WORKSHOP REPORT

Increasing the resilience of the hydropower sector in Nepal to climate extremes

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Executive summary

The two-day workshop on Increasing the resilience of the hydropower sector in Nepal to climate extremes brought together the users of current and future climate information from Nepal's hydropower sector to ICIMOD headquarters in Kathmandu, Nepal. The workshop organized by the International Centre for Integrated Mountain Development (ICIMOD) and the Met Office aimed to understand the current state and prospects of using climate information in Nepal's hydropower sector. ICIMOD and the Met Office jointly organised this workshop as a part of the Asia Regional Resilience to a Changing Climate (ARRCC) programme funded by the UK's Foreign Commonwealth and Development Office. The Nepal Development Research Institute (NDRI) provided technical support in the organisation of the workshop.

The ARRCC programme aims to improve the uptake and use of future climate projections in decision-making across the South Asia region. This workshop is a continuation of the workshop on climate services for South Asia's water and hydropower sectors, held in September 2019, organised under the ARRCC programme.

Resource persons from the Met Office, ICIMOD and NDRI reflected on the CARISSA work programme and its main goals, the workshop organised in 2019, and the importance of collective efforts from stakeholders and regional and global partners to mitigate the risks to the Hydropower sector to climate change, and enthusiasm to collaborate further on this crucial topic.

The beginning of the workshop set a tone on how the frequency and intensity of extreme rainfall events have increased in recent years resulting in major disasters, and how these disasters have taught the importance of proper climate observation networks and reliable data. The first session focused on participants' expectations and understanding of the decision landscape for hydropower stakeholders. A panel discussion with prominent figures from Nepal's hydropower sector discussed crucial topics such as risks for hydropower, guidelines/methodologies, prospects of establishing hydro-met stations at hydropower project sites, carbon financing and sediment monitoring. The afternoon session included presentations introducing climate data, the current risk of extreme rainfall in Nepal, the future risk of extreme rainfall in Nepal and a case study of the Koshi River Basin on extreme rainfall and river flow. An interactive game followed the presentations to learn about the value of integrating climate information into decision-making.

The second day started with a reflection on day one and a presentation on event-based modelling and flood frequency analysis for the Dudh Koshi basin. An interactive question-and-answer session followed the presentations and a group exercise using storylines helped participants envision the future and understand the decision landscape. The afternoon session focused on the knowledge of the participants on guidelines, tools for climate risk assessment on the design

and planning of hydropower, and missing links in the guidelines. A group session also assisted in identifying the missing guidelines, missing points in the guidelines or considerations regarding climate risk assessment in various existing policy documents. Participants listed the immediate outputs of the workshop from their experience. After the formation of the list, they were asked to assign their names to the output they could contribute to, resulting in a record of resources people available to work in incorporating climate data into the hydropower sector of Nepal.

The common themes that emerged through the workshop are:

- Data availability, improvement and sharing
- Climate risk assessment, climate extremes and future projections
- Inclusion of climate data in hydropower decisions
- Policy and existing guidelines

Through the two-day workshop, hydropower stakeholders were able to understand climate information and climate extremes. They were further motivated to include this information in hydropower development to fill the existing gap between the climate and hydropower sectors in South Asia.

Abbreviations and acronyms

ARRCC	Asia Regional Resilience to a Changing Climate
CARISSA	Climate Analysis for Risk Information and Services in South Asia
CORDEX	Coordinated Regional Climate Downscaling Experiment
CMIP5	Coupled Model Intercomparison Project Phase 5
DHM	Department of Hydrology and Meteorology
DoED	Department of Electricity Development
ERA5	European Center for Medium-Range Weather Forecasts Reanalysis 5th Generation
ESRM	Environment and Social Risk Management
ETCCDI	Expert Team on Climate Change Detection and Indices
GCM	General Circulation Model
GLOF	Glacier Lake Outburst Flood
GPD	Generalized Pareto Distribution
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
ICIMOD	International Centre for Integrated Mountain Development
IPPAN	Independent Power Producers Association Nepal
IPCC	Intergovernmental Panel on Climate Change
NDRI	Nepal Development Research Institute
HAR	High Asia Reanalysis
HKH	Hindu Kush Himalaya
IHA	International Hydropower Association

LDOF	Landslide Dam Outburst Flood
MSWEP	Multi-Source Weighted-Ensemble Precipitation
NAP	National Adaptation Plan
NDRI	Nepal Development Research Institute
NRB	Nepal Rastriya Bank
NEA	Nepal Electricity Authority
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
UNDP	United Nations Development Programme
WECS	Water and Energy Commission Secretariat

Contents

Background

In September 2019, ICIMOD and the Met Office, the UK's national meteorological agency, partnered to organise a workshop on climate services for the water and hydropower sectors in South Asia. This workshop, organised under the UK Aid-supported Asia Regional Resilience to a Changing Climate (ARRCC) programme, brought together climate researchers and providers, boundary organisations, and users of climate information to identify the needs, requirements and knowledge gaps related to climate information for the water and hydropower sectors in South Asia. The outcomes of the discussion highlighted the need to understand better the current and future risks of extreme rainfall events.

Since then, scientists from ICIMOD and the Met Office have been working to investigate the current risk of extreme rainfall and what climate models can tell us about how this may change. Current and future extreme rainfall in the context of a drainage basin to make the data more relevant to hydropower stakeholders.

This workshop, held in July 2022, allowed reconnecting with stakeholders in Nepal and presenting the outcomes of our work. Discussions with the key stakeholders helped us understand more about their decisions so that climate information can be delivered in a useful and usable way to inform decision-making.

Objectives

The workshop brought together providers of climate information (ICIMOD and Met Office) with users of current and future climate information (stakeholders from the hydropower sector in Nepal). The workshop, through interactive sessions, helped us understand and address the challenges that this sector faces and allowed us to present the climate information for Nepal that could be used to help tackle these. The discussion sessions were held to understand how climate information can be most effectively used by the hydropower sector in Nepal in order to increase resilience to current and future climates.

Expected outcomes

This expected outcome of the workshop includes understanding the current risk of extreme rainfall events in Nepal and how these are projected to change based on a range of future climate change scenarios.

By the end of the workshop, we expected to:

- Understand how stakeholders in the hydropower sector currently use climate information
- Describe the current risk of extreme rainfall events in Nepal
- Explain how climate models work and what they can tell us about the future climate of Nepal
- Link extreme rainfall to river flow with an example from the Koshi Basin and demonstrate how climate information can be integrated into planning, designing and decision making
- Work together on the climate risk assessment guideline and identify knowledge gaps which need to be addressed

Workshop proceedings

Day 1 – 12 July 2022: Hydropower and climate change: How do we increase resilience?

Morning session – Introduction and setting the scene

Katy Richardson, Met Office, provided the opening remarks on behalf of the Met office. She introduced CARISSA as work package 3 of the ARRCC programme, the main goal of which is to improve resilience in terms of climate change. She reflected on the workshop of 2019, highlighted that the objective of this workshop is to understand the knowledge of the risks of hydropower, and looked forward to active participation during this workshop.

Shankar Shrestha, NDRI, welcomed all the participants and expressed his and NDRI's happiness to work on this critical topic of NDRI's interest in collaboration with the Met Office and ICIMOD, and also looked forward to more joint projects in the future.

Basanta Raj Shrestha, ICIMOD, welcomed the participants to the workshop. Shrestha provided an introduction to ICIMOD and its Regional Programmes. He highlighted the importance of technology and innovation and focused on evidence-based data analysis and ICIMOD's role in influencing actions, policies, and programmes. He also noted that climate data and information needs to be relevant from the investment point of view. Despite being a critical energy source, the hydropower sector is facing risks due to climate change. Collective efforts from associated stakeholders and regional and global partners are needed to mitigate these risks. Shrestha recommended harnessing opportunities from innovation and utilising digital technology for this purpose.

Presentations

Mandira Singh Shrestha, ICIMOD, presented on hydropower and extremes and provided a summary of the 2019 workshop and objectives of the workshop. There is an increasing threat of climate change in the Hindu Kush Himalaya (HKH) region. There is more significant evidence that this region is warming up very fast, and this rate of increase is higher than the global average. There are clear indications that a high increase in precipitation is projected for the mid-latitude areas, with an increase in the intensity and frequency of extreme events. The HKH region is prone to many disasters. From 2000–2019, floods affected about 63% of the population in the HKH region. Globally, floods affected 42% of people, indicating a high vulnerability to floods in the HKH region. The Chamoli flood in Uttarakhand and the Melamchi flood in Nepal are some examples of recent floods, cascading hazards, and their impacts on infrastructure.

Shrestha highlighted the key issues and lessons from the past disasters: poor climate observing networks, the need to emphasise cross-learning, the need to strengthen mechanisms for communication and information dissemination, the need for consideration of cascading hazards, and adequate risk assessments. She referred to the existing guidelines available for hydropower development, such as the Guideline for the study of hydropower projects (DoED, 2018), the Hydropower Sector Climate Resilience Guide (IHA, 2019), and Guidelines on environmental and social risk management for banks and financial institutions (NRB, 2018). She then highlighted the objective of the workshop.

Rosie Oakes, Met Office, led an interactive exercise to facilitate participant introductions and expectations from participants. Oakes summarised the aims of the two-day workshop and facilitated an interactive exercise: "think-pair-share", where the participants were asked to write their expected outcomes from the workshop and then share them in pairs. Participants' expectations are summarised as follows:

Expectations/What do people hope to get out of the workshop

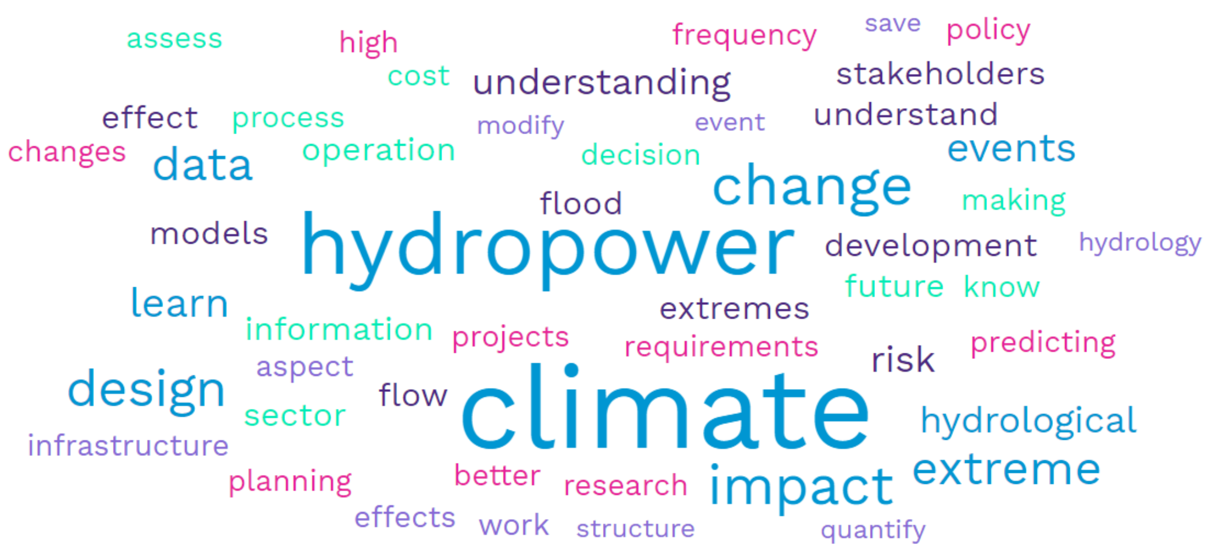
1. *Understanding climate models and climate change*
    - Quantification of climate, extreme events
    - Understanding climate extremes and their data in the HKH
    - High-resolution data
    - Know more about Met Office's research on climate extremes and the application to hydropower development
    - A general explanation of climate models and their usefulness in projecting the future
    - Effect of climate change on the hydropower sector
2. *Understanding the hydropower sector*
    - A better understanding of the hydropower sector's needs for climate risk analysis
    - How are practitioners responding to or planning to respond to extreme events?
    - Learn about stakeholder requirements and their understanding of the data (climate and hydrological).
    - To hear from the hydropower stakeholders and how to use the climate data.
    - How do hydropower stakeholders understand climate information?
    - Water availability impact dry as well as monsoon flow through climate change. There are only adverse effects and no positive effects during the dry season.
3. *Climate change → hydrology*
    - Extreme hydrological events and their effect on the hydropower sector
    - Minimum flow and maximum flood due to climate change
    - Changes in flood intensity and frequency
    - To learn more about the requirements of hydrological modelling

- A reliable means of predicting extreme flood events in frequency and magnitude

4. *Hydropower plant design*
    - How can we modify or change the plant designs from extreme events?
    - The traditional calculation method for hydrological data has to be modified
    - Design/Cost/Cost-benefit must fit into the development and design stage
    - Designing components to address future climate scenarios vs their cost
    - Integration of climate change impacts and multi-hazards into hydrological design parameters
    - How to incorporate climate change impacts on the design and operation of hydropower infrastructure?
    - Learn about the effect of extreme events that could be incorporated into the design aspect
    - Incorporation of future climate data in hydropower infrastructure design
    - Climate information for all phases of hydropower development, for existing hydropower projects and future ones
5. Understanding the impacts – steps to minimise this
    - Understand climate extremes and assess the impacts
    - What measures can we take to minimise impacts?
    - Risk likelihood and impacts
    - Assess the impact of climate change on hydropower projects to quantify the impact on the generation and the electrical value charge
6. Data
    - Create an institute for data collection
    - Realistic and transparent data
    - Identify the best tools to generate climate models that can represent the climate conditions of Nepal
7. Climate data for decisions
    - How can we include the findings from climate models in our decision-making process?
    - How can risk resilience be improved by integrating climate information in hydropower plants' planning, design, and operation?
    - How can research institutions help with the simple methodology for incorporating climate risk assessment in government policies and practices of the hydropower developers?
    - A better understanding of climate projections can inform long-term decision-making for the hydropower sector
8. Operations
    - How the extreme flood affects during and after the construction and operation phase?
9. Collaboration
    - Collaboration between the hydropower stakeholders and DHM for climate change information

10. Policy
- How do we convey the message to policymakers on the importance of an observation network?
- Learn more about policy changes required in hydropower sectors considering the climate change aspect

11. Others
- Understand the scope, process and institutionalisation of climate services in the economic sector
- Learn how this work can be aligned with ICIMOD's overarching work on sustainable hydropower



Mandira Singh Shrestha, ICIMOD, moderated the panel discussion on understanding hydropower stakeholders' decisions and the information landscape with three panellists – Ram Prasad Dhital, Sandip Shah, and Anand Chaudhary. The panellists first shared their perception of critical risks for the hydropower sector and their experiences in integrating climate risk assessments.

Shrestha opened the floor for queries from participants.

Q: What are the critical risks for the hydropower sector? And are there any guidelines/methodologies followed?

Ram Prasad Dhital, Former Chief, Electricity Regulatory Commission, Nepal

- Environmental, technical, and social risks are prevalent in the hydropower sector. E.g. A heavy landslide affected one of the tributaries in Madi Khola with the risk of temporary lake outburst. Understanding how to solve these issues is a huge concern.
- We need to be able to protect infrastructures from heavy rainfall events. There is a dilemma between prioritising design considerations (cost) and revenue when there are high construction costs.
- Some projects are not able to generate sufficient power because of low discharge. Therefore, such projects are at risk.
- The majority of the projects are not optimally designed. There is a need to address whether the current practice (regulation) of designing run-of-river projects with 40% dependable flow (Q40) is optimal and the best use of resources.
- People downstream of hydropower projects are at high flood risk and are, thus, not pleased with the projects.
- Therefore, there is a need to have reliable data and evidence-based policy restructuring.

Sandip Shah, Managing Director, Pashupati Renewables Pvt. Ltd.

- The design and construction of hydropower projects in Nepal always depend on the traditional approach to hydrology (hydrographs/flow duration curves derived using historical data), geography, and revenue schemes. We need to question if these schemes are still realistic for hydropower designs.
- As risk is a product of probability and impact, we need to question if the current practice of following a deterministic approach to hydrology rather than a probabilistic (stochastic) approach is still appropriate.
- Is it still feasible for the Nepal Electricity Authority (NEA) to accept projects with deterministic calculations?
- The Upper Bhote Koshi Hydroelectric Project, an internationally funded project, analysed the probability (likelihood) of events (GLOFs, earthquakes) during the project period. The basin experienced GLOF events in 1930, 1980 and 2016, respectively. Therefore, the deterministic approach based on past events needs to bed revisited. When it comes down to how much risk are we willing to take, and at what costs? Regarding financial investment, developers need to consider all scenarios of cost-and risks.
- The Khimti I Hydropower Plant conducted a climate assessment in 2008. The assessment found the following:
    - Flows will be normal for up to 20 years and then decrease
    - Total precipitation will be the same, but the seasonal distribution will differ, and
    - Very short but high-intensity monsoons and long dry seasons will occur
- The Upper Tamakoshi Hydropower Ltd carried out stress testing considering likely changes in the inflow hydrology and flood frequency analysis. It was expensive but had a good impact on the project, and the project resized many structures considering the

likely risks. Only internationally funded projects in Nepal carry out stress testing assessments. All projects need to carry out such assessments.

Anand Chaudhary, Treasurer, Independent Power Producers Association of Nepal (IPPAN)

A recent disaster occurred in the Madi basin, where a landslide led to the formation of a temporary lake. The government is not doing its part in data sharing and basin studies. Example: Madi basin lake.

Hydropower projects < 10 MW have been unable to generate the committed energy in the dry seasons due to lower flows than their design specifications. This has led to "penalties" being imposed. This needs to be reviewed and supported by climate information.

The government should oversee who will coordinate the projects and data sharing and prioritise basin studies. Power generation from Khimti will be affected by an upstream project in the dry season, and the government needs to look into these issues from a basin perspective.

Discussion

1. **Madan Lal Shrestha:** There are a lot of hydro-met stations under DHM (>80 will be automatic). Are hydropower developers involved in establishing these networks? DHM does not really establish these stations as per the requirement of the hydropower projects.

   In the Lower Dudhkoshi project, DHM was very hesitant about the continuation and maintenance of the stations after the completion of the project. How can this gap between mandated organisations and stakeholders be addressed?

2. **Ugan Manandhar:** If hydropower sectors were to get access to quality data, how are the projects looking into risk transfer mechanisms? One of the mechanisms could be insurance. Who is going to bear premium costs, financial loss, and damage? Because of fossil fuel consumption reduction in India due to electricity exports from Nepal, we could propose carbon financing, and we could share the benefit revenue. What are your views on this?
3. **Hari Pandit:** We do not have any documentation that shows the immediate/short-term/long-term impacts. First, we need to understand the scenarios with respect to available data, then map out events and then look into the measures to reduce the impact. For example, the potential revenue of the Jhimruk hydropower plant is NPR 360 million. And out of that, NPR 70 million is required to combat sediment only.
4. **Sanjiv Shah:** Similar kind of effects are seen in the Melamchi and Upper Dordi A hydropower projects, partly due to climate change. We cannot continue with

conventional thinking. What type of structure do we design now? We need to take a second look at the design philosophies and data required for that.

5. **Pawan Shrestha:** The effects of disasters will be seen not only by hydropower infrastructures but downstream areas too. Is this the responsibility of government bodies? The use of available data to forecast and provide impacts of climate change is important.
6. **Arun B Shrestha:** When it comes to climate information for hydropower, the focus has always been on the water. Consideration of sediment is also equally important. What is the state of knowledge for being able to talk about future sediment variability? Sediment monitoring is weaker than hydro-met monitoring. What should be the future direction of sediment monitoring?
7. **Babu Raj Adhikari:** What do you suggest as changes in policies to address climate change?

Answers:

1. **Ram Prasad Dhital:**
   Alternate benefit-sharing models should be introduced by developers. Multi-hazards should be considered seriously. The issue of sediment variability should be addressed by experts.
   Government should develop a decision support tool; technical guidelines is the need. Technical guidelines should also be considered in tariff generation.
2. **Sandip Shah:**
   We need to have a change in design philosophy and need to incorporate climate change as a major risk to hydropower projects. For all the hydropower projects that have installed gauging stations, data from such stations need to be made accessible.
   Every risk comes with a cost factor. Therefore, property damage must be incorporated. One after another incident occurred in Bhotekoshi: Jure landslide, earthquake. Insurance fully covered all the costs except for one event. The private sector needs to be ready to take risks and add the costs to cover those risks.
   As the baseline must be set in India, we have not been able to get carbon credit from carbon financing. We can move to alternate climate finance, interests, subsidies, long duration loans that will support the projects. The green climate fund requires a no-objection letter from the government, which is reluctant to provide it to the private sector.
   Regarding the sediment issue, many projects use the same quantity of sediment considerations for design purposes (3000 tons per annum). It needs to be changed as sediment load varies per the river system from east to west. And the impacts of cascading disasters should be looked into by ICIMOD.

3. **Anand Chaudhary:**
   Road excavation has increased the sediment load in most rivers; clean rivers are rare now. Our development projects do not look into sediment issues, mainly road projects.

Afternoon session: Current and future climate in Nepal – learning from observations and models

Rosie Oakes, Met Office, presented the climate model and how they work. Climate models can help us understand past, present, and future climates. There are different emission scenarios based on different policy decisions for the future. The climate model incorporates interconnected systems with lots of physical processes represented by a series of equations. The entire world is put into a series of grid boxes to run the calculations and get climate data through these models. Climate models have improved over time. Each assessment report from the IPCC has enhanced the models, and data has been improved over time. Models are getting more detailed (high resolution), more interactive, and can run faster. There is, however, too much uncertainty in the climate models, so running multiple models is important. We need to consider the difference between global climate models and regional climate models. Although the observed trends are the same, the values differ. With the information from the climate models, we can know the direction and scale of climate trends and see how extreme climate events could change in frequency and magnitude. However, we cannot predict what will happen on a specific day or month, and we cannot get specific values for a certain location using information from just one grid cell. We cannot use one scenario to predict the future.

Q&A:

Instead of partial differential equations, can we not use the finite element method for the prediction?

Different models are in different grids (resolutions). The limitations are not methodological but computational. Some ocean models use this approach, but the limitation is more computational.

Hamish Steptoe, Met Office, presented Nepal's current risk of extreme rainfall. Present-day extreme rainfall events are more significant than we think, and we must look at multiple data sources to assess rainfall accurately. Reliable estimates of data only come through long records of data. We must move away from a single deterministic estimate to a more probabilistic one. Local rain gauges, DHM rain gauges, satellite data, and computer models (these run back further in time and-multiple scenarios over hundreds of years, but the resolution is relatively low) are some of the precipitation measurements models. None of these is perfect, so looking at multiple sources can help overcome individual limitations.

The blended datasets were used over the Dudh Koshi basin, and 1 in 100 years' maximum daily rainfall (RX1Day) was estimated. Some observations of different gridded datasets are: Aphrodite 2 underestimated the RX1Day magnitude, and ERA5 gave a wider range of results.

Q: How long (duration) period dataset is considered for the frequency estimate?

A: 30 years or more. But essentially, the more data, the more reliable the prediction.

Katy Richardson, Met Office, presented the future risk of extreme rainfall in Nepal. What do climate models say about the future climate in Nepal? Looking at 2050s emission scenarios, many models are analysed to explore uncertainty, and all models showed an increase in temperature between 1.5 °C to 4 °C. Most models show a weather change. The value of extreme rainfall is higher in the future over the monsoon season in Nepal.

Model evaluation criteria: How well do the climate models capture the large-scale processes in the atmosphere that cause extreme precipitation events?

Model assessment criteria: In a south Asian monsoon, how well does the model capture wind speed and direction over the monsoon period?

For analysing projected changes in extreme daily precipitation in the 2050s, 47 models were considered (30 GCMs and 17 RCMs) over Nepal. There is an extensive range of plausible future changes in extreme daily monsoon precipitation. No scenario shows a reduction in extreme precipitation; one scenario shows little change, and 3 scenarios show increases of varying magnitude.

The next step would be to translate these scenarios into information about the river flow and flood frequency at the basin level and better understand what these scenarios may mean for the hydropower sector.

Saurav Pradhananga, ICIMOD, presented a study using hydrological modelling to extreme rainfall to river flow: An example from the Koshi basin. The study team used hydrologic modelling to simulate discharge in the Dudh Koshi basin, using HAR and GloSea5 data and analysed high flows from the simulated discharge. Hydrologic models can fill the missing gaps in existing records, estimate flows for ungauged rivers, generate long-term records to establish reliability, and provide input data for other research – environmental flows, forecast modelling, etc. The team yielded satisfactory results during model calibration and validation, even though the model did not capture all the peak events. The team fed gridded climate data products as inputs to generate and analyse future flows. Using gridded datasets to compare results, the team deduced that the discharge simulation with HAR datasets of 10 km resolution does not represent the flow in the catchment. However, the GloSea5 dataset of 0.8*0.5 resolution represents the results quite well. Simulated low flows do not match the observed dataset, as the GloSea5 dataset was only available for the monsoon period (June to September). The team used ERA5 rainfall data for the other months.

We can use the flow duration curve to look at high flows (Q10), which is around 550 cumecs at present. In one of the scenarios for the hypothetical future, the team checked 1 future scenario by increasing the 40% precipitation just for the monsoon; this flow is projected to change to Q25. This means high flows which exceed 10% of the present time are projected to exceed 25% of the time in the future. However, extensive work needs to be done to generate an ensemble of the future flow rather than rely on just one scenario.

During very high flows, sediment flow will also increase, directly impacting hydropower generation and damaging mechanical parts. It is, therefore, essential to look into high flows. Other avenues that can be considered design discharge estimation using hydrological models, the impact of climate change on mean and extreme discharge, development of future scenarios of discharge, spatial transferability of process-based hydrological model parameters in the catchment (for example, Dudh Koshi to Tamor), and sediment transport modelling.

Q&A:

Assuming a project is being designed for Q50, what is the confidence level?

Here, only one model is considered. It is preferable to select a few more models and look at the ensemble band of flows to generate more robust results.

Has the validation of the gridded rainfall been done with the ground rainfall station?

For this study, the comparison was made only against observed discharge data. We cannot directly compare the station rainfall with the gridded ones. However, the comparison can add confidence to the result if the station data can be converted to gridded data after applying interpolation techniques.

If this is the trend based on the flow duration curve, why can we not capitalise on high flows? If this is the trend, then we should put pressure on the government.

As the results were obtained from only one model, we cannot use this result directly. Considering many models can give a band of results based on which the future projected flows can be studied. We also need to design a new power purchase agreement from the hydropower point of view.

Interactive Game: Decisions for the decade: an interactive game to learn about the value of integrating climate information into decision making

In this interesting part of the workshop, participants were split into 3 groups and given 12 tokens each, indicative of paper money. In their notebook, they were asked to split a page into 2 parts "Power production" (business as usual) and "Flood defence" (flood event). A hypothetical past seasonal precipitation record was provided, with some precipitation events exceeding the flood limit: if a flow exceeds this level, that could be considered a damaging event. Based on the distribution of such flood events over the period of approximately 30 years, the attendees were asked to split the tokens for production and flood defence.

With the knowledge of past occurrences of flood events (once in six years in the first climate dataset), attendees were requested to separate their tokens for the 2 possible scenarios. A six-sided dice was then rolled to determine the nature of events that occurred. For example, if the dice resulted in the number 6, that would be a flood event. Now when the number 6 occurred, and if a participant had separated his/her token for flood defence, one of the tokens for flood defence was taken away. If the participant did not invest any amount or no token was left in flood defence, 2 of the tokens were taken away from the power production scenario. For numbers 1 to 5, no action was taken. A dice was rolled 10 times. At the end of the game, the participants with the maximum number of tokens left under the power production scenario are considered to have made a good decision on investment in flood defence.

The game was played again with a historical different data scenario where the probability of occurrence of flood events was increased to 37.5% (3 out of 8). For this game, eight-sided dice were used, and if a number from 6 to 8 occurred when a dice was rolled, it was considered a flood event. The participants were again asked to divide the twelve tokens into two parts (power production or flood defence). In this second session of the game, the concept of resilience was introduced. When a flood event occurred (numbers 6 to 8 when a dice was rolled), the same number of tokens as in the first game were taken away (one from the flood defence, if available, and, if not, two from power production). In addition, one additional token was flipped from the flood defence if the additional token was available. If not, two tokens were flipped from the power production section. And in the next round of the dice roll, if a consequent flood event occurred, the tokens that have been flipped earlier are taken away, in addition to the same number of tokens (one from "flood defence", if not available, two from "power production) that are taken away and flipped from respective scenarios. If a no-flood event occurs after the earlier flood event, the flipped tokens are flipped back to their normal face. The idea of flipping some tokens when a flood occurs was to demonstrate that the structures would be stressed when a flood event occurs and will need time to recover to their normal state. This was to demonstrate the concept of resilience. The best-performing investor would be with a higher number of tokens left in the production scenario after the end of the game.

In the second session of the game, a rare event of four consecutive floods occurred, resulting in losses of many tokens from the production scenario of all participants. The participants did not anticipate the rare event of such consecutive floods occurring when the chance (probability) of an individual flood event was 3 out of 8. The game showed that the past event data was a sample based on, say, 30 years, and the probability of flood occurrence (uncertainty) during the shorter project duration can be different, as seen in this game. It was also noted that some participants followed the "probability" concept and others followed their "emotions" while taking decisions with risks. The game was useful for understanding the concept of "uncertainty", "risk", and "resilience".

Day 2 – From climate science to decision making

Morning session – Using storylines to explore future adaptation

Rosie Oakes, Met Office, started the second day of the workshop by reflecting on the first day by brainstorming the word cloud of keywords as the expectations of participants from the workshop. Hydropower and climate were the two most significant words in the word cloud, including other words such as change, data, design impacts, etc. Oakes summarised the key thoughts of the participants into three categories.

First – understanding: Participants wanted to know how climate change is functioning (also wanting to learn about climate change) in the hydropower sector. Participants wanted to understand more about climate change, and climate change impacts on hydrology as well.

Second – integrating: As per the word cloud, the participants were interested in how they could integrate climate information in hydropower design and planning and use the climate information in operation.

Third – data sharing: The third important point from the word cloud was the need for data sharing (hydrology and impacts) across international borders. Another point was decision-making and the way forward, focusing on the way forward for hydropower developers.

Oakes highlighted the main points from day one as the concern of hydropower developers regarding possible future changes and why climate information is not easy to integrate into decisions. She gave an example of the Madi Basin disaster and pointed to the situation of impact documentation in Nepal and the importance of reframing the design framework. Oakes shared that the participation of experienced experts would help chart a clear way forward by the end of the workshop. The rest of the morning session was divided into presentations from the partner research organisations and the Met Office, followed by an exercise on future visioning.

Extreme rainfall events and their correlation with flood occurrence: NDRI

Divas Basnyat and **Divya Laxmi Subedi**, **Nepal Development Research Institute (NDRI)**, presented the initial findings of the "Event-based modelling and flood frequency analysis for the Dudh Koshi as a case study". The presentation summarised the first day's keywords, highlighting data uncertainty when using climate models. Using historical climate and hydrological data to design hydropower projects is no longer valid as the future is expected to differ from the past (due to the non-stationarity of climate data). The conventional practice addressed uncertainty using probability distribution functions to model climate/hydrological data, which can define climate/hydrological variability as a "known unknown". However, we are entering the “unknown unknown” phase due to climate and other future uncertainties. The conventional approach of using probability distribution functions derived from historical data to model uncertainty is not appropriate anymore. Hence, “resilience” is necessary for hydropower design and planning. Resilience needs to be defined in two parts – “robustness”, which requires our decisions to be appropriate for different probable (expected) futures, and “flexibility”, which requires our design and planning to adapt to an unexpected future (i.e., the “unknown unknown”).

The presentation then highlighted past events of extreme rainfall leading to climate-induced disasters such as the flooding and high sediment load in the Bagmati Basin in 1993, Jure landslide damming in 2014, and the cascading multi-hazard led debris/sediment-laden floods in Melamchi in 2021. Projected changes of different climate change indices proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) in the Dudh Koshi basin were presented. The indices highlighted the availability of metrics other than the maximum 1-day precipitation (RX1day), which can be linked to floods, sediment load, and landslides.

The methodological framework for event-based modelling to study the impact of climate change (vis-à-vis RX1Day) on floods in the Dudh Koshi basin was presented, which includes:

(i) Historical rainfall data analysis: The gauge data available from DHM is insufficient. Therefore, selected satellite datasets were used to conduct a frequency analysis of historical RX1Day data.

(ii) Future projections based on CORDEX CMIP5 RCMs: Bias-correction of high precipitation data using Generalised Pareto Distribution (GPD) was carried out, and the future RX1Day data for different climate scenarios were derived. The projected data was checked for trend and stationarity, and a non-stationary rainfall frequency analysis was used.

(iii) Finally, the catchment-level RX1Day values for different return periods (i.e. in 50 to 1000 years) will be spatially and temporally downscaling(disaggregated) and used to drive the HEC-HMS model to derive future floods in Dudh Koshi basin. This is then used to assess the impact of climate extremes on foods (change analysis),

Preliminary results from the event-based hydrological modelling using HEC HMS, bias correction, future projection under RCP 4.5 for the selected climate models, and initial hydrological model results were shared.

It was concluded that resilient hydropower needs to be robust (for the current climate and climate impacts we can predict – known unknown) and flexible (for impacts we cannot predict – unknown unknown)

A Q&A session followed the presentation

Can I model and predict the flood event if I have the time series data for each month?

Yes. In the presentation graph, the dark line represents the observed data received from the Department of Hydrology and Meteorology (DHM). We used 10-12 days of data for event-based analysis for this study.

Floods will increase in 1:100 years by up to 49% by the 2050s. What does that mean?

The maximum one-day precipitation is projected to increase to 49%, based on climate projections for selected models.

In one of the rainfall maps, why do we have the blocks? It looks like the results of the modelling.

This is because we are using gridded datasets.

When we see the hydrograph of HEC HMS, it does not seem like it is catching the peaks. What is the reason?

We used MSWEP gridded datasets. It can be said that MSWEP is not catching the peak of the observed data. Another factor might be that we cannot entirely rely on the hydrological data. Here we are assuming that the hydrograph is correct.

Is there a positive trend? It is scattered. Is it true?

The Mann-Kendall trend analysis tests whether the time series has a "monotonic upward or downward trend" trend, and the p-test value shows that the RX1Day data has a monotonic upward trend.

Between academics and researchers, to what extent do we need this data to design the hydropower project?

We will have a special session in the afternoon for group discussion. We understand that more work is needed, and we will incorporate the ideas to how best we could present the data to the users.

Historic 1 in 100-year flood is more frequent. As an investor, how am I going to use this information? I still need to have a safe landing on my investment. Should I go by science? But what will happen in the basin and landscape if we put in the emotion? No one will care about human emotion if we only base our decisions on science.

We have to present our findings understandably. Return periods mean the probability of the event occurring once in so many years (return period). But there is always the chance (low probability) that these events may happen more often. There are many uncertainties (climate and others) which means that we are entering the domain of the unknown-unknown. Hence, it is a risk assessment and management decision for the investors and regulators.

From the private sector perspective, they will use 1 in 100 years flood as a design flood in hydropower design, but the main concern is the downstream people. They will not agree as they are more at risk than the upstream people. Therefore, Nepal's Government must come forward to manage and mitigate the risk.

We see only the results of RCP4.5. Where are the RCP8.5 results?

We have the preliminary results of RCP8.5. But we are not satisfied with the results. Hence, we need to work on it to make it better.

It should make much sense from the design perspective. What about the regulatory perspective? For the private sector, do you have plans to consider the uncertainty?

Suggestion: There are many projects in Dudh Koshi, and climate change poses an additional risk. Given the high uncertainty, a risk-sharing mechanism between the public and private sectors must be designed and agreed upon.

We need to design it adequately so that it is safe, not only for 1 in 100 years but for higher return periods (500–1000 years and more).

The resilience of hydropower to climate change is complex due to the landscape. This presentation has shared an idea on how we can plan and design. The indices have been there for 20-30 years with no changes. Are we willing to follow these indices? Or do we need to revisit these indices to estimate the extreme values? Are we able to come out with indices that are relevant to our region? There is a scope for change in these indices now.

We fully agree with the concept. But the importance of data plays a significant role. If the DHM provides enough data for the last 20-30 years, then we could use these indices in a better way to develop regional models (relationships of these indices to climate impacts – floods, sediment load). For example, Water and Energy Secretariat (WECS) has developed regional models for flood analysis in ungauged basins using multiple regression analysis using climate, catchment, and hydrological data of available catchments.

Rosie Oakes: We will address the indices and the needed guidelines in the latter session.

I would be interested to know about the low-flow analysis. Frequency analysis of low flow is equally essential because private sectors do power purchase agreements based on the low flows.

We agree with your concern. The model ICIMOD's Saurav Pradhananga showed the day before can do the low flow analysis. Therefore, we request that ICIMOD consider the low flow analysis in future research. However, we are ready to support the research entirely.

Joseph Daron, Met Office, presented three climate risk narratives for Nepal, one for the current day and two for the future. The two future narratives were of two types, one was a pessimistic future, and the other was an optimistic future. He shared various definitions explaining climate risk narratives. He talked about what it is likely to be when the climate changes in the future, referenced the movie "Imagining the future", and explained how difficult it is to predict and imagine the future. The participants were split into four groups for the group work. The groups were provided with the storylines for the present day as well as narratives for the possible future. Each group, after the discussion, provided inputs on any changes they would like to make in the narratives, shared their version of the climate risk narratives for the present day, and imagined the future, including the pessimistic and optimistic scenarios.

Rosie Oakes, Met Office, shared feedback from the group discussion on the learnings and the narratives. She focused her talk on the key actions people could take for effective resilience. The exercise was essential to understand the process for developing future scenarios, whether development or climate.

The participants were divided into three groups and requested to go through relevant sections of the narratives and indicate what was present or missing for conducting climate risk analysis. Each group selected a moderator and rapporteur for the discussion and was provided thirty minutes for discussion and five minutes for reporting back. The summary of reporting by all three groups is listed below:

Group 1: Rapporteur: Rosie Oakes

Group 1 decided not to change the climate risk narrative for the present day and keep the information as it is. They named the climate risk narrative for future-1 "The glorious future", and they listed the predicted changes as follows

- Good point: Nepal will export electricity by 2030
- Will achieve the objectives of Green Carbon
- 1.5 °C warm Nepal (optimistic), 1.8 °C for global warming, will rise up to 2 °C
- Technological advancement and notifications through smart watches can happen

- Nepal will be in favour of hydropower development, and the DHM will find other sources of money

They named the climate risk narratives for future 2 "The Gloomy Future", and the list of predicted changes are as follows:

- Massive migration within the conflict areas
- An increase in conflict predicted
- High electricity costs and in rural areas, people will face more deforestation and climate disasters

Group 2: Rapporteur: Hamish Steptoe

They named the climate risk narrative for present-day "Present day good enough" and listed the changes in the narratives as follows

- Flooding is mentioned, but landslides are equally important and frequently occur in Nepal.
- Good Point: Some people benefit from no information (they will not panic and live a simple life)
- Power purchase in India is not working optimally
- Imports from China are increasing
- The electricity generated from Arun IV is planned to export to India only

They named the climate risk narrative for future-1 "I have a Dream, Happy Nepali Prosperous Future" and listed the predicted as

- Optimistic: Nepal is doing very well in the Asian Games
- Nepal would be the chair of COP 30, with the target of fulfilling the commitments by 2050
- More improvements in science
- DHM will share more data

They named the climate risk narrative for future 2 "Sad Nepali Dark Nepal" and listed the predicted changes points as

- Nepal would see 12 different prime ministers in 12 months
- Two prime ministers will be swept away by floods during the inauguration of two major hydropower projects
- Nepal will face the economic blockade

Group 3: Rapporteur: Rojina Haiju

They named the climate risk narrative present-day "For Hydropower and Beyond" and listed the changes in the narratives as

- 93% of Nepal's people have access to electricity
- India is also investing in infrastructure in Nepal (India Nepal joint vision statement on Power sector cooperation and also promoting trade)
- Load shedding: due to insufficient power and India's high prices, there are fluctuating power cuts in the industries
- During the wet season, the supply is more than the demand and supplying 364 MW in the wet season. The previous year, 1/3 of the power generated was exported
- The real constraint is not generation but rather shortcomings in transmission
- 91 out of 111 private projects are less than 10 MW
- In June last year, heavy rainfall and flash flood also destroyed transmission lines of the Indrawati Hydropower Project, disturbing energy transfer for around 1 month
- Floods in Dordi corridors also destroyed 47% (911) of the 1945 MW investment of the private sector
- There is currently no regulation to use future climate information in managing changing climate risks, but Annex 2: States Environment & Social Risk Management Consideration in Hydropower Projects published under the Guideline on Environment and Social Risk Management (ESRM) for banks and financial institutions by the central bank of Nepal

To manage climate risk, the role of government is critical. Their share is significant as Nepal has 47% private investment, which is different from other countries. Therefore, they named the climate risk narrative future-1 "Resilient Future", where they listed the following key predicted points

- Nepal will host T20 Cricket World Cup
- Pollution growth will be 40 million
- Tourists from India and China will come due to explore Nepal due to the excellent connectivity of roads and railways
- Hydropower will generate 85% of Nepal's energy, whereas 15% will be from solar and wind power
- Nepal will be a net electricity exporter by 2026
- Will be careful in managing the resources and cross-border electricity trade in the region will also have alternative energy storage
- Insurance will play a major role in the future in overcoming loss and damage

- The hydropower organisation's cost will be covered by a 50% royalty cost for new observation, not just the maintenance. The royalty costs will also bear the relevant costs

They named the climate risk narrative for future 2 "Dystopian Future" and listed the following predicted points

- The population will be 52 million
- If climate change risks are not managed, hydropower will generate 60% of the energy demand and solar, and other alternative energy will be even cheaper, and the remaining energy demand will be imported from India at a high price

Afternoon session – Gaps ad next steps

Climate risk assessment guidelines group exercise

The afternoon session mainly focused on climate risk assessment and review of guidelines for the study of hydropower projects, 2018, shared by Mandira Singh Shrestha.

The session started with exercise 1. Participants were asked to answer the first question, "what are the various guidelines and tools that participants were aware of, and how are those guidelines used for climate risk assessment on design and planning of hydropower?". All participants shared the names of various guidelines of which they were aware.

"What additional guidelines or tools would they like to be available, and what is missing?". Keywords shared by the participants following the question were detailed design standard, climate risk assessment, updated environmental flow consideration, tools for weather generator, climate models downscaling and bias correction tools and stress test overall tool for climate risk assessment, low flow guidelines, multi-hazard mapping tools, etc. The majority of available guidelines were found to be not specific about assessing climate risks. Sedimentation is a major problem in Nepal's rivers, but none of the guidelines included sedimentation hydrology.

For this exercise, participants were divided into 4 groups and were provided with the section of "guidelines for the study of hydropower projects". - **Hydrological and Sedimentation studies** – pages 9-10, 56, 117, 118, 119, collection of long-term data- rainfall and discharge, flood frequency analysis with the question "Is it adequate, what is missing in the guidelines?

Risk Analysis- Page 99-100,164, 165, 166, Hydrological, financial, geological, design and construction with the question" What is there and what is missing in the guidelines and needs to be incorporated?". As requested, all groups shared the lists of included and missing points within climate risk assessment guidelines. Each group selected a moderator and rapporteur for the discussion and was provided twenty-five minutes to discuss and five minutes to present.

Group 1:

Hydrological and sediment (included)	Not included
P<10MW: -Rainfall -Discharge (field measurement) -Hydrologic modelling for ungauged -continuous measurement Sediment: - Collect sediment samples -Continuation of sampling - Determine the tentative value for median grain size d50 - Private Sector Development	- Climate Change impact not spelt out
10-50MW: -Assess the impacts of climate change with uncertainty analysis on the availability of flow based on long-term flow data and other secondary data	Document for assessment, impact, and mitigation is not available
50-100MW: - GLOF -Storage Projects -Sequence of operation -Assessment of climate change impact	- Document for assessment, impact, and mitigation is not available
Risk analysis	
10-50 MW: (Included)	Not included
Hydrology: - Flow variation - Seasonal, monthly - Drought + data - Limit of Energy - Generation (Upper-Lower) Flood risk: - Geology -Slope -GLOFs - Landslide Dam Outburst Flood Sediment: - Impact of sediment on hydraulic structure - Hydro Mechanical Engineering	Specific climate change impact
50-100 MW: (Included)	Not Included
Financial: - Construction Methodology - Currency risk - Bank interest - Insurance policy	Specific climate change impact

- Revenue variation Geological: - Past geological events - Error in investigation - Seismic risk	

Group 2:

Less than 10 MW Projects

- Requirements are changing for private stakeholders
- The methodology is not clear
- Qualifications of personnel (Clarifications needed)
- Transboundary Issues

10 to 50 MW projects

- The uncertainty analysis methodology needs clarification
- Linking National Adaptation Plan (NAP) climate scenarios

Guidelines:

- Weather stations establishment in snow-fed catchments will need more clarity and separate guidelines
- Guidelines for cascade projects
- Establishing stations, robust data
- Low flow events identifications

Group 3:

1) Data availability for climate risk assessment
2) Tool kit for data analysis and risk analysis
3) Basin-wise risk analysis (than individual projects)
4) Government has to carry out a risk assessment and provide information on the project for the mitigation
5) Example: United Nations Development Programme (UNDP) carried out mitigation in the case of the Khimti Project
6) Projects in the same basin should continue sediment data collection and share it with the projects

Risk analysis:

1) Risk Analysis is needed in the case of smaller storage projects (50–100MW) sediment yield
2) Global warming impacts on GLOF study
3) High-intensity risk flow (induced by discharge for the study of landslides and debris flow
4) Temporal variations in river flows

Group 4:

Pre-feasibility –

- A water availability study is available.

Feasibility:

What is there:

- GLOF study
- Climate models (predicting extreme runoff events)
- 30 years of data consideration
- Hydrological study
- Extreme flow analysis
- Return Period mentioned for <10 MW 200 years and for > 100 MW 500 years
- Flood frequency analysis
- Geological and sediment studies included
- >10 Landslide Dam Outburst Floods (LDOFs)

Not included:

- Need for a body that could analyse risk-prone areas for the hydropower developers
- Fundamentally there should be a dedicated climate service centre to develop the tool
- A Review Committee led by the Government of Nepal is required
- Rapid assessment, climate stress test
- Climate study and stress analysis

Outline:

- Step-1: Identify the performance metric.
- Step 2: Risk classification (how and why)
    - Climate change and variability analysis, water availability analysis (probabilistic)

- Climate risks due to extreme events
- Erosion and sedimentation

- Step-3: Risk assessment (Who should do it)
    - Government, central bank, developers, other institutes
- Step-4: Mitigate or manage climate risk (How to do it)
- Step-5: Institutional arrangements
    - Mechanisms for coordination between the actions of government, civil society, and the private sectors

After the group presentation, participants discussed existing risk analysis guidelines, the drawbacks of not considering climate, and ways to improve the guidelines regarding climate risks. Highlighted the importance of climate stress tests before the project design and focused on the need for climate resilience adaptation, institutions for coordination, and co-working on climate adaptation. Discussion summarised in the following points

- In the inclusion of the project's economic parameters, how will project developers address the financial issues?
- Under normal circumstances, what are the developer/ hydropower stakeholders looking to incorporate in design, hydrographs, and flow duration curves? Nepal Electricity Authority uses 50% monthly, and adding climate change risk will increase the band. In such cases, how can the designs be improved?
- How can the events, such as particular rainfall, rainfall extremes experienced in different parts of the country, cloud bursts, etc., be calculated?
- The outline, when considered, could be holistic, beyond climate risk analysis, what would be the role of hydropower developers for sustainable hydropower development. There is a need for a climate risk assessment tool, including co-developed, co-designed products for sustainable hydropower development.

Hamish Steptoe, Met Office and **Saurav Pradhananga, ICIMOD,** facilitated the group session on finding gaps and necessary climate information. Steptoe spoke about the current risk of extreme rainfall in Nepal and the Met office's observations and analysis. The participants were then divided into three groups and given the task of listing the three immediate actions they felt as the outputs of the workshop. The key actions, as listed by the participants, are as follows:

- ✓ Training programme for policymakers and project developers – capacity building at all levels
- ✓ Data availability and improvement – availability, access sample assessment tool
- ✓ Climate risk assessment mandated – guidelines include an operational mechanism for implementation
- ✓ Interactive decision support tool

- ✓ Sharing existing data
- ✓ Analysis tools – what is needed, what tool, what regional climate models
- ✓ Capacity building for data analysis
- ✓ Find out how climate change issues can be incorporated into guidelines

Participants were allowed to mark their names where they could contribute to one or more actions from the list, which made them realise their roles and responsibilities regarding sustainable hydropower development under extreme climate conditions.

In his closing remarks, **Joseph Daron, Met Office**, shared that the presentation, discussions and interactive exercises were very motivating. He informed that the Asia Regional Resilience to a Changing Climate (ARRCC) would end, but the Met Office would want to keep the interactions going. He shared that at the beginning of the workshop, they scoped the upcoming programme for the next five years and that the workshop would help improve the design of the upcoming project. He thanked the organising partners as well as the participants for extending their valuable input and time.

Divas Basnyat, NDRI, expressed his privilege to participate in the workshop. He reflected on the keywords that came up during the workshop, such as understanding climate information and climate extremes, linkage of flood and extreme events, and guidelines for hydropower development. He noted the pool of diverse knowledge the participants and stakeholders in the room had on climate change, hydropower design and climate extremes. He acknowledged the presentation style, games and group work presented by the Met Office and ICIMOD. He also noted the important messages that ICIMOD, Met Office and NDRI representatives delivered during the sessions. The panel discussion and the presentations were all very useful and relevant to improve climate services in the hydropower sector. Reflecting on the works and presentations of the workshop, he expressed NDRI's motivation to work further to fill the gaps in our region. He also informed the audience about NDRI's forthcoming projects and NDRI's interest in future collaboration with ICIMOD and Met Office. He thanked the organisers and the participants for the very fruitful two-day workshop.

Birendra Bajracharya, ICIMOD, expressed how he considered this workshop a great learning opportunity. He shared the participants' commitments as a motivating factor for the beginning of the new journey in climate change and hydropower. He thanked the organisers and shared that he expected more significant contributions from everyone for the forthcoming "Wiser Asia" project.

Annex A: List of participants

SN	Title	Name	Designation	Gender	Institution
1	Mr.	Ananda Chaudhary	Treasurer	Male	Independent Power Producers Association of Nepal
2	Dr	Anu Kumari Lama	Tourism Specialist	Female	International Centre for Integrated Mountain Development
3	Ms.	Anugya Sapkota	Hydropower Engineer/ Team Leader	Female	Hydro-Consult Engineering Ltd.
4	Dr.	Arun Bhakta Shrestha	Programme Manager: River basin and Cryosphere	Male	International Centre for Integrated Mountain Development
5	Mr.	Babu Raj Adhikari	Senior Divisional Engineer	Male	Ministry of Energy, Water Resources and Irrigation
6	Mr.	Basu Dev Bhandari	Chief Manager, Hydropower	Male	Hydroelectricity Investment and Development Company Limited
7	Mr.	Divas B. Basnyat	Coordinator Water & Climate Program	Male	Nepal Development Research Institute
8	Ms.	Divya Laxmi Subedi	Research Associate	Female	Nepal Development Research Institute

SN	Title	Name	Designation	Gender	Institution
9	Mr.	Girish Raj Lamsal	Research Associate	Male	Nepal Development Research Institute
10	Dr.	Kapil Gnawali	Senior Divisional Hydrologist	Male	Water and Energy Commission Secretariat
11	Dr.	Karma Tshering	Remote sensing and DRR Specialist	Male	International Centre for Integrated Mountain Development
12	Mr.	Kunjan Lal Pradhan	Research Engineer	Male	Hydro Lab Pvt. Ltd
13	Mr.	Madan Lall Shrestha	Academician	Male	National Academy of Science and Technology
14	Mr.	Manohar Shrestha	Managing Director	Male	Hydro-consult
15	Mr.	Padmendra Shrestha	PhD Candidate	Male	School of Geography, Development & Environment/University of Arizona
16	Dr.	Pawan Kumar Shrestha	Chairman	Male	Hydro Tunnelling and Research Pvt. Ltd.
17	Mr.	Pradeep Gangol	Chief Executive Officer	Male	Power Trade and Energy Exchange Ltd.
18	Mr.	Pratik Man Singh Pradhan	Vice President of Business Development	Male	Butwal Power Company

SN	Title	Name	Designation	Gender	Institution
19	Mr.	Raj Singh	Senior Electrical Engineer	Male	Institute of Engineering
20	Dr.	Ram Prasad Dhital	Senior Regulatory Advisor	Male	Financial Sector Stability Program/ FCDO
21	Dr.	Ramesh Ananda Vaidya	Advisor	Male	International Centre for Integrated Mountain Development
22	Ms.	Rojina Haiju	Research Associate	Female	Nepal Development Research Institute
23	Mr.	Ronit Kayastha	Senior Officer, Hydropower	Male	Urja Developers Pvt. Ltd.
24	Mr.	Sandip Shah	Chairman & Managing Director	Male	Pashupati Renewable Pvt. Ltd.
25	Dr.	Sanjiv Shah	Managing Director	Male	Shah Consult International Pvt. Ltd.
26	Ms.	Sarita Shrestha	Head of Business Integration	Female	Urja Developers Pvt. Ltd.
27	Mr.	Shankar Shrestha	Executive Director	Male	Nepal Development Research Institute
28	Mr.	Ugan Manandhar	Climate and Environment Advisor	Male	Foreign, Commonwealth & Development Office
29	Mr.	Vishnu Bahadur Singh	Chief Executive Engineer/ President	Male	Nepal Hydrogeological Association

SN	Title	Name	Designation	Gender	Institution

Resource Persons:

30	Dr.	Mandira Shrestha	Programme Coordinator Climate Services • MENRIS	Female	International Centre for Integrated Mountain Development
31	Mr.	Saurav Pradhananga	Water and Climate Analyst	Male	International Centre for Integrated Mountain Development
32	Dr.	Hamish Steptoe	Senior Scientist (International Applied Science and Services)	Male	Met Office
33	Dr.	Joseph Daron	Manager (International Applied Science and Services)	Male	Met Office
34	Dr.	Katy Richardson	Senior Scientist (International Applied Science and Services)	Male	Met Office
35	Dr.	Rosie Oakes	Senior Scientist (International Applied Science and Services)	Male	Met Office

Annex B: Agenda

Day 1 – 12 July 2022: Hydropower and climate change: How do we increase resilience?

Morning session–Introductions and setting the scene

Time	Programme	Resource persons
10:00–10:10	Registration	
10:10–10:30	Opening session	
	Welcome remarks	Katy Richardson, Met Office
	Opening remarks	Shankar Shrestha, NDRI
	Welcome remarks	Basanta Raj Shrestha, ICIMOD
10:30–10:40	Summary of the 2019 workshop and objectives of the workshop	Mandira Singh Shrestha, ICIMOD
10:40–11:00	Introductions and expectations from participants	Rosie Oakes, Met Office
11:00–11:30	Coffee break	
11:30–12:30	Understanding the decision landscape for hydropower stakeholders – panel	Government and industry stakeholders
12:30–13:30	Lunch break	

Afternoon session–Current and future climate in Nepal: Learning from observations and models

Time	Programme	Resource persons
13:30–13:45	The current risk of extreme rainfall in Nepal	Hamish Steptoe, Met Office
13:45–14:00	What is a climate model, and how do they work?	Rosie Oakes, Met Office
14:00–14:15	Future risk of extreme rainfall in Nepal	Katy Richardson, Met Office
14:15–14:30	Extreme rainfall to river flow: An example from the Koshi Basin	Saurav Pradhananga, ICIMOD
14:30–14:45	Q&A	
14:45–15:15	Coffee break	
15:15–16:45	Decisions for the decades (interactive game to learn about the value of integrating climate information into decision-making)	Hamish Steptoe/Rosie Oakes, Met Office
16:45–17:00	Summary of Day 1 and plans for Day 2	Mandira Singh Shrestha, ICIMOD

Day 2 – 13 July 2022: From climate science to decision making

Morning session – Using storylines to explore future adaptation

Time	Programme	Resource persons
09:30–09:45	Welcome and lessons from Day 1	Rosie Oakes, Met Office
09:45–10:15	Event-based modelling and flood frequency analysis focused on Dudh Koshi	Divas B Basnyat, Divya Laxmi Subedi and Rojeena Haiju, NDRI
10:15–10:45	Q&A	
10:45–11:00	Coffee break	
11:00–12:30	Break out groups – Using storylines to envision the future and understand the decision landscape	Joseph Daron, Met Office
12:30–13:30	Lunch break	

Afternoon session – Gaps and next steps

Time	Programme	Resource persons
13:30–15:00	Discussion on Climate Risk Assessment guidelines – presentation and group work	Mandira Singh Shrestha, ICIMOD
15:00–15:30	Coffee break	
15:30–16:15	What are the gaps? What climate information did you wish you had? End of workshop questionnaire	Rosie Oakes, Met Office and Saurav Pradhananga, ICIMOD
16:15–17:00	Closing session Sharing workshop outcomes and next steps Final thoughts from stakeholders Closing remarks	Mandira Singh Shrestha, ICIMOD Joseph Daron, Met Office Divas Basnyat, NDRI Birendra Bajracharya, ICIMOD

Rapporteurs: Divya Laxmi Subedi and Rojeena Haiju, NDRI