**BUTWAL POWER COMPANY LIMITED**

Buddhadanagar-10, Kathmandu



**Hydrological Study report of**

**ANDHI KHOLA HYDROPOWER PROJECT (9.4 MW)**

**SYANGJA**

**February 2023**

**Prepared by:**

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ANDHI KHOLA HYDROPOWER PROJECT (9.4 MW)

**UPDATED FEASIBILITY STUDY REPORT**

Main Report

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**February 2023**

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# LIST OF ACRONYMS

AMSL above Mean Sea Level

ASCE American Society of Civil Engineers

AR Access Road

B/C Benefit/Cost

BL Base Line

BM Bench Mark

BoQ Bill of Quantities

CBR California Bearing Ratio

DBM Design Base Memorandum

DC Direct Current

DCPT Dynamic Core Penetration Test

DDR Detailed Design Report

DEM Digital Elevation Model

DHM Department of Hydrology and Meteorology

DoED Department of Electricity Development

D/S Downstream

EDR Eastern Development Region

EIA Environmental Impact Assessment

EIRR Economic Internal Rate of Return

EPC Engineering, Procurement, Construction

ERMC Environment and Resource Management Consultant

ERT Electric Resistivity Tomography

FAT Factory Acceptance Tests

FDC Flow Duration Curve

FIDIC International Federation of Consulting Engineers

FSR Feasibility Study Report

GLOF Glacial Lake Outburst Floods

GoN Government of Nepal

GPS Global Positioning System

GWh Gigawatt Hour

HCE Hydro-Consult Engineering

HEC-RAS Hydrologic Engineering Centres River Analysis System

HP Hydropower Project

HFT Himalayan Frontal Thrust

HRT Head Race Tunnel

H/W Headworks

ICIMOD International Center for Integrated Mountain Development

lEC International Electrotechnical Commission

lEE Initial Environment Examination

IEO International Electro Technical Commission

INPS Integrated Nepal Power System

IPP Independent Power Producers

IRR Internal Rate of Return

ITP Inspection and Test Plan

KV Kilo Volt

MASL Meters Above Sea Level

MBT Main Boundary Thrust

MCT Main Central Thrust

MDE Maximum Design Earthquake

MHPP Ministry of Housing and Physical Planning

AKHPU Andhi Khola Hydropower Project (Upgrading)

MW Mega Watt

NBM New Bench Mark

NEA Nepal Electricity Authority

NPV Net Present Value

O&M Operations and Maintenance

OBE Operating Basis Earthquake

ODWFS Oil Directed Air Forced

OFWF Oil Forced Water Forced

ONAF Oil Natural Air Forced

ONAN Oil Natural Air Natural

PGA Peak Ground Acceleration

PH Powerhouse

PPMO Public Procurement Monitoring Office

PRoR Peaking Run of River

RM Rural Municipality

RoR Run of River

SEIA Supplementary Environmental Impact Assessment

SPT Standard Penetration Test

SRTM Shuttle Radar Topography Mission

S/S Substation

STDFS South Tibetan Detachment Fault System

ToR Terms of Reference

UFSR Updated Feasibility Study Report

UNCHS United Nations Commission on Human Settlements

U/S Upstream

V Volt

WECS Water and Energy Commission Secretariat

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# HYDROLOGY

## Introduction

Andhi Khola hydroelectric and rural electrification Project (AHREP) is located near Galyang Bazar, about 80km south-west from Pokhara on the siddhartha rajmarga in Syangja District, Gandaki Zone, Western Development Region, Nepal. Andhi Khola Hydroelectric & Rural Electrification Project (AHREP) was commissioned in 1991 and has installed capacity of 5.1 MW. The Project was jointly funded by Government of Nepal (GON) and United Mission to Nepal (UMN). Butwal Power Company Ltd. owns and operates the power plant.

The power produced is being mostly supplied to the 33kV national grid owned and operated by Nepal Electricity Authority (NEA) and part of power produced is distributed directly by BPC to local communities in Syangja and Palpa Districts. BPC has planned to further extend the rural electrification in those districts.

The existing Andhi Khola Hydropower Plant is designed for firm power supply i.e. with 93 percentile exceedance level. Second hand EM equipments were installed in the powerhouse because of the lact of resources then. BPC has decided to construct the Andhi Khola Hydropower Project (U) (AKHPU). AKHPU is a run-off-river-the river type hydropower project planned to be constructed in the same place by replacing the the existing AHREP. The updated feasibility study report was prepared in June 2008.

The feasibility study conducted in May 2005 has been updated to check financial, technical and environmental viability of the project.

Table ‑: Salient features of the project

| **Descriptions** | **Parameters** |
| --- | --- |
| Catchment area | 444 km2 |
| Type of power plant | Run-of the-river |
| Design Discharge | 7 m3/s |
| Low flow( 1 in 2 years period) | 1.4 m3/s |
| Capacity | 9.4 MW |
| **Diversion weir** |  |
| Diverion weir type | Concrete gravity with obermeyer crest gate |
| Weir Length/Height | 60 m /6.5 m above natural bed (0.5 m concrete added on top of the existing weir and 1.2 m inflatable dam (Obermeyer Spillway Gates) |
| **Intake chamber/gravel trap** |  |
| Length | 10 m |
| Trash rack opening sixe, width x height | 2 m x 3 m ( Three Opening width 6 m) |
| Intake gate opeing size, width x width x height | 1.5 m x 2 m, 2 nos |
| Intake canal size, length x width x height (river side wall) | 20 m x 1.5 m x 5.2 m (max. ), 2 nos |
| **Settling Basin** |  |
| No. of bays | 4 nos |
| Flushing system | Serpent sediment sluicing system (S4) |
| Length | Inlet transiton 23.68 m, uniform section 30 m |
| Width of inlet transition, start  Width of uniform section | 1.5 m 2 nos (3 m total)  4.0 m (width of one bay) |
| Total depth (including hopper) | 6.9 m |
| Hopper Depth | 1.7 m |
| Transition section between the settling basin outlet and the headrace tunnel portal | 18.5 m long and 6.0 m wide side channel |
| **Headrace tunnel** |  |
| Shape | D-shped fully lined (concrete /stone Masonry) |
| Length | 1284 m |
| Corss sectional area | 4.25 m2 |
| **Irrigation system** |  |
| Pump irrigation system | 350 mm dia, propeller pump, Max head 1.2 m located at intake |
| Irrigation water supply pipe for pump | 350 mm dia, 4 mm thick, located close to the irrigation outlet. |
| **Surge shaft** | Addition of 1.5 m height in the existing surge tank with c/s area 12 m2 |
| **Penstock**  -diameter | 1000-900 mm twin steel pipe (vertical, not embedded) |
| -length | Vertical 244 m, Horizontal 32 m |
| **Entrance shaft to powerhouse**  -length | 234 m |
| -diameter | 4 m |
| **Powerhouse**  -type | Underground |
| -size | 37 m long, 6.6 m wide and 11 m high with semicircular shape above the spring line |
| **Head**  -gross | 247. 25 m |
| -net | 239.60m |
| Design Flow | 4.87 m3/s |
| **Tailrace tunnel**  -Shape | D-shaped fully lined ( concrete /stone masonry), with 600 mm deep cut in the existing tunnel bed |
| -length | 1087 m |
| -cross-sectional area | 5.25 m2 |
| **Turbines**  -type | Pelton (3 jets horizontal shaft arrangement) |
| -no of units | 3 nos |
| **Generators**  -type | Synchronous, brushless, self excited |
| No of units | 3 nos |
| Capacity | 5 MVA |
| Voltage | 6.6 kV |
| **Transmission Line** |  |
| -length | 0.5 km |
| -voltage | 132 kV |
| **Mean annual saleable energy Production** | 66.23 GWh in a normal year |
| Dry Energy ( Mid December-mid April) | 16.60 GWh |
| Wer Energy ( mid April-mid December) | 49.63 GWh |
| Commissioned date | 22nd of Chaitra 2072 |

accurate assessment of long-term hydrology is essential to any hydropower project. The longer the hydrological records, more reliable are the estimation of design parameters for the project. In the case of ungauged (i.e., either limited or no stream flow records) river, direct measurements of hydrological parameters are not available, so, it is necessary to look at catchments that have similar catchment characteristics and meteorological records for the estimation of the hydrological data.

The hydrological study of the project area comprises the desk study, field investigation, collection of hydrological and meteorological data from nearby project area, and various literature reviews. Briefly the hydrological study covers the following:

* Collection of Hydrological data from the gauging stations,
* Processing of the data as required,
* To evaluate climate cycle and the impact of climate change based on the collected data,
* Preparation of report

## Catchment Characteristics

Catchment properties refer to the physical and geographical features of an area that influence the flow of water in a watershed. These properties include the size, shape, slope, soil type, vegetation cover, and land use. The interaction of these properties affects the amount and distribution of rainfall that becomes runoff and contributes to the overall water balance of the catchment. Understanding catchment properties is important for effective water management, as it helps in predicting the response of a watershed to precipitation events and in designing appropriate water management strategies.

Additionally, catchment properties play a crucial role in determining the rate and duration of runoff, as well as the potential for flooding, erosion and sedimentation. They also impact water quality by affecting the movement and distribution of pollutants in the watershed. By considering catchment properties in hydrological models, engineers and scientists can more accurately predict and manage water resources, ensuring a sustainable water supply for future generations. Thus, a comprehensive understanding of catchment properties is essential for effective water resource management and decision making.

The andhi Khola is one of the major tributaries of the kali gandaki river which belongs to the Narayani Basin. It originates from Dahare Lek and its catchment extends up to Panchase Danda (hill). The highest point on the catchment area has an elevation of 2517 m above mean sea level. Average gradient of the river within the project area is about 1 in 135.

The basin has characteristic of mountainous catchment. The total catchment area upstream of the intake site is 444 km2. The intake site is located at an elevation about 630 m and is approximately 1 km North-West from the Galyang Bazaar.

There is no gauging station at the intake site of the existing Andhi Khola Hydropower Project though it is in operation since last 14 years and thus lacks hydrological database.

A guging station has been installed at about 3 km upstream form the intake of the existing andhi khol hydropower project by BPC one year back and guagung data is being recorded twice a day. Which could be used in future for correlation and/or comparison purpose. DHM has established gauging station at dumrichaur some kilometer further downstream from the andhi khola headworks and the same data have been used to analyse hydrlogixal data for the propose project. Therefore, a compartion of catchment characteristics of the andhi khola at dumrichau and intake area is needed because of the location of gauging station. The recorded data at the dumrichaur stream gauging station to andkhola intka using the catchment ration of 0.933 (444 Km2/476 km2).

|  |  |  |
| --- | --- | --- |
| Elevation |  |  |
|  | Area (Km2) | % |
| <3000 | 444 | 100 |
| >3000 | 0 | 0 |
|  | 444 |  |







## Climate

Climate is a major factor influencing the water cycle and hydrology of a region. The following aspects of climate should be considered when preparing a report on the impact of climate on hydrology:

* Precipitation patterns: The amount, frequency, and distribution of precipitation in a region greatly affect the water balance and runoff.
* Temperature: Temperature influences the rate of evaporation and snowmelt, which can affect runoff and water supply.
* Atmospheric circulation: The distribution of pressure systems and prevailing wind patterns can alter the amount and distribution of precipitation in a region.
* Climate variability and change: Climate variability and change can alter precipitation patterns, temperature, and atmospheric circulation, which can have significant impacts on the hydrology of a region.
* Climate extremes: Climate extremes, such as droughts and floods, can have severe impacts on water resources, including water availability and quality.
* Snowpack and glaciers: Snowpack and glaciers store large amounts of water, which can be an important source of water in many regions. Climate change can alter snowpack and glacier dynamics, which can have impacts on water availability and water resources.
* Land use and land cover changes: Climate change can also impact hydrology through changes in land use and land cover. Deforestation, urbanization, and other forms of land use change can alter the water balance and runoff in a region.

By considering the impacts of climate on hydrology, engineers and scientists can better understand the water cycle and make informed decisions about water resource management. Additionally, understanding the impacts of climate change on hydrology can help to develop strategies for adapting to future changes in the water cycle.

It is important to note that the impacts of climate on hydrology can be complex and interrelated, and can vary greatly between regions. A thorough understanding of the impacts of climate on hydrology is essential for making informed decisions about water resource management, and for developing effective strategies for adapting to a changing climate.

## Available Data

### Hydrological Data

There is a provision of daily data recording station at the intake of the Jhimruk project. The automatic data recorder records at 8 Am and 8 Pm. No Instantaneous data are found during the data collection procedure. The daily discharge measurement from the gauge is recorded from 1995-2022. This latest data is used to evaluate the mean monthly discharge, mean annual discharge, flood discharge and low flow discharge as discussed below in this report.

### Gauge Installation and data recording

### Meterological Data

Since there is no rain gauge at the intake location, no rainfall data are collected. However, there is rainfall station set up by Department of Hydrometeorology (DHM), whose data can be acquired and used for the rainfall analysis. One rainfall station is within the catchment area; whose influence is relatively high. There is a provision of daily data recording station at the intake of the Andhi Khola Hydropower Project. The automatic data recorder records at 8 am everyday. No Instantaneous data are found during the data collection procedure. The daily discharge measurement from the gauge is recorded from 1995-2022. This latest data is used to evaluate the mean monthly discharge, mean annual discharge, flood discharge and low flow discharge as discussed below in this report.

## Basin Rainfall

Basin (or catchment) rainfall refers to the total amount of precipitation that falls within the boundaries of a specific watershed or catchment area. The spatial and temporal distribution of rainfall in a basin plays a crucial role in determining the water balance and runoff of the watershed. Basin rainfall is influenced by a number of factors, including climate, geography, topography, and land use. Accurate measurement and monitoring of basin rainfall is essential for understanding the water balance of a watershed and for effective water resource management. Basin rainfall data is used in hydrological models to predict runoff, inform water resource planning, and design water management strategies. Understanding the patterns and variations of basin rainfall over time is also important for assessing the impacts of climate change on the water cycle and for making informed decisions about water resource management in a changing climate.

In addition, basin rainfall is also used to evaluate the impacts of land use and land cover changes on the water cycle. For example, changes in land use from natural vegetation to urbanization can result in increased runoff, while changes in land cover from forests to agriculture can result in changes in the distribution of precipitation and runoff.

Accurate measurement of basin rainfall is achieved through a network of rain gauges, which measure precipitation at regular intervals. The data collected from these gauges is then used to create rainfall maps and to estimate the total amount of precipitation that falls within the boundaries of a watershed.

Basin rainfall is also an important factor in the design of flood management systems, as the total amount of precipitation, as well as the rate and duration of runoff, can influence the likelihood and severity of flooding. Basin rainfall data is also used to monitor drought conditions, as reduced precipitation can result in decreased water availability and increased water stress in a watershed.

The average annual basin rainfall is 1897 mm. The catchment is medium precipitation type with respect the basin rainfall. The 24 hour maximum precipitation is 324 mm, which is one sixth of the average annual rainfall indicating potential hydrological risk (UFSR, 2008).

## Long Term Mean Monthly Flow

### Direct measured data

Long-term mean monthly flow is a critical component of hydropower project design and management, as it affects the energy production and efficiency of the project. In the context of hydropower projects, long-term mean monthly flow refers to the average flow of water in a river or stream over a period of several decades.

Hydropower projects rely on a consistent flow of water to generate energy, and the long-term mean monthly flow provides crucial information about the availability and reliability of this resource. By understanding the long-term mean monthly flow of a river or stream, hydropower project developers can design and operate the project in a manner that optimizes energy production while also considering the impacts on the river and its associated ecosystems.

In the context of hydropower projects, the long-term mean monthly flow is used to estimate the potential energy generation of the project, and to determine the size and capacity of the project's infrastructure. This information is critical for the planning and design of the project, as it helps to ensure that the project is appropriately sized to meet the energy needs of the region, while also ensuring that the project operates in a sustainable and responsible manner.

The long-term mean monthly flow also helps to inform decisions about the operation of the project, including the scheduling of energy generation, the management of water releases, and the maintenance of the project's infrastructure. By understanding the long-term mean monthly flow, hydropower project managers can optimize the project's operation and efficiency, and ensure that the project is meeting the energy needs of the region while also protecting and preserving the health of the river and its associated ecosystems.

The Mean monthly flow from the collect data over the period of 29 years of data is presented in the

Table ‑: Mean Monthly Flow of Andhikhola River

| **Month** | **Discharge (m3/s)** |
| --- | --- |
| Baishakh | 3.69 |
| Jestha | 6.38 |
| Ashadh | 36.22 |
| Shrawan | 75.01 |
| Bhadra | 75.34 |
| Ashwin | 43.92 |
| Kartik | 16.98 |
| Mangsir | 9.07 |
| Poush | 6.66 |
| Magh | 5.72 |
| Falgun | 4.81 |
| Chaitra | 4.00 |

Figure ‑: Hydrographical representation of Mean Monthly flow of Jhimruk River

### Comparision with implemented Mean Monthly Flow

Figure ‑: Comparison of implemented mean monthly flow and measured mean monthly flow

Only in the month of Shrawan, the measured data is lesser than the hydrological estimation during UFSR. In the dry months the measured data is almost similar as that of estimated data. For the wet months (Jestha, Ashadh, Bhadra, Ashwin) the measured data are greater than the estimated flow during UFSR.

### Water Sharing in Andhi Khola

There are some irrigation systems in the Andhi Khola River Basin. Dahathum Changchangdi Irrigation scheme, Damuwa Phant Proposed scheme, Sataun Tapu Irrigation scheme, Kulbandh Irrigation schme, Lamage Phant Irrigation scheme, Thuli Benshi Irrigation Scheme, Tikaja Phant Irrigation scheme are the in operation. Some of them are in normal operation whereas some of them are damaged and operate in monsoon season only. The above mentioned irrigation systems are located in the upstream of the intake of Andhi khola. There are no schemes in the down stream of the Intake of the project.

### Riparian Release

Riparian release is a critical component of hydropower project management, as it affects the water quality, aquatic ecology, and overall health of the river and its associated ecosystems. In the context of hydropower projects, riparian release refers to the discharge of water from the project back into the river downstream.

Hydropower projects can have significant impacts on the natural flow regime of rivers and streams, and riparian release is used to mitigate these impacts and maintain the health of the river and its associated ecosystems. Riparian release involves the release of water from the project at specific rates, times, and seasons to mimic the natural flow regime and to maintain the ecological and hydrological balance of the river.

In the context of hydropower projects, riparian release is used to maintain the water quality, temperature, and flow regimes required for the survival and productivity of fish and other aquatic species. This helps to maintain the overall health and diversity of the river and its associated ecosystems, as well as to support the recreational and commercial uses of the river, such as fishing, boating, and wildlife watching.

Riparian release is also critical for the water quality management of the river, as it helps to maintain the natural water chemistry, including pH, dissolved oxygen levels, and nutrient levels, which are important for the health of the river and its associated ecosystems.

By implementing appropriate riparian release strategies, hydropower projects can be designed and operated in a sustainable and responsible manner, providing clean and reliable energy while also protecting and preserving the health of the river and its associated ecosystems.

As per UFSR, the long-term mean monthly flow for driest month, Chaitra at the intake of is 2.63 m3/s. As per prevailing environment act of Nepal, the downstream release should be 10% of minimum long-term mean monthly flow, i.e., 0.26m3/s will be released downstream as the riparian release for aquatic life.

## Flow Duration Curve (FDC) and Design Discharge

Flow duration curve (FDC) is an important tool in the assessment of the reliability and sustainability of hydropower projects. The FDC graphically represents the relationship between flow volume and frequency, showing the proportion of time that a river or stream experiences various flow rates.

FDC provides important information on the expected flow regime, including the magnitude and frequency of low flow, high flow, and average flow conditions. This information is critical for the design and operation of hydropower projects, as it affects the availability of water for power generation and the environmental impacts of the project.

By using FDC analysis, hydropower project developers and operators can determine the most appropriate design for the project, including the size of the dam, the capacity of the power generation equipment, and the water management practices to be implemented. This information can also be used to assess the project's reliability and sustainability, including its ability to generate power during low flow periods, its capacity to meet energy demands, and its potential to impact the environment.

FDC analysis is also an important tool in water resources management, as it provides valuable information on the flow regime of a river or stream, including the occurrence of low flow, high flow, and average flow conditions. This information can be used to determine the water availability for various uses, including irrigation, drinking water, and industrial water supply, and to assess the potential impact of hydropower projects on the environment.

As per USFR, the design discharge is 4.87 m3/s which is available for 65% of the time in the certain year.

### FDC from the measured data

### Comparision of FDC of UFSR

## Flood Analysis

Flood flow is the maximum flow of water that occurs in a river, usually caused by heavy rainfall or the rapid melting of snow. Flood flows are typically much higher than the normal or average flow of a river, and can cause significant damage to property and infrastructure along the river banks. Flood flows are often characterized by their magnitude, duration, frequency, and timing. In hydrology, understanding flood flows is important for managing and mitigating the risk of flood damage, designing and building flood protection infrastructure, and ensuring the safe and sustainable use of water resources. To better understand flood flows, hydrologists use various tools and techniques, such as monitoring streamflow data, conducting hydrological modeling, and studying historical flood events. Knowledge of the characteristics of flood flows in a certain river basin is critical for making informed decisions and developing effective flood management strategies.

In addition to monitoring and modeling, hydrologists may also use flood frequency analysis to estimate the probability of a flood of a certain magnitude occurring in a river basin. This information can be used to set flood warning thresholds, design flood protection infrastructure, and plan for emergency response. Furthermore, knowledge of the distribution of flood flows in a river basin can also provide insights into the vulnerability of different communities and ecosystems to flooding, and help guide decision-making in terms of land use planning, urbanization, and other human activities that may impact the flood regime.

It is important to note that climate change and human activities, such as deforestation and land use changes, can impact the magnitude and frequency of flood flows. As a result, ongoing monitoring and analysis of flood flows is critical to ensure that flood management strategies remain effective over time. By better understanding flood flows, we can ensure the safe and sustainable use of water resources, reduce the risk of flood damage, and protect communities and ecosystems from the impacts of flooding.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Method** | **Flood flows** | | | |
| **1 in 2-yr** | **1 in 10-yr** | **1 in 20-yr** | **1 in 100-yr** |
| Log Normal | 561 | 907 | 1005 | 1189 |
| Log Pearson Type III | 507 | 893 | 1052 | 1434 |
| Gumbel | 516 | 863 | 996 | 1297 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Method** | **Flood flows** | | | |
| **1 in 2-yr** | **1 in 10-yr** | **1 in 20-yr** | **1 in 100-yr** |
| Log Normal | 328 | 678 | 834 | 1227 |
| Log Pearson Type III | 332 | 672 | 815 | 1158 |
| Gumbel | 345 | 646 | 761 | 1021 |

Flood seems to be frequent.

### Diversion during Construction Flood

Construction flood flow is the maximum flow of water that is calculated for a dry period, typically during the construction phase of a project that is located near a river or stream. This flow rate is an important consideration in the design and construction of projects, as it represents the highest flow rate that can be expected during the driest period of the year. The purpose of calculating the construction flood flow is to ensure that the project is designed and built to withstand the highest possible flow of water, and to prevent damage or failure of the project during a flood event.

Construction flood flow is typically calculated based on historical streamflow data and/or hydrological modeling, taking into account the local climate, land use, and other factors that can impact the flow of water in the river or stream. The calculation of construction flood flow is important for a variety of projects, including bridges, dams, levees, and other infrastructure that are located in or near a river or stream. It is also a critical consideration for projects that have the potential to impact the flow regime of a river or stream, such as large scale land use changes or the construction of new reservoirs.

By taking into account the construction flood flow in the design and construction of projects, we can ensure that these projects are safe, sustainable, and resilient to the impacts of flooding. This helps to reduce the risk of damage or failure, and protects communities and ecosystems from the impacts of flooding.

## Low Flow

Low flow is a term used in hydrology to describe a period of reduced flow in a river or stream, typically characterized by a decrease in the volume and velocity of water. Low flow can occur due to a variety of reasons, including low rainfall, high evaporation, increased water withdrawals for human use, or a combination of these factors. Low flow is an important consideration in water resources management, as it can impact the availability of water for various purposes, including drinking water, irrigation, and hydroelectric power generation.

Low flow can have a significant impact on hydropower projects, as it affects the ability of the project to generate electricity. Hydropower projects rely on a steady flow of water to generate electricity, and low flow can result in reduced electricity generation and revenue. This is particularly relevant for hydropower projects that operate with limited storage capacity and are dependent on streamflow for power generation.

In addition to the financial implications, low flow can also impact the operation of hydropower projects and the environment. For example, low flow can increase the risk of water quality problems, such as increased water temperature and reduced oxygen levels, which can harm aquatic ecosystems and fish populations. Low flow can also result in increased erosion, which can impact the stability of the dam and its ability to function properly.

To minimize the impacts of low flow on hydropower projects, project operators use various management strategies, such as using advanced forecasting tools and water management practices, such as reducing water withdrawals during low flow periods, increasing water releases during high flow periods, and implementing fish passage measures. By managing low flow effectively, hydropower projects can maintain their operational efficiency and minimize their impacts on the environment.

Overall, low flow is an important consideration in the design, operation, and management of hydropower projects, as it affects the financial performance and environmental impacts of these projects. By taking a proactive and strategic approach to low flow management, hydropower projects can be designed and operated in a sustainable and resilient manner, providing clean and reliable energy for communities and businesses.

## Trend Analysis

### Methodology

The Mann-Kendall test is a statistical test used to determine whether there is a monotonic trend in a time series data set. The test is non-parametric, which means that it does not assume any particular distribution for the data.

The test statistic for the Mann-Kendall test is based on the number of "concordant" and "discordant" pairs in the data set. A concordant pair is a pair of values that are either both increasing or both decreasing, while a discordant pair is a pair of values that are increasing and decreasing. The test statistic is calculated as the difference between the number of concordant pairs and the number of discordant pairs, divided by the total number of pairs.

The null hypothesis for the Mann-Kendall test is that there is no trend in the data, while the alternative hypothesis is that there is a trend. If the test statistic is positive and the p-value is less than a certain threshold (such as 0.01), then the null hypothesis is rejected, and it can be concluded that there is a monotonic trend in the data.

The Mann-Kendall test is often used in climate research to detect trends in temperature and precipitation data, as well as in other fields where time series data is collected such as hydrology, economics, and finance.

It is important to mention that Mann-Kendall test is sensitive to the presence of outliers, so it's important to preprocess the data accordingly.

The Mann-Kendall test is a nonparametric statistical test used to determine if there is a monotonic trend in a time series. The p-value is the probability of obtaining a test statistic as extreme or more extreme than the one calculated from the sample, assuming that the null hypothesis is true. A small p-value (typically less than 0.01) indicates that the trend is statistically significant and that the null hypothesis can be rejected.

The p-value for the Mann-Kendall test can be calculated using the following steps:

* Calculate the test statistic, S. This is the sum of the signed ranks of the differences between each pair of observations in the time series.
* Determine the number of observations in the time series, n.
* Calculate the standard normal deviate, Z. This is given by: Z = (S - (n \* (n - 1) / 4)) / sqrt((n \* (n - 1) \* (2 \* n + 5) / 18))
* Look up the p-value for the Z-score in a standard normal table or calculate it using a software package.
* Interpret the p-value. A small p-value (typically less than 0.05) indicates that the trend is statistically significant, and the null hypothesis can be rejected.

Note that this method assumes that the data is independent and the time series is not serially correlated. Also, different software packages might have different method to calculate the p-value.

Here in this analysis a java based software DScreen is used to analyze the data series. The user manual of Dscreen is provided in the annex of this report.

### Result

The mean annual discharge, 5-years moving average and 10-years moving average is calculated and presented in the Table …… . This series is used for the trend analysis to find if there is trend or not in the data series.

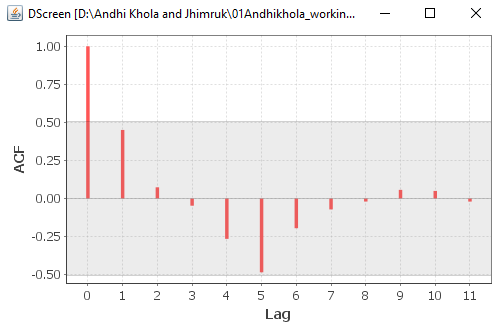
| Fiscal Year | Mean annual discharge (m3/s) | 5-years moving average (m3/s) | 10-years moving average (m3/s) | Remarks |
| --- | --- | --- | --- | --- |
| 61-62 | 29.7 |  |  |  |
| 62-63 | 25.7 |  |  |  |
| 63-64 | 23.6 |  |  |  |
| 64-65 | 29.5 |  |  |  |
| 65-66 | 27.9 | 27.2 |  |  |
| 66-67 | 35.1 | 28.3 |  |  |
| 67-68 | 41.3 | 31.5 |  |  |
| 68-69 | 33.4 | 33.4 |  |  |
| 69-70 | 64.2 | 40.4 |  | Incomplete data |
| 70-71 |  | 43.5 | 34.5 | Data missing |
| 71-72 | 11.6 | 37.6 | 32.5 | Incomplete data |
| 72-73 | 20.2 | 32.3 | 31.9 |  |
| 73-74 | 28.4 | 31.1 | 32.4 |  |
| 74-75 | 20.8 | 20.3 | 31.4 |  |
| 75-76 | 19.2 | 20.0 | 30.5 |  |
| 76-77 | 20.7 | 21.9 | 28.9 |  |
| 77-78 | 28.2 | 23.5 | 27.4 |  |
| 78-79 | 27.2 | 23.2 | 26.7 |  |
| 79-80 | 35.4 | 26.1 | 23.5 | Incomplete data |

The mean annual data series, 5-years moving average and 10-years moving average are plotted in the figure below.

The mean annual data is analyzed to obtain the trend of the series. The result of the data series is presented below.

The series is analayze with different lag of same series to obtail the plot of ACF vs different lags. The persistence in the data is said to be present if the correlation of the lag 1 lies outside of the confidence limit. On such case, pre whitening of data is necessary. However, in the seires considered for analysis, lag 1 correlation is inside the confidence limit. The conclusion that there is no persistence in the annual series. Now, the Man-kendall test can be proceeded. The result of Man-Kendall test is simple and represented by MK test statistics, tau and probability of exceedance values. For the considered series, following is the result of MK test. Detail result is attached in the annex of this report.

|  |
| --- |
| S = -25 |
| tau = -0.2381 |
| p = 0.2365 |



Auto correlation function.

Mean annual discharge plot

The gap in the plot of mean annual discharge is because of upgrading work. The data is not available in that period of time. 5-year moving average and 10-year moving average is also plotted in the plot.

The monthly average of each month for different years is also analyzed. The result of the Man-Kendall test is tabulated below. The details calculation and results are presented in the annex of this report.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Description | Man-Kendall's statistical value | Man-Kendall's  Tau | Man-Kendall's  p-value | Apparent trend |
| Mean Annual Discharge | S = -25 | tau = -0.2381 | p = 0.2365 | -0.405/year |
| 5-Years moving average | S = -15 | tau = -0.1429 | p = 0.4923 | -0.851/5-yr |
| 10-Years moving average | S = -41 | tau = -0.9111 | p = <0.0001 \*\*\* | -0.726/10-yr |
| Baishakh | S = 42 | tau = 0.3500 | p = 0.06257 \* | 0.149/year |
| Jestha | S = 31 | tau = 0.2594 | p = 0.1764 | -0.017/year |
| Ashadh | S = 12 | tau = 0.1000 | p = 0.6238 | 0.343/year |
| Shrawan | S = -20 | tau = -0.1471 | p = 0.4372 | -1.535/year |
| Bhadra | S = -74 | tau = -0.5441 | p = 0.06738 \* | -4.174/year |
| Ashwin | S = 2 | tau = 0.01471 | p = 0.9675 | 0.050/year |
| Karkit | S = -22 | tau = -0.1618 | p = 0.3901 | 0.027/year |
| Mangsir | S = -21 | tau = -0.2000 | p = 0.3252 | -0.005/year |
| Poush | S = -22 | tau = -0.1833 | p = 0.3474 | 0.033/year |
| Magh | S = 13 | tau = 0.1429 | p = 0.5154 | 0.072/year |
| Falgun | S = 13 | tau = 0.1238 | p = 0.5565 | 0.040/year |
| Chaitra | S = 28 | tau = 0.2333 | p = 0.2254 | 0.039/year |

### Discussion

Alterations in the hydrological regime occur due to the influence from changing climatic conditions such as GHG emissions, pollution, environmental changes such as deforestation, plantation etc. Moreover, the change is due to the influence from physical changes at the land surface such as Land use, infrastructure, water use etc. In order to determine the impacts on the hydrology, continuous, long record and good quality data are required.

From the analysis of the data series of Andhi Khola, it is clearly seen that most of the series do not have significant trends as suggested by the Mann-Kendall’s test. However, in case of 10-years moving average series and monthly average series for the month of Bhadra shows that there is significant trend of decreasing discharge. 10- years moving average series has only 10 number of data in the series, so the result is not reliable. For the month of Bhadra, it could be related with the hydrological change. The reason could be climate change, environmental change or physical change.

For the months Jesth, Shrawan, Bhadra and Mangsir, the apparent trend of discharge appears to be decrasing whereas for the rest of the months the apparent trend appears to be increasing. The numerical value of trend for different series can be obtained from the table above.

## Glacier Lake Outburst Flood (GLOF)

No sign of GLOF is recorded in the catchment.

## Conclusions

Based on the above studies on hydrology, followings conclusions can be drawn for the design of hydropower project components.

* The available discharge data of Andhi Khola reveals that there is no significant trend of changing discharge either increasing or decreasing because of the climatic reason, environmental reason and physical changes. However, for the month of Bhadra, there is significant trend.
* The flood extreme values are less than the values obtained for UFSR, so it is recommened to stay with the same values as obtained in the UFSR.

## Recommendations

It is recommended to continue to measure the daily average data of Andhi Khola.

Since, the monthly average of Bhadra shows significant trend of decreasing discharge, it is recommended to opt the detailed analysis of impact of climate change using climate model such as GSM, RCP. These model uses the availale temperature and rainfall series to predict the future temperature and precipitation seires using predictor tools recommended by IPCC. Ultimately, the predicted temperature and precipitation is used to obtain discharge by using hydrological models such as HEC HMS, NAM, BHV.

# REFERENCES