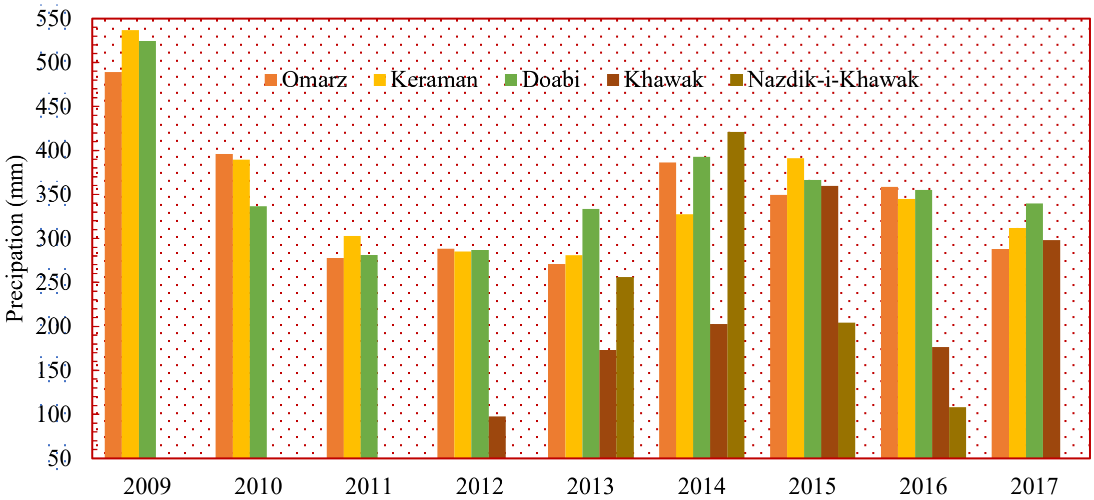

Figure 8. *Annual precipitation at five stations (2009-2018)* [11]. The same scenario is affirmed by satellite imagery analyses as well.

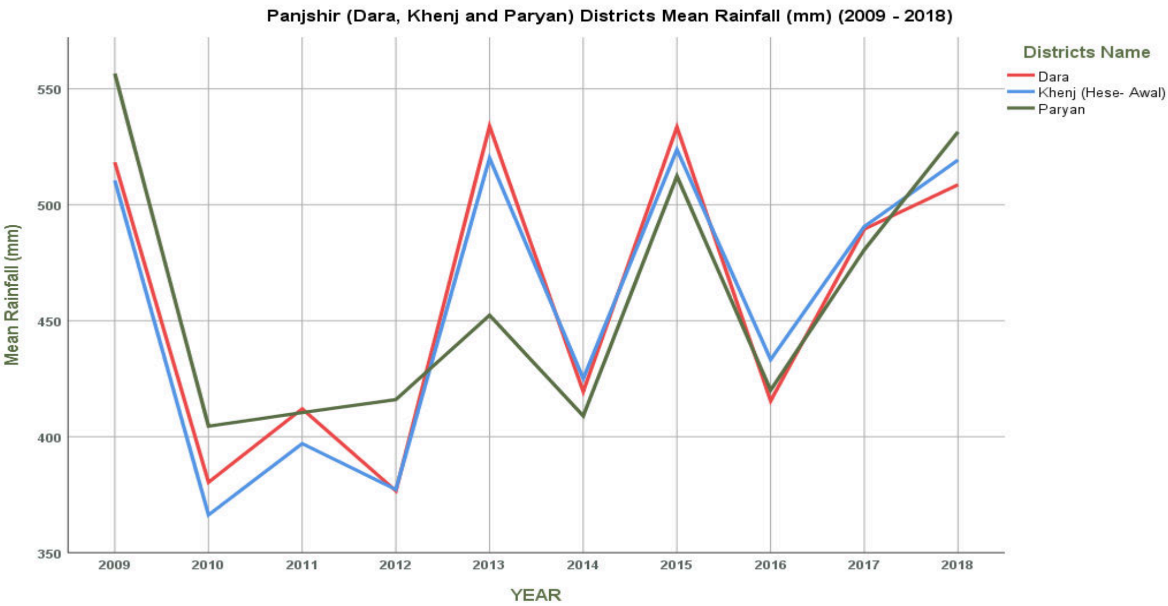

Figure 9. *Mean rainfall in Dara, Khenj, and Paryan districts (2009-2018)* [9].

The precipitation analyses reveal the variability in rainfall over time. During the last decade, the fluctuation in precipitation agreed with ground data and spatial data.

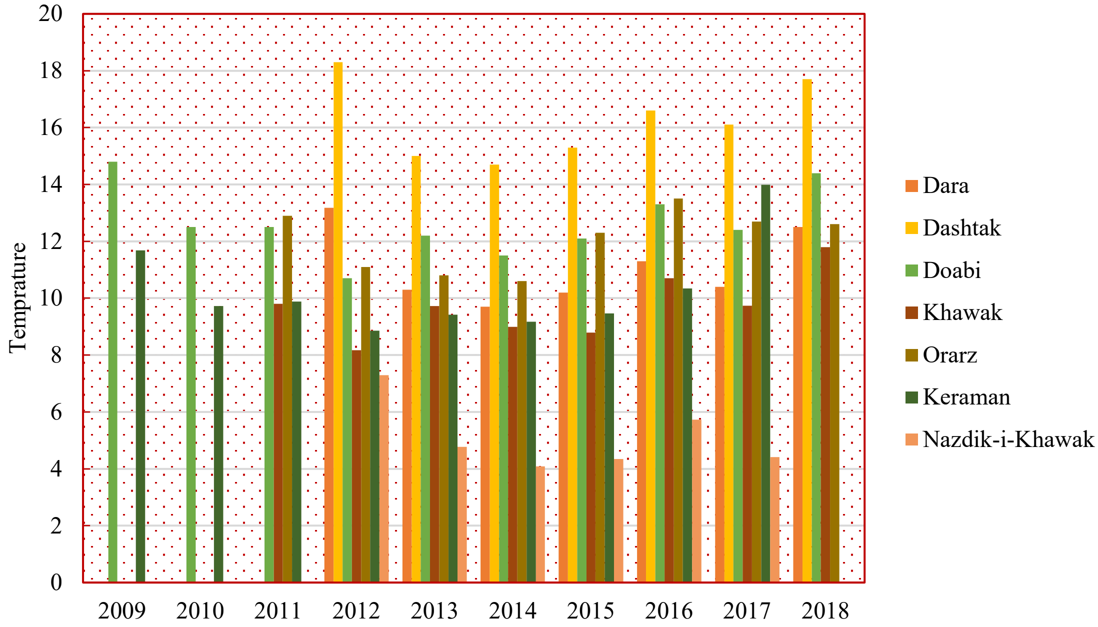

Figure 10. *Mean annual temperature in five stations (2009-2018)* [12].

Figure 7 shows that the temperature has been slightly increasing. These changes lead to the acceleration of the glacier melting rate and discharge increase. Consequently, it follows that the glaciers are disappearing, with a retreat rate that is faster than ever.

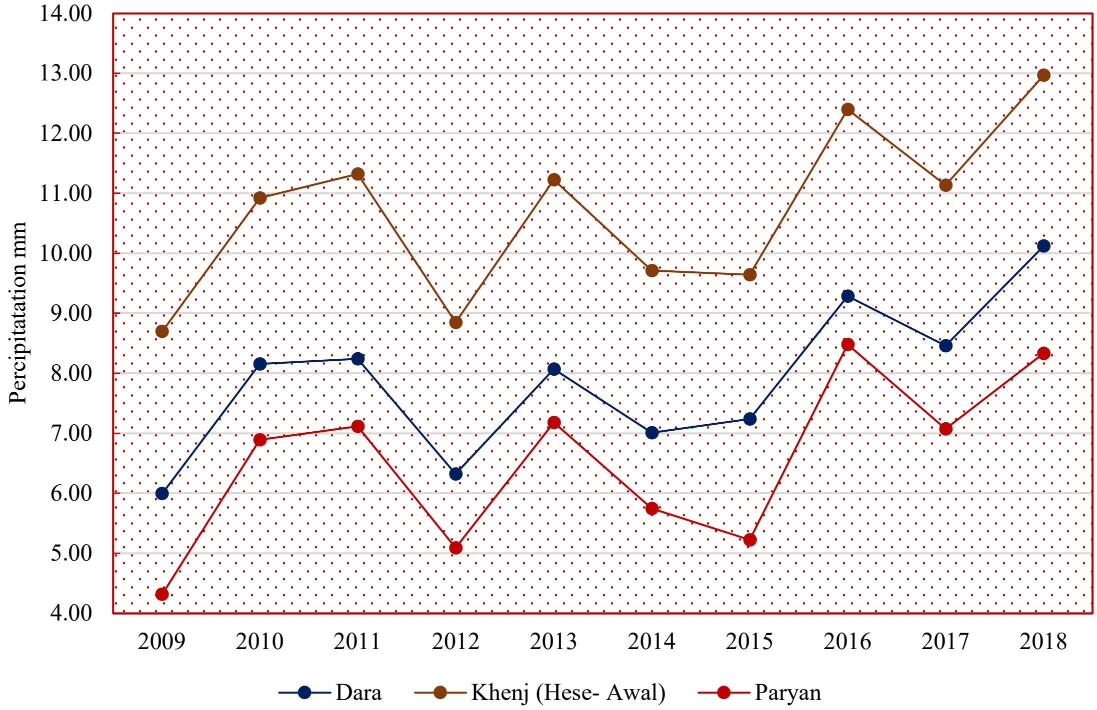

Figure 11. Mean temperature (2009-2018) LST (Temperature) – Monthly satellite imagery [9].

An increase in global temperature has negative impact on remote-sensing data aligned with station data, while it can be caused in decreasing precipitation and increasing glacier lake discharge.

Table 2: The Number of lakes and their characteristics.

OBJECTID	PROV_34_NA	DIST_34_NA	FREQUENCY	COUNT_Area	MIN_Area	MAX_Area	MIN_Altitude
1	Panjsher	Dara	59	59	0.004523	0.260115	2972
2	Panjsher	Khenj (Hese-Awal)	51	51	0.003563	0.17178	3792
3	Panjsher	Paryan	124	124	0.002726	0.199405	3217

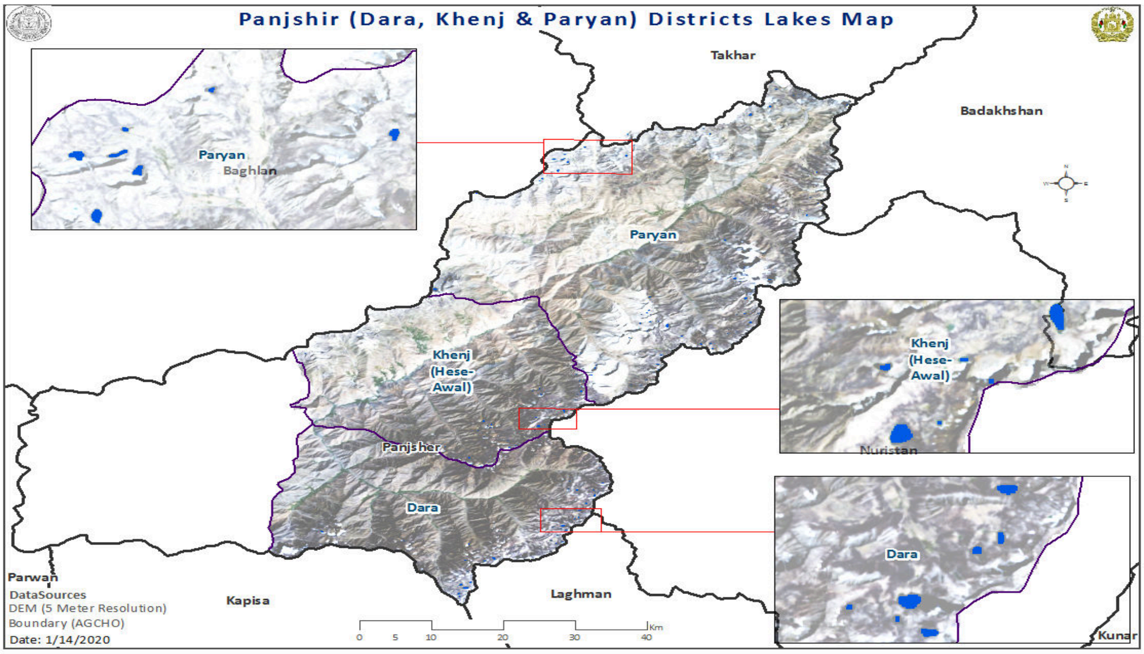

Figure 12. Lake map of Dara, Khenj and Paryan districts.

The above map shows the location of all lakes in Dara, Khenj, and Paryan districts.

Table 3: High-risk lakes in Dara, Khenj, and Paryan.

OBJ	PROV_34_NA	DIST_34_NA	FRQ	COUNT_Area	MIN_Area	MAX_Area
1	Panjsher	Dara	1	1	0.105490036	0.105490036
2	Panjsher	Khenj (Hese- Awal)	3	3	0.024665858	0.080523988
3	Panjsher	Paryan	16	16	0.02199968	0.199404933

In the Dara district, there is only one lake, in the Khenj District there are three lakes, and in Paryan district there are 16 lakes at high risk.

Table 4: Medium risk lakes in Dara, Khenj, and Paryan.

OBJECTID	PROV_34_NA	DIST_34_NA	FREQUENCY	COUNT_Area	MIN_Area	MAX_Area
1	Panjsher	Dara	1	1	0.105490036	0.105490036
2	Panjsher	Khenj (Hese- Awal)	10	10	0.024665858	0.17177954
3	Panjsher	Paryan	35	35	0.020343881	0.199404933

There is one lake in Dara district, 10 lakes in Khenj district, and 35 lakes in Paryan district with medium risk.

Table 5: Low-risk lakes in Dara, Khenj, and Paryan.

OBJECTID	PROV_34_NA	DIST_34_NA	FREQUENCY	COUNT_Area	MIN_Area	MAX_Area
1	Panjsher	Dara	1	1	0.105490036	0.105490036
2	Panjsher	Khenj (Hese- Awal)	10	10	0.024665858	0.17177954
3	Panjsher	Paryan	35	35	0.020343881	0.199404933

The low risk lakes are 36 in Paryan, 12 lakes in Khenj, and one lake in Dara district.

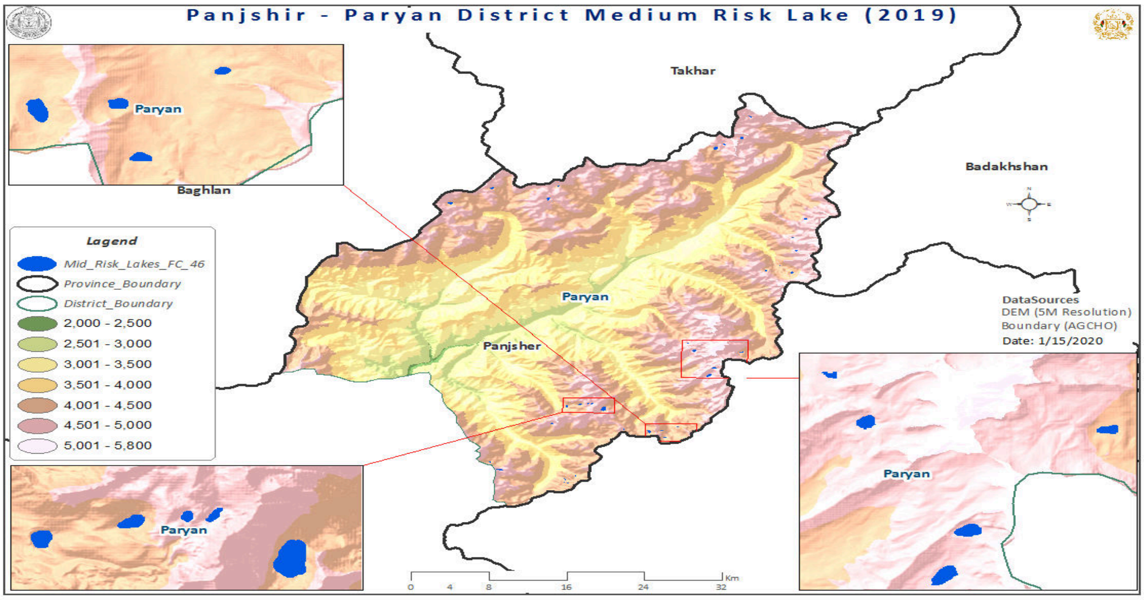

Figure 13. Location map of risk lakes in Paryan district.

The maps in Figure 10 show the location, type, and quantity of high, medium, and low-risk glacier lakes within the Paryan district.

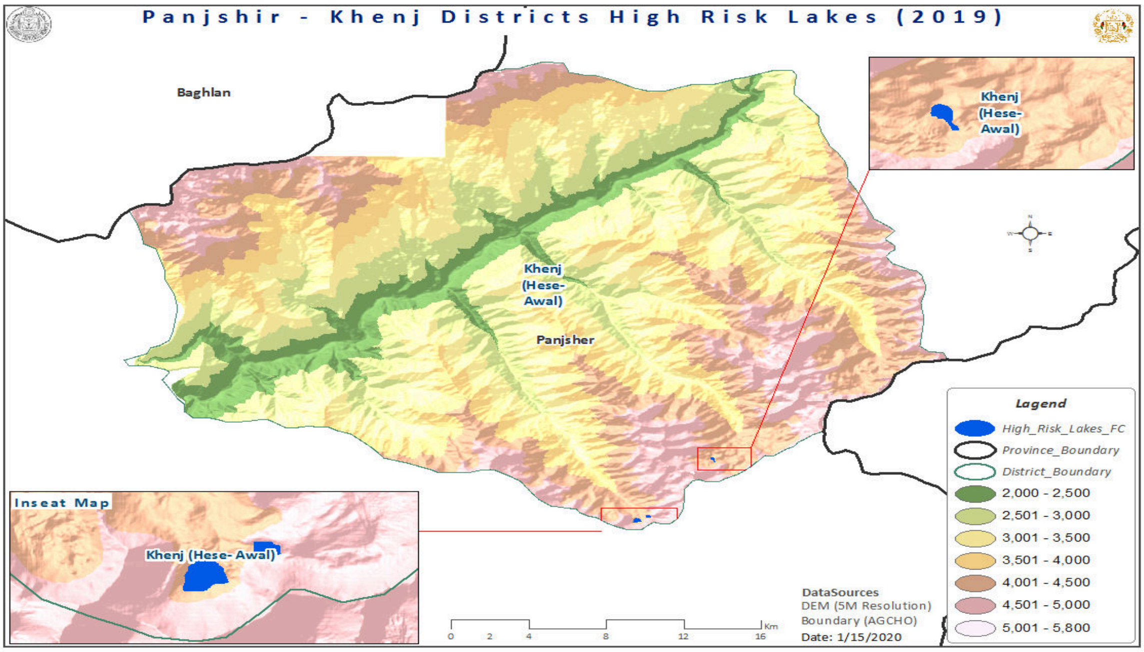

Figure 14. Location map of risk lakes in Khenj district.

Figure 11 shows the location, type, and quantity of high, medium, and low-risk glacier lakes within the Khenj district.

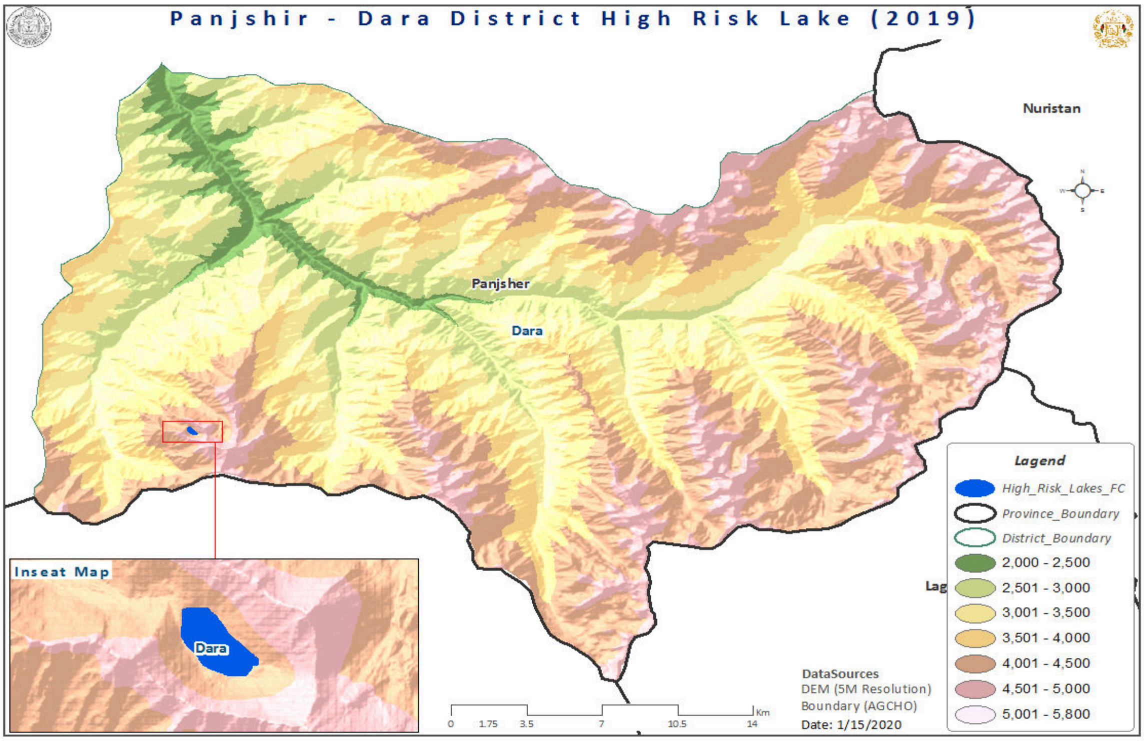

Figure 15. Location map of risk lakes in Dara district.

There is only one high-risk lake in the Dara district of the Panjshir province that threatens citizens and their property (Figure 12).

4. Findings

The glacier lakes are a potential threat to villagers, their houses, farmland, and properties. This study reveals that all of the post- and newly formed lakes are not threats to human life and their property. The characteristics of the hazardous lakes are identified as newly formed or not, sources that feed the lake (the more water feeding the lake results in a higher risk of outburst), the location and condition of the lake (the steeper slope carries a higher risk of eruption), and type the material in the dam structure that resists the fluid pressure. These factors should be considered when categorizing the risk for outburst flooding.

5. Conclusions

Climate change due to increasing temperatures has a positive impact on forming glacier lakes both in the size and number. While increasing temperature causes greater glacier melting, this process decreases the volume of the ice caps and delivers more water to lakes. Evaporation from glacier lakes was not analyzed. While the short-term effects of glacier melting may be an increased water supply source, the threat of water scarcity in the long-term during warm summers must be considered. Results are in line with the other relevant studies in terms of total flood volume, few glacier outburst floods are true megafloods. In terms of erosional and depositional impacts, formed over very short time scales and are pervasive in the landscape and geological record can attribute to megaflood.

References

[1] Arez GJ (**2007**) "Afghanistan natural geography" *Kabul University* (vol. 1, no. 1, pp. 59–71)

[2] Mir RA, Jain SK, Lohani AK, Saraf AK (**2018**) "Glacier recession and glacial lake outburst flood studies in Zanskar basin, western Himalaya" *Journal of Hydrology* (vol. 564, pp. 376–396) https://doi.org/10.1016/j.jhydrol.2018.05.031

[3] Drenkhan F, Guardamino L, Huggel C, Frey H (**2018**) "Current and future glacier and lake assessment in the deglaciating Vilcanota-Urubamba basin, Peruvian Andes" *Global and Planetary Change* (vol. 169, pp. 105–118) https://doi.org/10.1016/j.gloplacha.2018.07.005

[4] Puspitarini HD, François B, Zaramella M, Brown C, Borga M (**2020**) "The impact of glacier shrinkage on energy production from hydropower-solar complementarity in alpine river basins" *Science of The Total Environment* (vol. 719, pp. 137488) https://doi.org/10.1016/j.scitotenv.2020.137488

[5] Carrivick JL, Tweed FS (**2019**) "A review of glacier outburst floods in Iceland and Greenland with a megafloods perspective" *Earth-Science Reviews* (vol. 196, pp. 102876) https://doi.org/10.1016/j.earscirev.2019.102876

[6] Sun J, Zhou T, Liu M, Chen Y, Shang H, et al. (**2018**) "Linkages of the dynamics of glaciers and lakes with the climate elements over the Tibetan Plateau" *Earth-Science Reviews*

(vol. 185, pp. 308–324) https://doi.org/10.1016/ j.earscirev.2018.06.012

[7] Shrestha M, Koike T, Hirabayashi Y, Xue Y, Wang L, et al. (**2015**) "Integrated simulation of snow and glacier melt in water and energy balance-based, distributed hydrological modeling framework at Hunza River Basin of Pakistan Karakoram region" *Journal of Geophysical Research: Atmospheres* (vol. 120, no. 10, pp. 4889–4919) https://doi.org/10.1002/2014JD022666

[8] Taniwal MZ (**2018**) "Afghanistan general geography" *Karwan University* (vol. 59,)

[9] Sajood MK (**2019**) "DEM (ASTER satellite imagery); ET (Evapotranspiration), LST (Temperature) and Precipittion Monthly satellite imagery" (https://worldview.earthdata.nasa.gov/) *Accessed*: *1 November **2019***

[10] Veh G, Korup O, Walz A (**2020**) "Hazard from Himalayan glacier lake outburst floods" *Proceedings of the National Academy of Sciences* (vol. 117, no. 2, pp. 907–912) https://doi.org/10.1073/pnas.1914898117

[11] Ministry of Energy and Water (MEW) - Afghanistan (**2018**) "Afghanistan agrometeorological bulleting" (http://mew.gov.af) *Accessed*: *1 November **2019***

[12] Ministry of Energy and Water (MEW) - Afghanistan (**2018**) "Hydrological data" (http://mew.gov.af/) *Accessed*: *1 November **2019***