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Engr. Ch. Muhammad Arif

Engr. Ch. Muhammad Arif, President Pakistan Engineering Congress is a distinguished civil engineer with an illustrious career spanning over five decades. After completing his early education at Govt. Central Model High School and Govt. College Lahore, he pursued a B.Sc in Civil Engineering from the University of Engineering and Technology (U.E.T.) Lahore. Throughout his career, he has excelled in planning and executing complex infrastructure projects, particularly in the construction of highways, major river bridges, and other prestigious developments both within Pakistan and abroad. His expertise in executive and management control has earned him a reputation for handling challenging projects with remarkable efficiency.

He retired as Chief Engineer from the Communication & Works Department, Punjab, after years of exemplary service. His extensive knowledge in contract law, administration, and arbitration has made him a respected figure in dispute resolution, acting as an arbitrator for major inland and international contracts of the National Highway Authority (NHA), Water and Power Development Authority (WAPDA), and the Communication & Works Department Punjab. His contributions to academia include serving as an external examiner for U.E.T. and as a visiting faculty member at the Punjab Engineering Academy, where he has imparted his expertise on contract administration and arbitration.

Beyond his professional endeavors, Ch. Muhammad Arif has actively participated in various engineering associations. He has held prestigious positions such as President of the Punjab Highways and Building Engineers Welfare Association, Member of the Board of Governors of the Govt. Engineering Academy Punjab, and Executive Council Member and Vice President of the Pakistan Engineering Congress. His contributions to the field have been widely recognized, receiving appreciation from the Chief Minister of Punjab, the Minister for Communication & Works Punjab, and the Secretary of the C&W Department for his meritorious services on several occasions.

Currently, he serves as the Chief Executive of a renowned consulting engineering firm, where he has been leading the design and supervision of major infrastructure projects, including highways, buildings, water supply, and sewerage schemes, for the past sixteen years. His expertise, leadership, and dedication continues to shape the engineering landscape in Pakistan.



Engr. Ch. Muhammad Arif

President,
Pakistan Engineering Congress
(78th Session)

Table of Contents

Ser. No.	Paper No.	Title of Paper	Author's Name	Page No.
1	-	WELCOME ADDRESS ON WORLD WATER DAY-2025	Engr. Ch. Muhammad Arif, President Pakistan Engineering Congress	01
2	-	ADDRESS BY THE CHIEF GUEST ON WORLD WATER DAY-2025	The Honorable Mr. Kazim Ali Pirzada, Minister for Irrigation, Punjab	5
3	205	GMRC-WAPDA'S CONTRIBUTION TO GLACIER MONITORING IN PAKISTAN	Syed Hammad Ali	9
4	206	CLIMATE CHANGE & FRESH WATER SUPPLY OF PAKISTAN	Riaz Nazir Tarar, Zeeshan Riaz Tarar	29
5	207	VULNERABILITY CHALLENGES TO HIGH ALTITUDE WETLANDS AND THEIR FEEDING GLACIERS IN PAKISTAN REGARDING CLIMATE CHANGE	Abdul Qadir, Javeria Faisal	51
6	208	ROLE OF DIAMER BASHA DAM (DBD) ON FOOD, ENERGY SECURITY AND CLIMATE CHANGE MITIGATION OF PAKISTAN	Engr. Zahid Majeed	65
7	209	INDUS TELEMETRY PROJECT (A PROJECT FOR TRANSPARENT DISTRIBUTION OF PROVINCIAL SHARES)	Engr. Dr. Muhammad Riaz, Engr. Amjad Saeed, Engr. M. Sarab	79
8	210	GLACIAL MELTING IN PAKISTAN AND THE CONSEQUENT TRIBULATIONS FOR THE COUNTRY'S VULNERABLE POPULATION	Khurram Saleem, Shahab Ahmad	105

9	211	USING RAW GROUND WATER FOR THE DEVELOPMENT OF ORGANIC MINERAL WATER	Zaib-un-Nisa, Abdullah Yasar, Ahmad Ibrahim, Iqra Wasif	117
10	212	HEAVY METAL POLLUTION IN MANGROVE STANDS ALONG PAKISTAN COASTLINE	Dr. Munawwer Rasheed, Dr. Malik Wajid Hussain Chan	129
11	213	IMPACT OF CLIMATE CHANGE ON GLACIER MASS BALANCE AND TERRESTRIAL WATER STORAGE OF KUNHAR RIVER BASIN, KPK, PAKISTAN USING MACHINE LEARNING APPROACH	Mustajab Ali, Usman Ali	179
12	214	ASSESSING GLACIER DYNAMICS AND SNOW COVER CHANGES IN KASHMIR USING REMOTE SENSING AND GIS: A REVIEW	Dr. Javeria Saleem, Prof. Dr. Sheikh Saeed Ahmad	197
LIST OF PAPERS PRESENTED AT VARIOUS WORLD WATER DAY(S) BY PAKISTAN ENGINEERING CONGRESS				207

Welcome Adress
By
Engr. Ch. Muhammad Arif

President
Pakistan Engineering Congress

Welcome Address

By

Engr. Ch. Muhammad Arif

President Pakistan Engineering Congress

On World Water Day, 2025

On the theme of "Glacier Preservation"

Honorable Chief Guest
Distinguished Delegates,
Executive Council Members,
Fellow Engineers, Ladies & Gentlemen,

Assalam-o-Alaikum!

It is truly an honor and privilege to welcome you all here today as we come together to commemorate World Water Day 2025 which infact falls on 22nd March but has been rescheduled for today due to Holy Ramdan.

Since 2005, Pakistan Engineering Congress has been proudly observing this important day, adopting global themes that call for attention to fundamental water issues. This year, the theme is "Glacier Preservation," a pressing subject that highlights the sustainable management of water resources, the promotion of conservation, and the protection of these vital reserves.

Ladies & Gentlemen!

Glaciers, known as "rivers of ice," are not only awe-inspiring natural wonders but also significant to the planet's ecological balance. They serve as one of the largest reservoirs of freshwater on Earth, storing an astounding 69% of the world's freshwater. Communities living downstream of glacier-fed rivers rely heavily on these melting glaciers during warmer months for agriculture, drinking water, and hydropower. Glaciers are found in all major mountain ranges around the globe. The biggest glaciers are found in Alaska and Patagonia. As we talk of Pakistan, there are over 7,000 glaciers in the northern regions of Pakistan in Gilgit-Baltistan and Khyber Pakhtunkhwa.

Ladies & Gentlemen!

Glaciers play an imperative role in regulating the Earth's climate through the albedo effect, reflecting sunlight and helping to cool the planet. However, global warming has placed these icy giants under severe threat, accelerating their melting and creating a feedback loop of rising

temperatures. This loss poses serious risks, from water scarcity and disrupted ecosystems to sea-level rise and intensified climate change impacts.

But glaciers are more than just environmental treasures; they hold profound economic, cultural, and even spiritual value. They attract millions of tourists and are deeply woven into the traditions and beliefs of many communities worldwide.

Ladies & Gentlemen!

I would say, the fight to preserve glaciers is a fight for life on Earth. These icy giants are more than a symbol of nature's beauty—they are critical to sustaining our planet's ecosystems, economies, and communities. As we witness their alarming decline, the time for complacency is over. Every individual, organization, and nation has a role to play in safeguarding these natural treasures for future generations.

On this occasion, let us pledge to take meaningful actions—big and small—to combat climate change and protect our glaciers. Whether it is advocating for sustainable practices, supporting conservation efforts, or simply making environmentally conscious choices in our daily lives, every step counts to safeguard this precious resource for future generations.

Kindly remember, protecting glaciers is not merely an environmental responsibility; it is an investment in humanity's future. Together, we can preserve these majestic rivers of ice and ensure that their legacy endures for generations to come

Ladies & Gentlemen!

Today, I am pleased to share that the Pakistan Engineering Congress has curated 9 insightful papers by distinguished speakers to address this important theme. I extend my heartfelt appreciation to the authors for their dedication and contributions, which will advance our understanding and inspire action for this cause.

On this World Water Day, let us pledge to do our part—working together to preserve our glaciers and ensure clean water access for all.

Thank you!

-: Pakistan Paindabad :-

Adress
By
The Honorable Mr. Kazim Ali Pirzada,
Minister for Irrigation, Punjab

As Chief Guest
On the eve of
World Water Day 2025
Pakistan Engineering Congress

Address

By

The Honorable Mr. Kazim Ali Pirzada,
Minister for Irrigation, Punjab

On World Water Day, 2025

On the theme of "Glacier Preservation"

Respected members of the Pakistan Engineering Congress,

Esteemed Guests,

Ladies, and Gentlemen!

Assalam-o-Alaekum!

Good Morning and thank you for the honor of being here as your Chief Guest on this remarkable occasion of World Water Day 2025. Today, we gather not only to celebrate the irreplaceable resource that sustains all life "The Water", but to also shine a spotlight on an important issue that demands our collective action, that is Glacier Preservation.

As we look around the room, we are reminded of Pakistan's unique geographical blessings, home to the mighty Karakoram, Himalayas, and Hindu Kush ranges, boasting some of the world's largest glaciers outside the polar regions. These "Water Towers" of Asia serve as the lifeblood for our rivers, agriculture, industries, and, indeed, for millions of lives downstream. Yet, these glaciers, our natural reservoirs of fresh water are under severe threat.

Climate change has unleashed unprecedented challenges. Rising global temperatures have accelerated glacial melt, causing erratic water supplies, increased risks of glacial lake outburst floods (GLOFs), and threatening the delicate ecosystems that depend on these icy giants. For a water-stressed nation like Pakistan, the consequences are dire, as we face growing water scarcity, reduced hydropower potential, and challenges to food security.

Ladies and gentlemen!

This is a call to action—urgent, collective action. We cannot control nature, but we can control our response to its changes. The preservation of glaciers demands a multi-faceted approach. It starts with "mitigation, adaptation, and awareness". Allow me to outline a few key priorities:

Ladies & Gentlemen!

To slow glacier melt, we must act decisively to curb greenhouse gas emissions. This requires transitioning toward renewable energy sources, promoting energy efficiency, and reforestation efforts. Pakistan's own initiatives are commendable in this direction.

Efficient use of our water resources is vital. Engineers, scientists, and policymakers must work together to modernize our irrigation systems, develop water storage infrastructure, and minimize waste. Every drop saved upstream means resilience downstream.

Communities living near glacier-fed regions must be empowered through knowledge and tools to manage and adapt to the risks of glacial melt. Public awareness campaigns can foster environmental stewardship at all levels.

Ladies & Gentlemen!

Glacier preservation is a global challenge that transcends borders. Pakistan must strengthen partnerships with neighboring countries, leveraging shared knowledge and resources to protect the Himalayas, Karakoram, and beyond.

As engineers, policymakers, and citizens, you hold the expertise, resources, and influence to spearhead this mission. Pakistan Engineering Congress, with its rich legacy of driving innovation and progress, is uniquely positioned to lead the charge in glacier preservation. Together, we can turn challenges into opportunities—developing sustainable technologies, fostering innovation, and leaving a legacy of resilience for future generations.

Ladies and gentlemen!

The fate of our glaciers is intertwined with the future of our nation. Let us make a solemn commitment today—a commitment to act, to innovate, and to safeguard the lifelines of our rivers, our agriculture, and our people. Let us be the torchbearers of change in preserving the icy wonders that fuel our world.

On this World Water Day 2025, let us not just celebrate water but take a stand to protect its very source "our majestic glaciers". For in their preservation lies the promise of life, prosperity, and hope.

Thank you.

-: Pakistan Paindabad :-

Paper No.205

GMRC-WAPDA'S CONTRIBUTION TO GLACIER MONITORING IN PAKISTAN

Syed Hammad Ali

GMRC-WAPDA'S CONTRIBUTION TO GLACIER MONITORING IN PAKISTAN

By

Syed Hammad Ali[1]

ABSTRACT

Pakistan is highly vulnerable to the impacts of climate change, particularly due to the projected higher than average temperature increases in the region. One significant threat highlighted in the country's National Climate Change Policy (NCCP) is the recession of glaciers in the Hindu Kush, Karakoram, and Himalayan mountain ranges. These glaciers are essential freshwater sources for the Indus River System (IRS), which plays a crucial role in Pakistan's water supply and agricultural sector. The glaciers in the northern regions of Pakistan, particularly in Gilgit-Baltistan (GB) and Khyber Pakhtunkhwa (KP), are at great risk. With over 7.1 million people in these areas relying on water from glaciers, any change in glacier dynamics could severely affect the water supply. The increasing global temperatures are expected to accelerate glacial melt, leading to short-term flooding in the region. However, as glaciers continue to shrink, water inflows into the Indus River System will decrease, which will negatively impact agriculture, hydropower generation, and water availability in the long term. To address this issue, Water and Power Development Authority (WAPDA) initiated glacier studies back in 1990s. Pakistan Snow and Ice Hydrology Project Phase-I (PSIHP-I), funded by Canadian government, began in 1985 and was one of the first efforts to study glaciers in the Upper Indus Basin. It involved collaboration between WAPDA and Canadian universities to monitor glaciers and snowmelt. The Pakistan Snow and Ice Hydrology Project Phase-II (PSIHP-II), launched in 1991, further advanced these studies by establishing a network of 20 high-altitude weather stations (ranging from 1,500 to 4,700m.a.s.l). These stations provided valuable meteorological data essential for understanding the dynamics of snow and glacier melt. The collected data contributed to the calibration of the UBC Watershed Model (UBCWM), which was used to develop flow forecasting systems for the Indus, Jhelum, and Kabul rivers, helping improve water resource management. In 2012, Glacier Monitoring Research Centre (GMRC) was established to upgrade the PSIHP and continue monitoring glacier changes. GMRC conducts research on the effects of climate change

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on glaciers and their impact on water resources in Pakistan. It works under the umbrella of WAPDA to support the broader goals of ensuring water availability for agriculture and hydropower generation. Using advanced monitoring technologies, field research, and data from weather stations and remote sensing, GMRC tracks glacier behavior, melt rates, velocity, and their contribution to the flow of major rivers like the Indus, Jhelum, and Kabul. GMRC's research provides critical insights into glacier dynamics, which are vital for effective water resource planning and management in the face of climate change. The information gathered by GMRC helps Pakistan better prepare for the challenges posed by glacial recession and its effects on water resources. By continuing to monitor glaciers and study their dynamics, Pakistan can better manage its water and energy resources, ensuring sustainability for future generations.

Keywords: Glacier Monitoring, UBC Watershed model, PSIHP, GMRC, WAPDA

Introduction & Background

Pakistan's fresh water resources are based on snow and glacier-melt and monsoon rain. The cryosphere (snow, glaciers & permafrost) of the Upper Indus Basin (UIB) including parts of the Himalaya, Hindu Kush and Karakoram is a major source of waters in the river Indus and its tributaries Jhelum, Chenab and Kabul [1]. The water flows from glaciers and high mountain regions are affected by more extreme weather conditions, melting glaciers and thawing permafrost. They are very sensitive to climate change. The proper monitoring of the glaciers, the permafrost and the water flows in the UIB is therefore an important task and can contribute to a better use of water resources in view of the changing climate and to issue early warning in case of floods [2]. Pakistan is very vulnerable to floods, causing damages that significantly affect the population and the national economy. The UIB comprises the catchments of River Indus above Tarbela; River Jhelum above Mangla, River Chenab above Marala and River Kabul above Nowshera [3]. According to different studies snow and ice melt water contribution from this area is more than 70% of the river flows [4].

Pakistan is similar to many countries in the Central Asian region in that within its borders lie regions of extensive high mountains adjacent with lowlands. The mountains provide the principal sources of water supply for large populations living in the nearby plains. Thus there is a strong interdependence between highlands and lowlands. This interdependence is particularly felt in Pakistan where the mountain hydrology is dominated by glaciers and snowfields which are the most extensive in Asia and where the lowlands have no other significant untapped surface water sources than the

Indus River and its tributaries [5]. Another common theme in Central Asian hydrology is that major rivers cross international boundaries. Thus, as with the Ganges and Brahmaputra, the waters of the Indus system are shared between several countries, making for uneasy international relationships [6].

The Karakoram Mountains of northern Pakistan provide the only areas of the country with substantial precipitation and an annual moisture surplus. Most of the remainder of the Indus Basin has low precipitation and a water deficit in most or all of the year. Historically, surface water supply in Pakistan depended more upon the easterly Indus streams and rainfall; both mainly derived from the summer monsoon. Under the terms of the Indus Waters Treaty, and through large-scale development works since it was signed, Pakistan has become increasingly dependent on the main Indus and its westerly tributaries. These are primarily fed by melting of snow and ice in the high mountains [7].

The level of water development now achieved means that the actual flow of the rivers in all but the 2-3 months of high summer flows is controlled and utilized. Without reservoir storage there would be a severe deficit in water and power throughout these months. A major goal of water development has been storage and reallocation of the summer high flows. While the larger part of these flows still goes directly to the sea, irrigation and power are critically dependent upon what can be stored in the major reservoirs. The adequacy, and efficient management of these systems, in turn depends upon the timing, fluctuations and scale of the river runoff. However, as demand has approached or exceeded the capacity of these systems, severe problems of irrigation water shortage and electricity load-shedding have begun to occur at certain times of the year. The proposed projects for further reservoirs on the main stem of the Indus, point to the need for greater knowledge and a forecasting capability with respect to the high mountain sources of runoff [8].

Up to the 1980s there had been no comprehensive, long-term hydrological investigations in the Karakoram region. Intensive short-term investigations had been undertaken by several groups, for example the Batura Investigation Group and the International Karakoram Project. Many mountaineering expeditions had gathered data, but on a more or less ad hoc basis [9].

With these circumstances in mind, and bearing in mind, too, that Pakistan had little internal capability for snow and ice research, a joint Canada-Pakistan project for hydrology investigations, training and transfer of technology relating to snow and glacier resources was undertaken. It was

initially conceived in 1981. The programme and goals of the research were developed and approved by relevant agencies in Pakistan and Canada over the next three years, and activities began in 1985. Initially a three-year venture, the project was extended to June 1989.

Pakistan Snow and Ice Hydrology Project (PSIHP) Phase-I (1985-89)

PSIHP (Phase-I) was a cooperative project between Pakistan's Water and Power Development Authority (WAPDA), the International Development Research Centre (IDRC) in Ottawa, and various Canadian universities. In Pakistan, project coordination was undertaken by the Hydrology Research Directorate (HRD) of WAPDA in Lahore. In Canada, the project was coordinated within the Cold Regions Research Centre at Wilfrid Laurier University (WLU), Waterloo, Ontario. Scientists from the universities of Waterloo, Ottawa, British Columbia and the Inland Waters/Lands Directorate of Environment Canada also contributed. The universities of Manchester (UK) and New Hampshire (USA) provided additional expertise.

The main objectives of the project were to:

a) Initiate research into glacio-hydrologic aspects of the Upper Indus Basin relevant to water resource development and forecasting.

b) Introduce and test technical methods and models appropriate to the environment of the Himalayan Indus

c) Define the terms of an on-going monitoring and forecasting system for snow and ice regime basins

d) Train a core of Pakistani scientists/engineers to continue this work.

Achievements Of the Snow and Ice Hydrology Project

There have been several major achievements of the PSIHP:

a) The creation of a group of trained, experienced personnel in WAPDA to form the nucleus of its proposed Snow and Ice Division.

b) The production of an Operations Manual for snow and ice investigations in the UIB. The Canadian principals have prepared a series of manuals to provide such a handbook. An extensive library of research and handbook materials has been sent to WAPDA.

c) The drafting of a long-range research and operational plan for snow and ice investigations by WAPDA.

d) The building of a model for the hydrological balance of snow and ice basins. PSIHP concentrated its activities in three main basins-those of the Kunhar (Kaghan), Biafo and Barpu-Bualtar. Water balance studies

of each of these, based mainly on SIHP field observations, have been made. The Kaghan and Barpu-Bualtar are recommended as long-term study and training basins. In addition, less intensive studies have been carried out in the Rakhiot Glacier Basin (Nanga Parbat), in Shimshal Valley, at Pasu Glacier and Khunjerab Pass. Reconnaissance of features and possible monitoring sites has been carried out in the Upper Gilgit, Swat, Astor, Hunza, Hispar and Braldu valleys.

Pakistan Snow and Ice Hydrology Project (PSIHP) Phase-Ii (1991 -97)

The project was activated on 3 January 1991 with the signature of a contribution agreement between CIDA and IDRC, which became effective on 1 October 1990. IDRC then signed a commercial contract with BCHIL and a memorandum of grant conditions with the project beneficiary WAPDA. The cost of preparatory field mission by BCHIL and IDRC in October 1990 was covered by the commercial contract, but no work was effectively carried out by BCHIL until after 18 February 1991.

During 1994 an 18 month time extension was approved by CIDA (12 months for the project itself and 6 months for final evaluation and other administrative wrap-up procedures in Canada). In December 1996, at WAPDA's request a second extension was approved by IDRC and CIDA. The project completed was therefore on 30 June 1997.

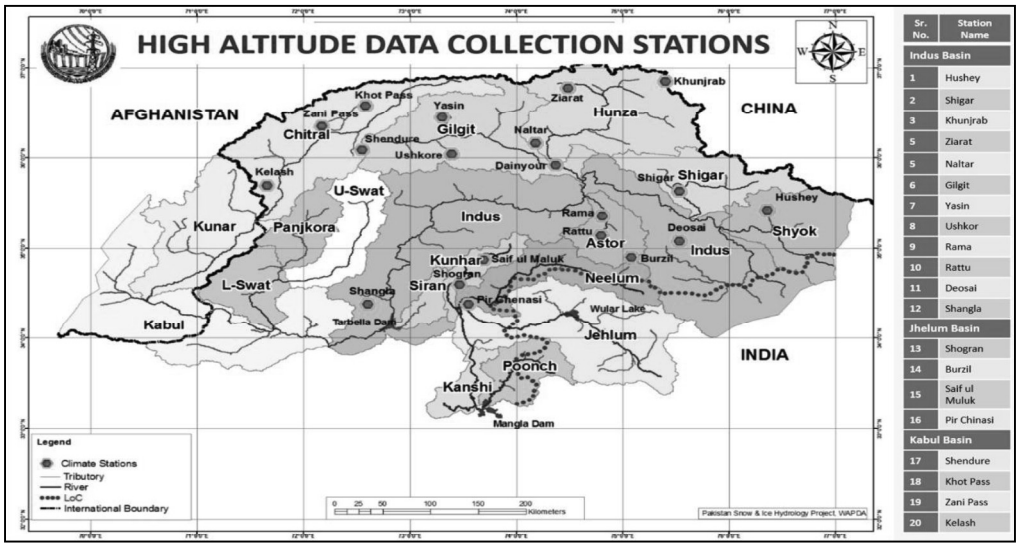


Figure-1: Location Map of DCP Stations of GMRC-WAPDA

The primary objective of the project was to conduct field-based monitoring of selected glaciers and collection of cryospheric and meteorological data by installation of 20 Data Collection Platforms (DCP) in the Upper Indus

Basin (UIB) at elevations ranging from 1,500 to 4,730 meter above sea level (Figure 1). Both phases of the project were successfully completed in June 1997, with the meteor burst communication system operating reliably and consistently, transmitting data to the master station in Lahore. Furthermore, the data management system by using University of British Columbia Watershed Model (UBCWM), which was established as part of the project, continued to generate seasonal and 10-day flow forecasts for key locations i.e. Indus River at Tarbela, Jhelum River at Mangla, and Kabul River at Nowshera.

Establishment Of Glacier Monitoring Research Centre (GMRC) 2012

Pakistan Snow and Ice Hydrology Project (PSIHP) were upgraded in November 2012 to establish the Glacier Monitoring Research Centre (GMRC). This initiative was set up to address the pressing concerns regarding the impact of climate change on the country's glaciers, which are crucial for water resources in Pakistan. As glaciers are a key source of freshwater, their melting poses significant risks to water supply, agriculture, and hydropower generation. The GMRC aims to enhance scientific understanding of glacier dynamics, monitor changes in glacier mass, and track hydrological impacts due to climate change. In addition to that, a field office was established in Skardu, to support on-ground glacier monitoring activities. This project operates under the General Manager of Hydro Resources Management (HRM) and plays a pivotal role in restarting and improving the glacier monitoring program, ensuring better data collection and analysis to inform climate adaptation strategies in Pakistan.

Functions of GMRC-WAPDA

Following are the main functions of GMRC to supports water resource management strategies.

1. High-Altitude Hydro-met Network

Glacier Monitoring Research Centre (GMRC) maintains a network of 20 Automatic Weather Stations (AWS) across the Upper Indus Basin (UIB) in Pakistan, with strategic placements in the Indus, Jhelum, and Kabul Basins. This network, established in 1993, plays a crucial role in monitoring weather patterns and gathering critical data to understand the regional impact of climate change. Of the 20 stations, 12 are situated within the Indus Basin, 4 in the Jhelum Basin, and 4 in the Kabul Basin, all of which span elevations ranging from 1500 to 4730 meters above sea level (m.a.s.l) (Figure 2). Each Data Collection Platform (DCP) that collects essential meteorological parameters, such as temperature, precipitation, relative humidity, wind speed, wind direction, wind gust, snow water equivalent (SWE) and solar

radiation. These parameters are critical for understanding the regional climate conditions and their effects on glaciers and snowmelt. The stations' data helps in modeling snow and ice dynamics, assessing water availability, and predicting the impacts of changing weather patterns on hydrology in the region. The AWS network is essential for long-term monitoring, providing valuable data for research on glacier mass loss, water resource management, and formulating strategies for climate adaptation in the Upper Indus Basin, where water is a vital resource for agriculture, hydropower, and livelihoods.

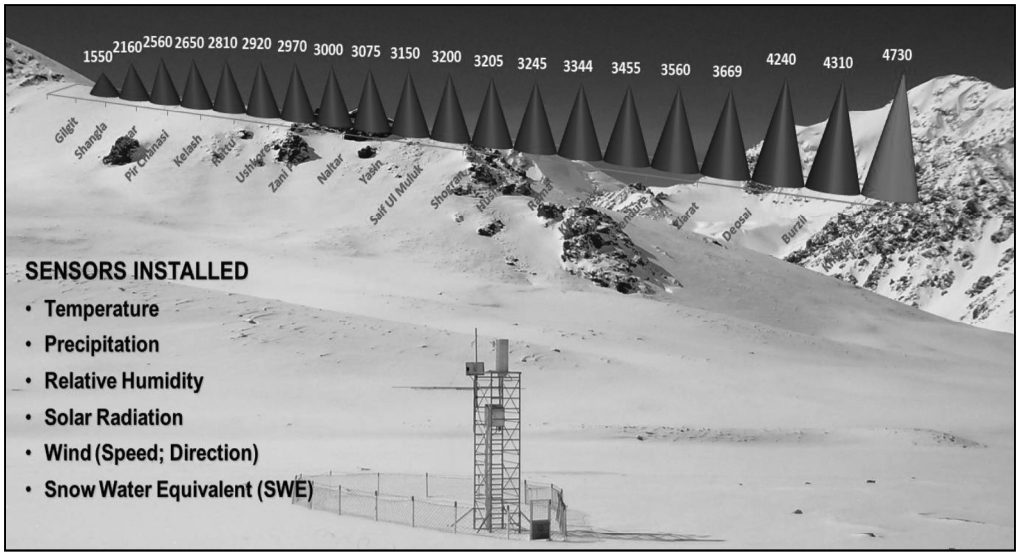


Figure-2: Elevations Of GMRC-WAPDA DCP Stations And Sensor Installed

2. Flow Forecasting by Using UBCWM

The data collected from the 20 Automatic Weather Stations (AWS) in the Upper Indus Basin (UIB) is transmitted in real-time via Meteor Burst Communication System (MBCS), ensuring timely and accurate data flow for various hydrological and climatic analyses. This robust communication system supports the forecasting of river flows in critical areas such as River Indus at Tarbela, River Jhelum at Mangla, and Kabul River at Nowshera. The flow forecasts are produced on both 10-daily and seasonal basis (Rabi and Kharif agricultural seasons). The University of British Columbia (UBC) Hydrological Model (Figure 3) plays a pivotal role in generating these flow forecasts by incorporating meteorological data into simulations of river discharge. The forecasts are regularly shared with key agencies and authorities such as the Indus River System Authority (IRSA), the Pakistan Meteorological Department (PMD), and the management teams of Tarbela,

Mangla, and Cheshma Barrages. This collaboration ensures that water resource management decisions are informed by the most up-to-date and reliable data. Additionally, the collected meteorological data is invaluable for monitoring weather conditions across the UIB and conducting in-depth climate-related analyses. This information is crucial for understanding regional climate dynamics, supporting agriculture, water management, and adapting to the effects of climate change.

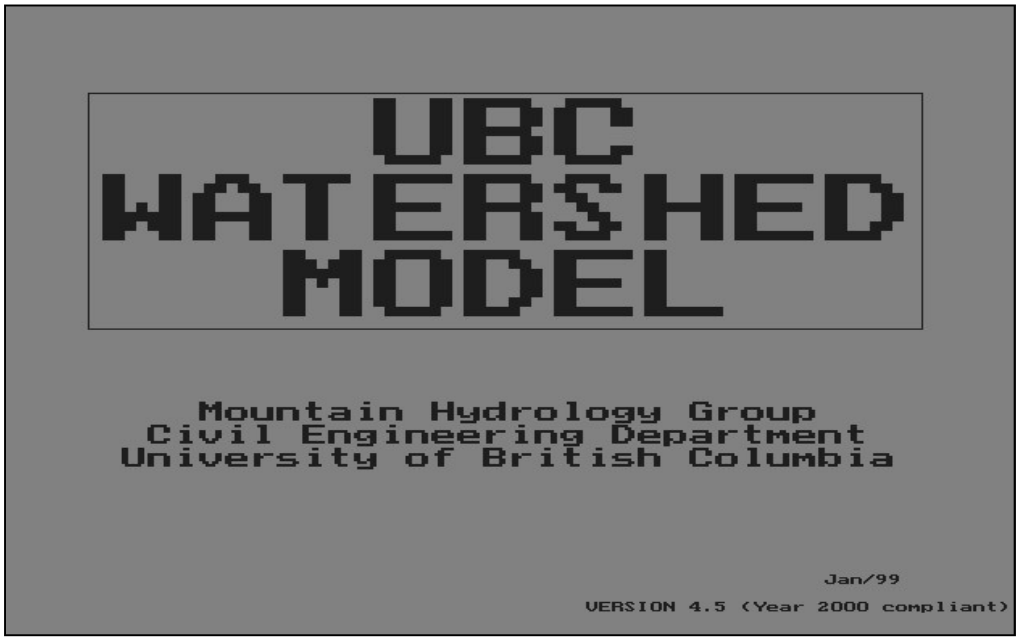


Figure-3: Dashboard of UBCWM

The University of British Columbia Watershed Model (UBCWM) is conceptual and continuous hydrological model. It is a semi distributed model. The UBCWM has been successfully applied for real time forecasting and research studies in different climatic regions of the world.

UBCWM uses the daily point value data of precipitation and maximum and minimum temperature as input to calculate the stream flow. The precipitation is taken in millimeters and temperature in degree Celsius. The model uses the historic flows, observed physically by gauging station at the outlet of the watershed to compare the model simulation. The UBCWM was designed for mountainous areas where meteorological data is sparse and mostly available at valley stations. The model uses the area-elevation band theory to deal with the orographic gradient of precipitation and temperature. The model also provide the information about the characteristics of watershed like snow water equivalent, energy available for snowmelt, evapotranspiration and interception losses, soil moisture, groundwater

storage and surface and subsurface components of runoff for each elevation band and also mean value over the watershed.

The physical description of watershed is done under a set of variable parameters for each assigned elevation bands such as mean band area, mean band elevation, glacier area, north south orientation, forested area, forest density impermeable fraction of soil. The watershed can be divided up to twelve bands with an equal interval of 500 meters, however from operation manual, it is suggested four to eight are enough to describe a watershed.

The UBCWM comprises of three sub model. The first model is related to metrological data and it distributes the point data of precipitation and temperature over the mid-elevation points of each elevation band in the watershed. The precipitation is controlled by critical temperature and falls either in the form of snow or rainfall. The melting of snow cover area and glacier extent is also controlled by this model. The second model deals with the soil moisture and indicates the behavior of watershed. It divides the watershed inflows into four types: fast as surface, medium as interflow, slow as upper groundwater and very slow as deep groundwater. The third model is related to routing and it generates the distribution of runoff components. It is based on linear storage reservoir theory. It assures the conservation of mass and water equilibrium.

3. Field Investigations

Glacier Monitoring Research Centre (GMRC), Water and Power Development Authority (WAPDA) plays a pivotal role in monitoring and understanding the behavior of glaciers in Pakistan, particularly in the Upper Indus Basin (UIB). As glaciers in this region are vital sources of freshwater, their response to climate change has significant implications for water resources, agriculture, and hydropower production. GMRC's initiatives focus on detailed monitoring and research to assess the impacts of climate change on glaciers, providing critical data for water resource management, flood forecasting, and climate adaptation strategies.

a) Benchmark Glacier Monitoring

One of GMRC's core strategies is to monitor five benchmark glaciers in the UIB catchment, which serve as key sites for detailed studies of glacial behavior. These glaciers are located in different sub-basins of the UIB (Figure 4), including:

a) Biafo Glacier in the Shigar Basin
b) Yashkuk Glacier in the Hunza Basin

c) Passu Glacier in the Hunza Basin
d) Hispar Glacier in the Hunza Basin
e) Raikot Glacier in the Astore Basin

These glaciers are selected due to their size, importance in the local hydrology, and their sensitivity to climate change. GMRC conducts baseline data collection for each glacier, focusing on key metrics such as ablation (melting) rates and glacier movement (velocity). These metrics provide insights into how these glaciers are reacting to rising temperatures, changes in precipitation patterns, and other climate-related factors. By establishing baseline data, GMRC aims to track the long-term changes in glacier dynamics, allowing for a deeper understanding of the rate of glacier melting and the overall health of these ice bodies. We have set up ablation stakes to measure ablation rates, monitor debris depth, and track surface velocity. This comprehensive data collection enables us to better understand glacier dynamics and provides critical insights for assessing the impacts of climate change on glacier health. Baseline data reveal ablation rates of 2 to 10 cm/d, surface velocity between 0.1 to 0.7 m/d, and debris thickness ranging from 2 cm to 80 cm, correlating directly with melt on benchmark glaciers. Over time, detailed surveys will reveal the actual impact of climate change on glacier behavior and help forecast future trends.

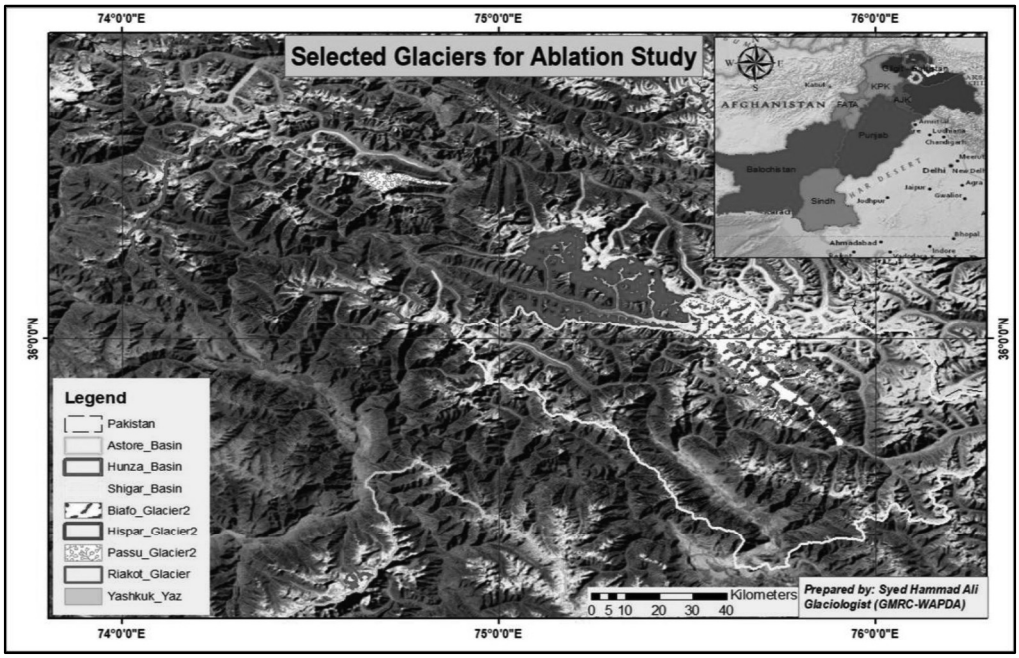


Figure-4: Selected Glaciers for Ablation studies in UIB'

b) Snout Surveys and Mapping of Glacier Terminus

In addition to monitoring the benchmark glaciers, GMRC also conducts snout surveys of approximately 50 glaciers in the UIB. The Hunza Basin, located in the Upper Indus Basin (UIB), is recognized for its extensive glacial coverage, making it one of the most highly glaciated catchments in the region. This basin is of significant importance due to its role in regulating water resources for downstream areas, contributing to the flow of the Indus River. Snouts of numerous glaciers in this catchment were surveyed for their movement. The findings from these surveys are crucial for understanding the region's hydrological processes, assessing water availability, and predicting future changes in the basin's glacial system due to climate change. (Figure 5). The snout or terminus of a glacier is the point where the glacier ends, and any movement or retreat at this location indicates important changes in the glacier's mass balance and health. By mapping fluctuations in the terminus, GMRC is able to create a record of glacier retreat and advance over time. This data serves as a control point for remotely sensed data. Remote sensing and satellite imagery provide valuable high-level insights into the condition of glaciers, but ground truthing is necessary to ensure the accuracy of these images. The snout surveys conducted by GMRC are essential for verifying the interpretations derived from remote sensing technologies and satellite imagery. Over the past decade, the majority of glaciers in the Upper Indus Basin have experienced significant retreat, with glacier snouts receding by 150 to 650 meters, reflecting the broader trend of glacier loss due to rising temperatures and climate change. However, some glaciers in the region have shown unexpected advancements, with their snouts moving forward by 50 to 180 meters. This variability in glacier dynamics highlights the complex and diverse responses of glaciers to changing climatic conditions, where factors like local topography, glacier type, and microclimates play a key role in determining whether glaciers advance or retreat in different parts of the basin.

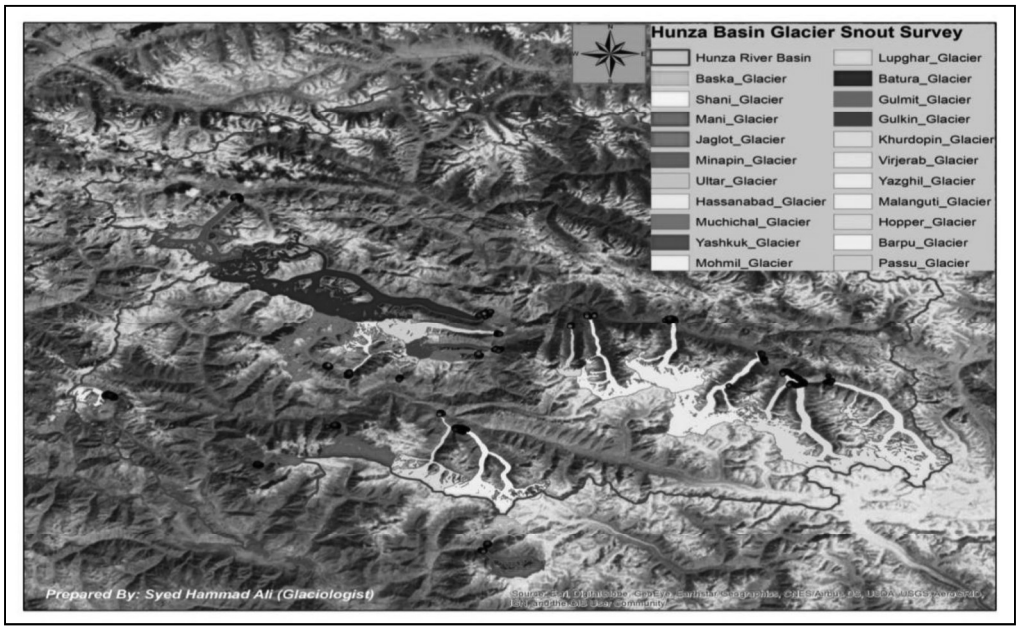


Figure-5: Selected glaciers for snout survey in Hunza Basin

c) Field & RS/GIS Based Glacial Lake Monitoring

Another crucial aspect of GMRC's work involves monitoring glacial lakes in the region, which have become increasingly significant due to the growing risk of Glacial Lake Outburst Floods (GLOFs). Glacial lakes form as glaciers melt, and if these lakes breach their natural dams (formed by moraine or debris), they can cause catastrophic flooding downstream. GMRC monitors these lakes through field visits and remote sensing/GIS applications.

Notably, GMRC has focused on monitoring three prominent glacial lakes Shishper, Khudopin and Dookpal Glacial Lakes (Figure 6). These lakes are located in high-altitude areas, and their stability is of great concern due to the risk of GLOFs, which could threaten downstream infrastructure, agriculture, and communities.

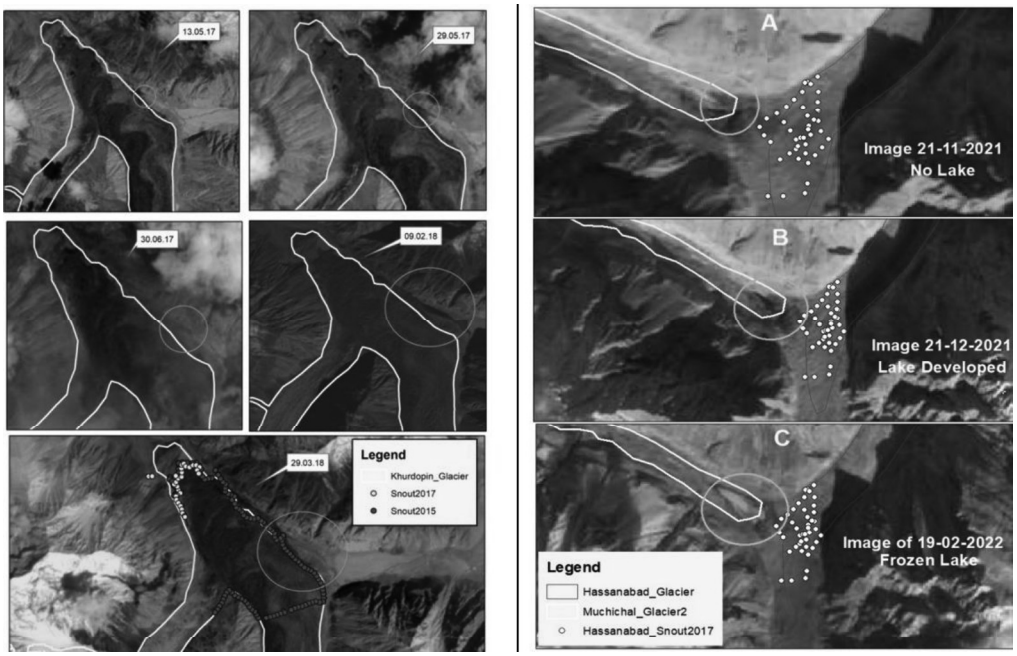


Figure-6: Development of Khurdopin & Shishper Glacial lakes



Figure-7: Dookpal Glacial Lake monitoring and mitigation works by GMRC

A particularly alarming event took place in 2019, when a devastating GLOF from the Dookpal Glacier struck the Golen Gol Hydropower Project in Chitral (Figure 7). The GLOF carried extreme sediment inflows, which were deposited in the project area, causing substantial damage. The sedimentation not only reduced the efficiency of the hydroelectric plant but also led to costly repairs and operational disruptions. This event highlighted

the critical need for effective monitoring and mitigation strategies to prevent the destructive impact of future GLOFs.

To address these risks, GMRC is involved in monitoring and mitigation works, including assessing the stability of glacial lake dams, predicting the likelihood of outbursts, draining of Lake water level by using pumps and pipes and developing open channel spillway to reduce the effect of GLOF and save the communities and infrastructure at-risk. These interventions significantly mitigated the risk of GLOF event. Since this modification, no GLOF events have been observed in the Golen Gol catchment, demonstrating the effectiveness of the approach.

d) Isotope Analysis for Glacial Stream Contribution

To further understand the dynamics of glacial melt water and its contribution to regional hydrology, GMRC initiated a pilot project with the Institute of Tibetan Plateau Chinese Academy of Sciences (ITP-CAS) for isotope analysis from glacial streams. This innovative approach helps determine the relative contributions of snow, glacier melt water, and rainfall to the stream flow in different regions of the UIB. Isotope analysis offers valuable insights into the origin and composition of stream flow, which can vary significantly depending on the source of the water. By distinguishing between glacial melt water, snowmelt, and rainfall, this research allows for more accurate predictions of seasonal water availability and enhances the understanding of glacier-fed river systems.

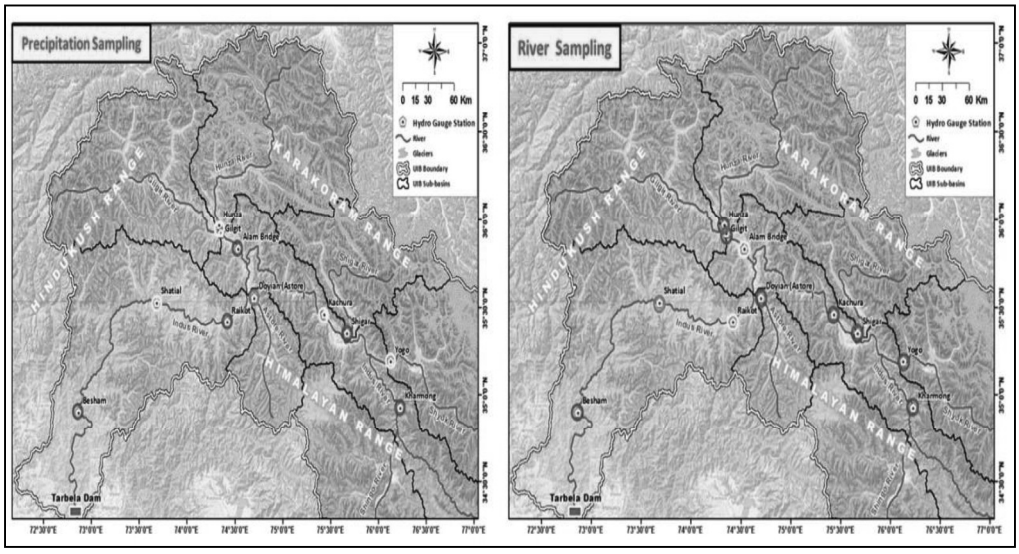


Figure-8: Collection Sites of isotope samples

The data gathered from the isotope analysis will help refine hydrological models used for flow forecasting, water resource management, and climate adaptation planning. Furthermore, it contributes to a deeper understanding of the role of glaciers in the region's water cycle and their importance as natural water storage systems.

e) Permafrost Monitoring

In another cutting-edge initiative, GMRC has collaborated with the ITP-CAS to establish a permafrost monitoring station at Deosai, which lies at an elevation of 4240 meters above sea level (m.a.s.l) (Figure 9). Permafrost is ground that remains frozen year-round and plays a key role in regulating the hydrology and ecology of high-altitude areas. However, as global temperatures rise, permafrost is beginning to thaw, which can lead to significant environmental changes, such as altered water flow patterns, increased erosion, and the release of greenhouse gases stored in the frozen soil.

The installation of a deep borehole by GMRC and ITP-CAS equipped with a 5TM Decagon sensor and a CR 800 series Campbell Scientific data logger offers valuable insights into the behavior of permafrost. The borehole measures key parameters electrical conductivity, soil moisture, and temperature at various depths ranging from 0 to 480 cm (Figure 9). These measurements enable scientists to monitor the thermal state of permafrost over time, helping determine whether it is warming, cooling, or starting to thaw. As permafrost is sensitive to climate change, understanding its thermal dynamics is crucial for predicting its response to rising temperatures.

The data collected from this borehole are critical for assessing the rate of thawing, as thawing permafrost can have significant implications for local ecosystems, infrastructure, and hydrology. It also influences hydrological cycles, potentially altering groundwater flow and leading to changes in vegetation and animal habitats. By comparing permafrost temperature profiles with surface temperature history, scientists can better understand thawing trends and predict future permafrost behavior. This knowledge is essential for mitigating the potential impacts of permafrost thawing and for developing adaptive strategies in affected regions.

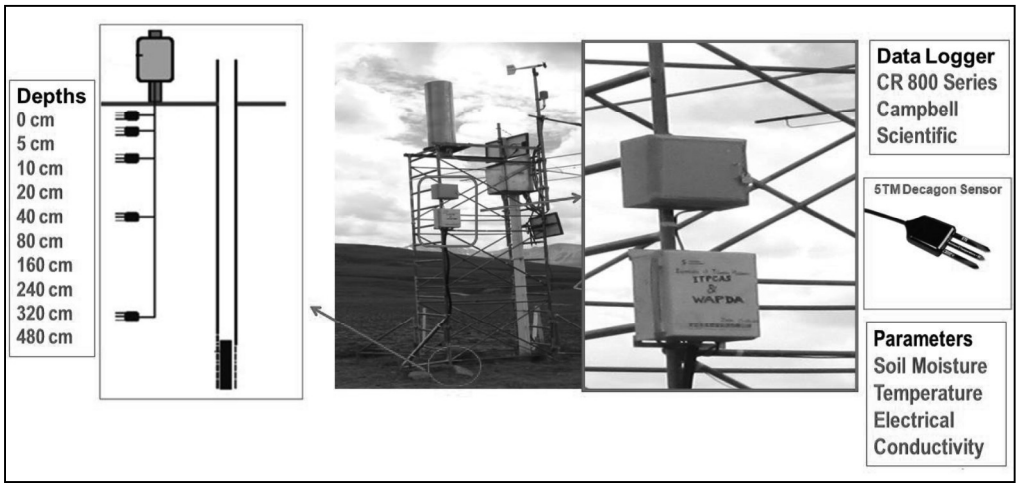


Figure-9: Permafrost Monitoring Equipment installed at Deosai DCP Station

4. Conclusions & Recommendations

Pakistan's glaciers are of great scientific and economic interest. Glacier variations and permafrost are the best indicators of climate change and the glaciers as fresh water reservoirs have an important economic role for drinking water, irrigation and the production of hydroelectric power as well as for the determination of flooding potential. Investments in a better monitoring of glaciers and rivers in the UIB help to avoid damages caused by extreme floods and may contribute to a more efficient use of water for irrigation and increased hydropower production from the reservoirs. Therefore improvement of the glacier monitoring network is need of time and economically viable and of high value for the population of Pakistan depending on the water resources of the Indus River. Compared to other countries with similar geography and considering the huge area covered with ice and snow the number of monitoring stations is still small and should be extended stepwise further on including more sensors, more parameters and more direct users.

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