PRELIMINARY ASSESSMENT FOR PUMPED STORAGE POTENTIAL IN UTTAR PRADESH

UPNEDA

VASUDHA FOUNDATION
Green ways for a good earth!

Authors
Jaideep Saraswat, Nikhil Mall, Rahul Patidar

GIS Team
Akinchan Singhai, Amit Yadav

Reviewers
Srinivas Krishnaswamy, Raman Mehta, Vrinda Gupta

Editorial
Swati Bansal

Design
Santosh Kumar Singh

About UPNEDA

In April 1983, the Uttar Pradesh Government established the Non-Conventional Energy Development Agency (NEDA) as an autonomous institution under the Department of Additional Energy Sources. Over time, the agency has been renamed as the Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA). Right from its inception, UPNEDA has been serving as the central authority responsible for executing a range of initiatives and policies pertaining to renewable energy within the state. These initiatives encompass diverse areas such as solar energy, biomass energy, pumped storage, and more.

About Vasudha Foundation

Vasudha Foundation is a non-profit organisation set up in 2010. We believe in the conservation of Vasudha, which in Sanskrit means the Earth, the giver of wealth, with the objective of promoting sustainable consumption of its bounties. Our mission is to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy and energy-efficient technologies as well as sustainable lifestyle solutions. Through an innovative approach and data- driven analysis, creation of data repositories with cross-sectoral analysis, along with outreach to ensure resource conservation, we aim to help create a sustainable and inclusive future for India and Mother Earth.

Disclaimer

The sites for Pumped Storage Projects (PSPs) analysed in this study have not undergone geological, hydrological, or environmental assessments, making it uncertain whether they are suitable for development. Additionally, there has been no examination of land ownership, except for the exclusion of urban regions, and no consultations with landowners or managers have taken place. It should be noted that the inclusion of these potential site locations in this list does not confer any development rights to the parties involved.

CISRS House, 14 Jangpura B, Mathura Road, New Delhi - 110014
For more information, visit www.vasudha-foundation.org

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1 EXECUTIVE SUMMARY

Pumped storage is a reliable and established energy storage technology that is essential for ensuring grid stability. It offers a range of benefits, including the capacity to store large amounts of energy for extended periods and serve as a backup during power outages. Some pumped storage systems can achieve impressive energy conversion rates of up to 80 percent. India has considerable pumped storage potential, with approximately 103 GW identified by the Central Electricity Authority. As of March 2023, eight pumped storage projects with a total capacity of 4,745.6 MW have been installed in the country. However, none of these projects are located in the state of Uttar Pradesh, which has ambitious solar targets to achieve.

To address this, our analysis has identified 33 potential pumped storage sites in Uttar Pradesh, with a combined energy storage potential lying between 186.96 GWh to 200.42 GWh. Our survey considers two topologies. The first involves linking existing reservoirs via penstocks and adding powerhouses to transform them into pumped storage facilities. The second involves identifying suitable locations for a second reservoir to be built alongside an existing lake or reservoir. Under the first topology, the energy storage potential ranges between 96.45 GWh to 109.91 GWh, while the second topology offers 90.51 GWh. Each site identified in the analysis has an energy storage potential ranging from 0.05 to 33.37 GWh. To put this in perspective, the Optimal Generation Mix Report estimates that India will require 336.4 GWh of energy storage capacity by 2029-30, with 128.15 GWh coming from pumped storage and the remainder from battery energy storage systems.

2 INTRODUCTION

As the quest to tackle climate change becomes more urgent, there is a need to ramp up the adoption of renewable energy (RE) projects. Technologically advanced, inherently abundant, and innately carbon-free, the renewable energy sources can be a key to driving emission reduction momentum.

In August 2022, the Government of India submitted its enhanced Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) which aims to achieve net-zero emissions by 2070. This long-term target is buttressed with short-to-medium-term targets like reducing the emissions intensity of GDP by 45 percent by 2030 from 2005 levels and deriving 50 percent of cumulative power installed capacity from non-fossil fuel sources by 2030. With the world's third-largest production of renewable energy, India is leading in the deployment of RE. As of April 2023, around 172.5 GW of RE has been installed in India including large hydropower plants. According to the draft National Electricity Plan issued by the Ministry of Power (MoP) in September 2022, renewable energy capacity is expected to reach approximately 569 gigawatts (GW) by 2031-32 with solar and wind to contribute around 467 GW.

Since the majority of the RE projects are intermittent in nature, there is an innate need to deploy technological solutions to enhance grid stability and flexibility.

2.1 NEED FOR ENERGY STORAGE

Power generation in India is currently facing a dilemma. While relying on thermal power plants will lead to an increase in emissions whereas reliance on intermittent RE can jeopardise grid stability and reliability. As a technology, energy storage presents itself as the omnipotent solution for smoothly integrating intermittent renewable energy into the electrical grid. It can provide grid support by balancing supply and demand, smoothing out fluctuations in renewable energy generation, and providing backup power during periods of peak demand or unexpected power outages.

Ancillary Services	Bulk Energy Services	Transmission Infrastructure Services	Distribution Infrastructure Services	Customer Energy Management Services
▪ Fast Frequency Response ▪ Primary/ Secondary/ Tertiary Reserve ▪ Voltage Support ▪ Black Start	▪ Electric energy time-shift (arbitrage) ▪ Electric Supply Capacity	▪ Transmission Upgrade Deferral ▪ Transmission Congestion Relief	▪ Distribution Upgrade Deferral ▪ Distribution Congestion Relief ▪ Voltage Support ▪ Ramp Support	▪ Power Reliability ▪ Retail electric energy time-shift ▪ Power Quality ▪ Demand Side Management Services

Figure 1: Energy Storage Services

The storage of excess renewable energy generated during periods of low demand can ensure that this energy is available during periods of high demand or when renewable energy sources are unavailable. This further enables efficient use of renewable energy sources and reduces the need for curtailment. Moreover, energy storage can also play a crucial role in ensuring energy security and resilience, particularly in remote or off-grid areas. Figure 1 illustrates the energy storage services in detail.

In addition, energy storage systems are instrumental in providing system services at various timescales.

- First, on short-term timescales (real-time to seconds), energy storage can provide rapid responses to sudden changes in demand and supply of electricity, such as the provision of inertia, fast frequency response, voltage regulation, and more.
- Second, on a medium-term timescale, energy storage can provide peak shaving and load-shifting services by storing excess energy during low-demand periods and discharging it during peak-demand periods.
- Finally, on long-term timescales, energy storage can provide energy shifting and backup power services. Figure 2 captures the role of energy storage in system services at different timescales.

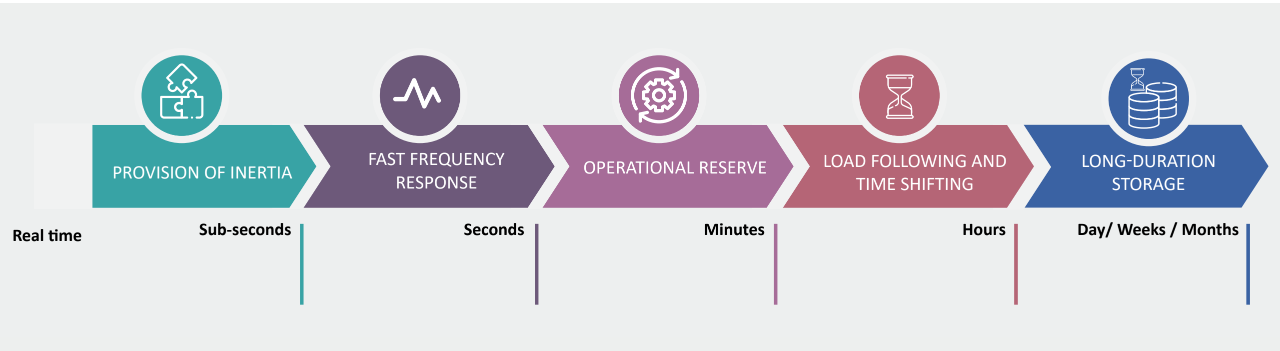

Figure 2: Role of Energy Storage in System Services for Different Timescales

2.2 ENERGY STORAGE TECHNOLOGIES

2.2.1 STORAGE TYPES

Energy storage technologies can be classified into four broad categories based on the principle on which they store energy viz. electrochemical, mechanical, thermal, and chemical energy storage. Figure 3 outlines various technologies that fall under the aforementioned categories.

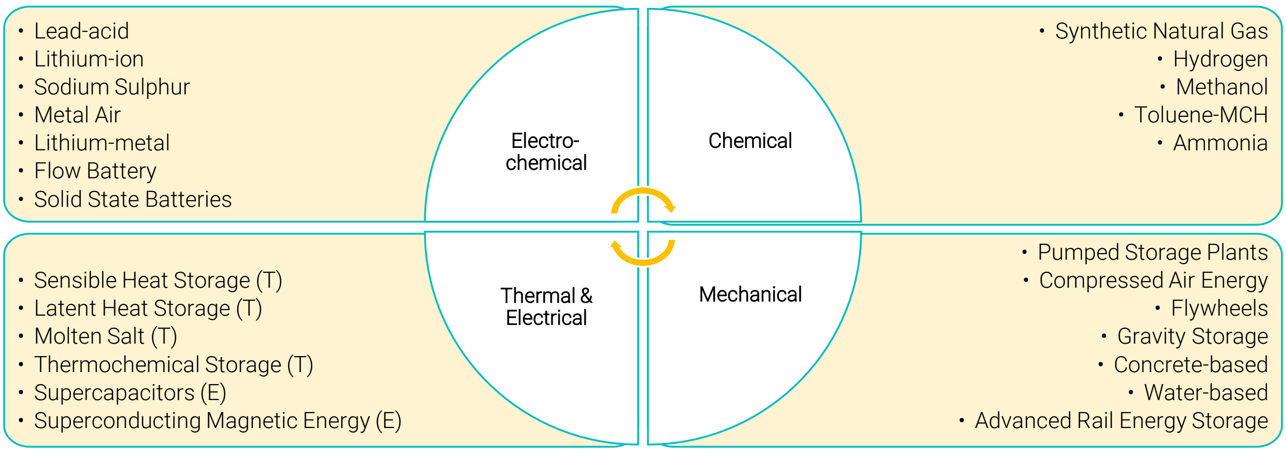

Figure 3: Categorisation of Energy Storage Technologies

2.2.2 COMMERCIALISATION OF STORAGE TECHNOLOGIES

The commercialisation of storage technologies is governed by a confluence of several parameters like application, policy and regulatory push, incentives, economics, and others. Moreover, the maturity levels are measured using Technology Readiness Levels ranging from 1 to 9, with 9 being the most mature technology. Figure 4 represents the technology readiness level and corresponding commercial stage of various storage technologies. As can be seen, technologies like PSP and lead acid batteries have been fully mature for some time, whereas technologies like solid-state and metal-air batteries are still in research and development (R&D) phase.

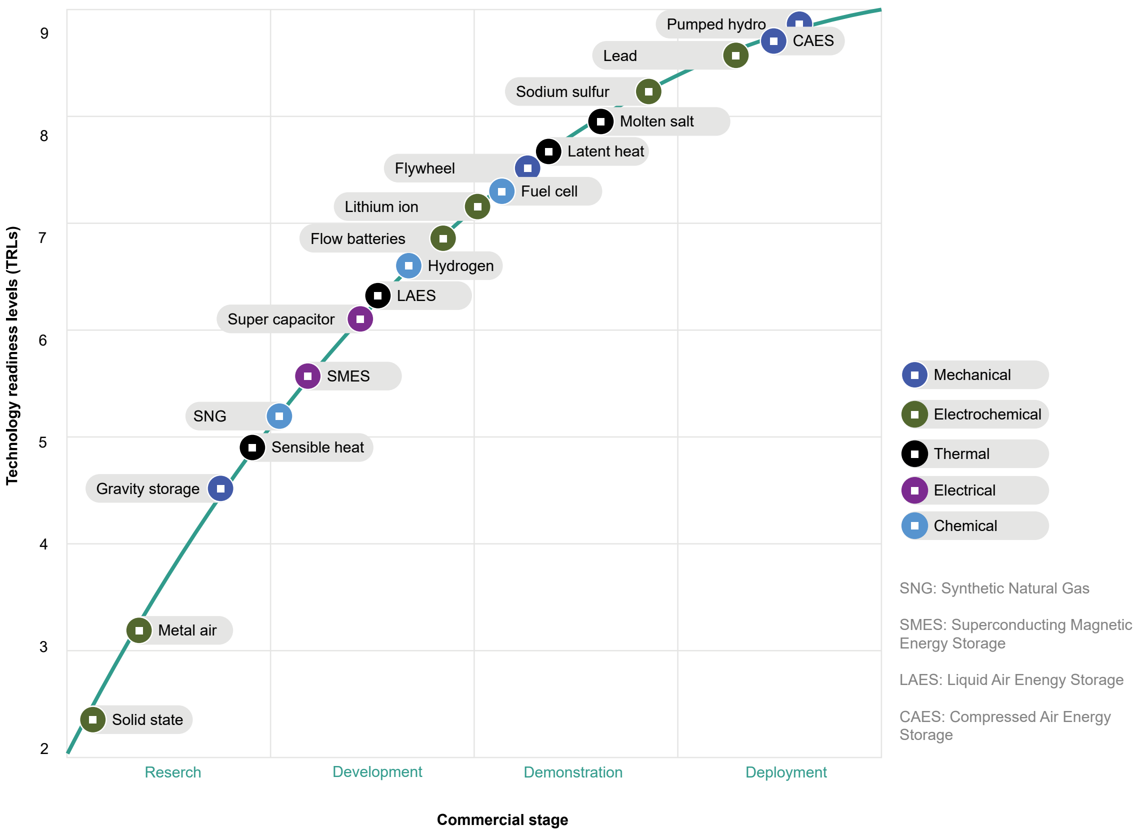

Figure 4: Technology Readiness Level (TRL) v/s Commercial Stage of Energy Storage Technologies

2.3 CHARACTERISTICS OF ENERGY STORAGE

There are a few characteristic features that helps to differentiate between various energy storage technologies. These include power rating, discharge period, energy density, power density, efficiency, response time, and more. A detailed explanation of the same is provided in Figure 5.

- **Power Rating** — It refers to the maximum amount of power that the system can deliver or absorb at any given times.
- **Discharge Period** — It refers to the maximum amount of power that the system can substantially deliver energy at a specific power level before its stored energy is depleted.
- **Energy Density** — It refers to the amount of energy that can be stored in a given mass of the system. It is typically measured in Wh/kg.
- **Power Density** — It refers to the amount of power that can be delivered or absorbed by the system per unit of its volume of weight.
- **Efficiency** — It refers to the ratio of the energy output of the system to the energy input, taking into amount the losses in the conversion process.
- **Response Time** — It refers to the amount of time it takes for the system to respond to a change in power demand or supply.

Figure 5: Key Characteristics of Energy Storage Systems

Table 1 summarises the technical characteristics of a few energy storage systems. As shown, the efficiency of mechanical energy storage systems is highest and ranges between 80-90 percent. Also, the power rating of PSP is highest along with a quick response time which makes it most suitable for applications like electric time-shift, T&D upgrade deferral, etc.

Table 1: Characteristics of Key Energy Storage Technologies

Technology	Power rating	Discharge	Energy density	Power density	Efficiency	Response time
	(MW)	period	(Wh/kg)	(W/l)	(%)	
PHS	100-1,000	4-24 hr	0.2-2	0.1-0.2	70-85	sec-min
CAES	10-1,000	2-30 hr.	2-6	0.2-0.6	40-75	sec-min
Flywheels	0.001-1	sec-hours	20-80	5,000	70-95	10-20ms
Gravity Storage	<40	6+ hrs.	-	-	80-90	-
NaS battery	10-100	1min-8h	150-300	120-160	70-90	10-20ms
Lead acid	0-20	sec-hours	30-50	10-400	70-80	<sec
Li-ion battery	0.1-100	1min-8h	200-400	1,300-10,000	85-98	10-20ms
Sodium-Sulfur	~50	sec-hours	150-240	140-180	75-90	<sec
Flow battery	0.1-100	1-10h	20-70	0.5-2	60-85	10-20ms
Molten salt	-150	Hours	70 - 210	-	80-90	min
Super-capacitor	0.01-1	ms-min	10-20	40,000-120,000	80-98	10-20 ms
SMES	0.1-1	ms-min	~6	1,000-4,000	80-95	<100ms
Hydrogen	0.01-1.000	min-weeks	600	0.2-20	25-45	sec-min
SNG	50-1.000	hours-weeks	1,800	0.2-2	25-50	sec-min

2.4 WHY PUMPED STORAGE PROJECTS?

As renewable energy capacities continue to rise and electricity demand becomes more volatile, existing base-load power assets are being underutilised. To overcome this challenge, it is crucial to have flexible energy generation assets, such as PSPs so that both base-load and peaking power can be provided efficiently and cost-effectively. Such assets are essential to meet India's constantly evolving energy demands.

To generate electricity, PSPs include two vertically separated water reservoirs. When electricity price levels are low, water from the lower reservoir is pumped to the higher elevated reservoir with the help of a pump and turbine or a reversible pump turbine. This pumped water is then released from the elevated reservoir to generate electricity during periods of high demand. The energy storage capacity of a PSP system is determined by multiplying the usable mass of water in the upper reservoir (in kilograms) by the gravitational constant ($g = 9.8\ m/s^2$), the head (in meters), and the system efficiency.

PSPs are well-suited to provide rapid ramping capabilities, covering generation shortfalls when renewable output falls unexpectedly, and providing intra-day and inter-day firming for renewables. They can also provide inertial energy storage (the heavy rotating generator) and black start capabilities. In addition, PSP is a robust and mature technology that has proven itself for more than a century. Large-scale energy storage projects like these have a long lifespan, which equates to cost-effective energy delivery throughout the project's lifetime.

Moreover, PSPs along with renewable energy sources have significantly lower greenhouse gas (GHG) emissions than any other energy storage technology. Finally, these projects utilise domestically produced materials including mechanical and electrical equipment, and hence can contribute to the purpose of *Atmanirbhar Bharat*. Thus, a unified construction of PSPs is necessary to achieving sustainable energy transition.

3 STATUS OF PUMPED STORAGE PROJECTS IN INDIA

3.1 POTENTIAL

India has a significant potential of pumped storage projects due to its mountainous terrain and abundance of water bodies. PSPs play a crucial role in balancing the country's power grid and addressing the growing electricity demand. Across India, around 63 sites have been identified for the development of Pumped Storage Schemes (PSS), with a cumulative potential installed capacity of 96529.6 MW[1]. Due to its favourable topography, Western India has the highest PSP potential at 37,845 MW.

However, as per the latest guidelines to promote PSP, the Central Electricity Authority (CEA) estimates that India has 103 GW of on-river pumped storage potential. In addition, a large capacity of off-river pumped storage potential is also available, which is currently being assessed[2].

3.2 CAPACITY

With a total capacity of 4,745.6 MW, India has installed eight pump storage projects as of April 2023, at various locations across the country. Out of this, only six plants with an installed capacity of 3,305.6 MW, are currently operating in pumping mode. The remaining two are not currently operating in pumping mode due to delays in the construction of the tail reservoir or vibration-related issues in the system. The state-wise details of the operational pumped storage projects are mentioned in Table 2:

Table 2: Details of operational Pumped Storage Projects in India[3]

Name of the Project	State	Implementing Agency	Ownership type	Installed Capacity (In MW)	Current Status
Bhira Hydroelectric Power Project	Maharashtra	Tata Power Company Limited (TPCL)	Private	150	Working in pumping mode[4]
Ghatgar Hydroelectric Power Project	Maharashtra	Maharashtra State Power Generation Company (MAHAGENCO)	State	250	Working in pumping mode
Kadamparai Power House	Tamil Nadu	Tamil Nadu Generation & Distribution Co. Limited (TANGEDCO)	State	400	Working in pumping mode

1 https://cea.nic.in/wp-content/uploads/annual_reports/2022/AR_2021_22_dated_03.11.2022.pdf

2 https://powermin.gov.in/sites/default/files/webform/notices/Guidelines_to_Promote_Development_of_Pump_Storage_Projects.pdf

3 https://cea.nic.in/wp-content/uploads/hepr/2022/01/pump_storage_1-1.pdf

4 Pumping mode is the operational mode of a pumped hydro storage system where water is pumped from a lower reservoir to an upper reservoir, typically during periods of low electricity demand or when renewable energy sources like wind or solar are generating excess power.

Name of the Project	State	Implementing Agency	Ownership type	Installed Capacity (In MW)	Current Status
Nagarjuna Sagar (N.J.Sagar) Hydroelectric Power Project	Telangana	Telangana State Power Generation Corporation Limited (TSGENCO)	State	705.6	Working in pumping mode
Srisailam Left Bank Power House	Telangana	TSGENCO	State	900	Working in pumping mode
Purulia Hydroelectric Power Project	West Bengal	West Bengal State Electricity Distribution Company Limited (WBSEDCL)	State	900	Working in pumping mode
Kadana Hydroelectric Power Project	Gujarat	Gujarat State Electricity Corporation Limited (GSECL)	State	240	Generation mode[5]
Sardar Sarovar River Bed Power House (RBPH)	Gujarat	Sardar Sarovar Narmada Nigam Limited (SSNNL)	State	1200	Generation mode
Total				**4745.6**	

3.3 PIPELINE

According to the CEA's latest report, as of February 2023, over 25 GW of pumped hydro projects are in the pipeline across India. Out of these, one PSP project with a capacity of 1000 MW is likely to be commissioned by 2023-24 while two PSP projects with a capacity of 1700 MW will be commissioned by 2024-25. However, several other PSP projects are still in various stages of development, including examination and survey & investigation phases. The details of these projects are mentioned in Table 3.

Following are the PSP projects under construction (as of 28.02.2023):

- 1000 MW Tehri Stage II project in Uttarakhand being implemented by the Tehri Hydro Development Corporation (THDC) is likely to be commissioned by 2023-24. It will be the first PSP at the central level.
- 500 MW Kundah Stage I, II, III & IV project in Tamil Nadu being implemented by Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) is likely to be commissioned by 2024-25.
- 1200 MW Pinnapuram project in Andhra Pradesh being developed by the Greenko Energy is likely to be commissioned by 2024-25.
- The Koyna Left Bank (80 MW) PSP project in Maharashtra is being developed by the Water Resources Department (WRD) of Maharashtra. It is currently under construction but on hold and is expected to be commissioned by 2027-28.

5 Generation Mode- During this mode, the stored water in the upper reservoir is released through turbines to generate electricity and meet the demand for electricity on the grid

Table 3: Status of pumped storage pipeline projects in India[6]

Name of the Project	State	Implementing Agency	Ownership Type	Capacity (In MW)	Current Status
Tehri Stage-II	Uttarakhand	THDC	Central	1000	Under Construction
Kundah (Stage I, II, III & IV)	Tamil Nadu	TANGEDCO	State	500	Under Construction
Pinnapuram	Andhra Pradesh	Greenko Energy	Private	1200	Under Construction
Koyna Left Bank	Maharashtra	WRD	State	80	Under Construction but stalled
Turga	West Bengal	WBSEDCL	State	1000	DPR concurred by CEA
Upper Sileru	Andhra Pradesh	Andhra Pradesh Power Generation Corporation (APGENCO)	State	1350	Under Examination
One Reservoir Existing & One to be constructed					
Upper Indravati	Odisha	Odisha Hydro Power Corporation Ltd. (OHPCL)	State	600	Under Survey & Investigation
Saundatti	Karnataka	Greenko Energy	Private	1260	Under Survey & Investigation
MP30 Gandhi Sagar	Madhya Pradesh	Greenko Energy	Private	1440	Under Survey & Investigation
Gandikota	Andhra Pradesh	New and Renewable Energy Development Corporation of Andhra Pradesh (NREDCAP)	State	1000	Under Survey & Investigation
OWK	Andhra Pradesh	Aurobindo Realty & Infrastructure Pvt. Ltd.	Private	800	Under Survey & Investigation
Chitravathi	Andhra Pradesh	NREDCAP	State	500	Under Survey & Investigation
Both Reservoirs to be constructed					
Warasgaon	Maharashtra	WRD	State	1200	Under Survey & Investigation
Bhavali	Maharashtra	JSW Energy	Private	1500	Under Survey & Investigation
Kurukutti	Andhra Pradesh	NREDCAP	State	1200	Under Survey & Investigation

6 https://cea.nic.in/wp-content/uploads/hpi/2023/02/pump_storage_02.pdf

Name of the Project	State	Implementing Agency	Ownership Type	Capacity (In MW)	Current Status
Karrivalasa	Andhra Pradesh	NREDCAP	State	1000	Under Survey & Investigation
Somasila	Andhra Pradesh	Shirdi Sai Electricals Ltd.	Private	900	Under Survey & Investigation
Yerravaram	Andhra Pradesh	Shirdi Sai Electricals Ltd.	Private	1200	Under Survey & Investigation
Paidipalem East	Andhra Pradesh	Indosol Solar Power Pvt. Ltd.	Private	1200	Under Survey & Investigation
Singanamala	Andhra Pradesh	Aurobindo Realty & Infrastructure Pvt. Ltd.	Private	800	Under Survey & Investigation
Sukhpura Off-Stream	Rajasthan	Greenco	Private	2560	Under Survey & Investigation
Paidipalem North	Andhra Pradesh	Indosol Solar Power Pvt. Ltd.	Private	1000	Under Survey & Investigation
Shahpur	Rajasthan	Greenko Energy	Private	1800	Under Survey & Investigation
Total				**25090**	

In addition to the above-mentioned PSP projects, there are currently five PSP projects that are on hold due to lack of progress by the developer in survey and investigation activities. With a combined capacity of 5320 MW, these projects were planned to be commissioned in Tamil Nadu, Karnataka and Odisha, as observed in Table 4.

Table 4: Pumped Storage Schemes Under Survey & Investigation Held Up[7]

Name of the Project	State	Ownership Type	Implementing Agency	Capacity (In MW)
Both Reservoirs are existing				
Kodayar	Tamil Nadu	State	TANGEDCO	1500
Sharavathy	Karnataka	State	Karnataka Power Corporation Ltd. (KPCL)	2000
One Reservoir Existing & One to be constructed				
Upper Kolab	Odisha	State	OHPCL	320
Balimela	Odisha	State	OHPCL	500
Both Reservoirs are to be constructed				
Sillahalla St.-I	Tamil Nadu	State	TANGEDCO	1000
Total				**5320**

7 https://cea.nic.in/wp-content/uploads/hpi/2023/02/pump_storage_02.pdf

3.4 RECENTLY RELEASED TENDERS AND RESULTS

Table 5: List of recently released tenders

State	Tendered Capacity (In MW)	Notification Date	Agency	Current Status	Tender details
Karnataka	1000	25th Feb 2023	Power Company of Karnataka Limited (PCKL)	Bid Awarded	For Procurement of 1,000 MW x 8 Hours per day Storage for 40 Years from Pumped Hydro Storage Plant/s (PHSP/s)
West Bengal	900	24th Feb 2023	West Bengal State Electricity Distribution Company Limited (WBSEDCL)	Request for Selection Issued	Selection of Developer of 900 MW Bandu Pumped Storage Project on Design, Build, Finance, Operate and Transfer (DBFOT)

4 REGULATORY LANDSCAPE IN PROMOTING PSPs

In India, the electricity market is divided into three key segments: generation, transmission, and distribution, each led by a different player. While private entities dominate the generation segment, the transmission and distribution segments are largely controlled by the central and state governments. The Electricity Act of 2003 facilitated the introduction of open access and trading of electricity through power exchanges.

Despite having power exchanges as a means of electricity trading, the majority of bulk power supply in India is tied up in long-term bilateral contracts between generators and distribution utilities. Compared to long-term electricity transactions, short-term transactions are far less common. The introduction of the ancillary services in the Indian market presents a promising opportunity for energy storage projects due to their ability to respond quickly and provide high power ratings. In 2015, India implemented the Reserves Regulation Ancillary Services (RRAS) in order to maintain the desired frequency and alleviate congestion in the transmission network. A market-based procurement of ancillary services is currently being considered, and the Central Electricity Regulatory Commission (CERC) is expected to release a roadmap for this procurement soon.

The combination of renewable energy and energy storage is another burgeoning market segment, creating new opportunities for energy storage projects. India made headlines in 2020 by awarding the world's largest solar plus storage tender, boasting an impressive capacity of 1.2 GW. A notable feature of this tender was the flexibility it offered to developers in selecting energy storage technology. It has now been revealed that one of the developers have opted to proceed with PSP technology. Undoubtedly, the reduction in the cost of energy storage technologies due to technological advancements and economies of scale has resulted in an increased interest in renewable-plus storage projects.

The Government of India has outlined various initiatives and policies to enhance the development of pumped storage projects in India. Figure 6 captures a snapshot of these initiatives.

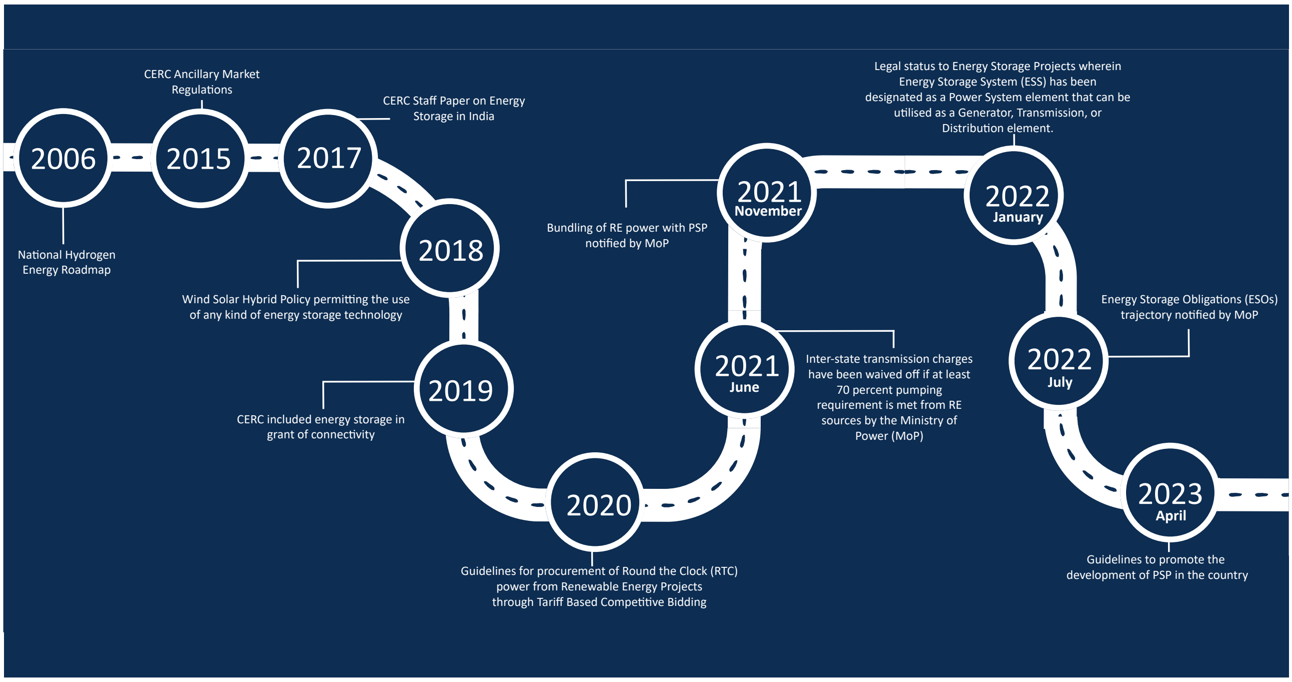

Figure 6: Roadmap of India's Key Energy Storage and Pumped Storage Measures

4.1 SUMMARY OF GUIDELINES TO PROMOTE THE DEVELOPMENT OF PSP IN INDIA

The government has released guidelines which identify potential sites for PSPs and encourage states to allocate these projects to Central Public Sector Undertakings (CPSUs) to take advantage of their financial and project execution capabilities. The guidelines also establish an Energy Storage Obligation trajectory for distribution companies, which aims to generate demand for storage, and waive Inter State Transmission System charges for PSP in order to facilitate the RE integration. The Central Government is providing budgetary support for the development of infrastructure facilities for hydropower and PSP, which can be used for other purposes as well. Additionally, the Central Electricity Authority (CEA) has issued revised guidelines that streamline the process of formulation and approval of Detailed Project Reports (DPR) for PSP, resulting in shorter timelines for projects allocated through tariff-based competitive bidding, integrated renewable energy projects, or captive plants.

The following guidelines are being issued for the promotion of pumped storage projects:

1. **Allotment of project sites:** The State Governments may allot project sites to developers in the following manner:
   - **On a nomination basis to CPSUs and State PSUs**: States can directly award hydro projects to CPSUs or State PSUs on a nomination basis for early development. CPSUs/State PSUs' experience and financial strength should be taken into consideration. Joint ventures between CPSUs/State PSUs can also develop such projects. CPSUs/State PSUs must ensure that contracts for equipment supply and project construction are awarded through competitive bidding, either through turnkey or well-defined packages.
   - **Allotment through competitive bidding**: PSPs project may also be awarded to private developers through a two-stage competitive bidding process. PSUs may also participate in the bidding process. The first stage is pre-qualification, based on financial strength, experience, track record, and ability to meet performance guarantees. The second stage involves calling bids based on quantifiable parameters like concession period. If allocated through certain modes, the home state has the right of first refusal up to 80 percent of the project capacity, and the tariff shall be fixed by the Appropriate Commission u/s 62 of the Electricity Act, 2003. The developer can sell the remaining storage space through short/medium/long-term PPAs, power markets, or bilateral contracts.
   - **Allotment through Tariff-Based Competitive Bidding (TBCB):** PSPs can also be awarded to developers on a TBCB basis. An SPV under a CPSU/State PSU can be tasked with carrying out S&I and preparing a detailed project report, acquiring land, and obtaining environmental and forest clearances. This approach would enable tariff determination based on a competitive bidding. The DPR can then be bid out for construction, and the SPV transferred to the successful bidder on the basis of composite tariff (including input power cost) if the developer arranges input power or tariff for storage on a per megawatt-hour basis if the procurer of the storage capacity arranges input power. The Appropriate Commission shall adopt the above tariff u/s 63 of the Electricity Act, 2003.
   - **Self-identified off-stream pumped storage projects**: In addition to the above methods, developers can identify potential off-stream sites for the construction of PSPs, which do not require allotment from state governments since they do not utilise river streams. All necessary clearances from state and central agencies must be obtained before construction. These projects will receive all concessions mentioned in the guidelines, subject to government directions.
2. **Timelines for start of construction work after award of the project:** Developers must commence construction within two years from the date of project allotment. In the event of delay in construction, the state has the right to cancel the project allotment. However, a one-year extension may be granted if the delay is due to pending environmental and forest clearances, and the applications have been submitted within the agreed timelines.

3. **No upfront premium for project allocation**: In order to ensure the viability of the PSPs, states shall ensure that no upfront premium is charged for project allocation.

4. **Market reforms**: Comparing pumped storage projects with other conventional and variable renewable energy sources purely based on financial factors neglects and downplays the economic advantages such projects provide. Monetising the ancillary services provided by pumped storage projects would provide a significant boost to the sector.

   The reforms include the monetisation of ancillary services provided by PSPs to support grid stability, notification of peak and off-peak tariffs to provide appropriate pricing signals, allowing PSPs to participate in all market segments of the power exchange, offering 80 percent of the power generated during the monsoon period to the home state at a fixed rate, and allowing developers to transfer unused capacity to other interested parties while sharing any gains made with the original beneficiary in a 50:50 ratio.

5. **Financial viability**: In the future, there will be a high demand for electricity storage, and PSPs will need to operate in two cycles due to an increase in variable renewable energy infusion. This offers PSP developers the opportunity to optimise their operations and earn suitable returns by taking advantage of high rates during peak hours in the power exchanges. To ensure the construction of viable PSPs, the Central Government may notify a benchmark tariff of storage for investment decisions of developers considering 6-8 hours of operation based on the difference between peaking and non-peaking rates. Only those PSP projects whose levelised cost of storage is within the benchmark cost of storage should be developed. Financial institutions like PFC, REC, and IREDA should treat PSPs at par with other renewable energy projects and offer long-term loans of 20-25 years tenure with a debt-equity ratio of up to 80:20 in consultation with the financial institutions.

6. **Taxes and duties**: The State Government shall consider reimbursing SGST on PSP project components to promote long-term benefits and socio-economic development. The exemption of land acquisition by off-the-river PSPs from payment towards stamp duty and registration fees could be beneficial. The Government may provide land at a concessional rate to developers on an annual lease rent basis. PSPs facilitate the conversion of energy, therefore, electricity duty (ED) and cross-subsidy surcharge (CSS) shall not be applicable to pumping power for charging PSPs. The government of India has stated that no water cess shall be levied on PSPs and hydropower projects, as there is no consumptive use of water.

7. **Exemption from free power obligation**: PSPs are for storing energy, not for generating it, and they are in fact net consumers of energy. As a result, they would not be held accountable for providing free power.

8. **Local Area Development Fund**: PSPs have a minimal environmental impact and have no resettlement and rehabilitation (R&R) issues. Therefore, there will be a requirement for the creation of a Local Area Development Fund.

5 GIS-BASED MAPPING OF ALL POSSIBLE PSP SITES IN UTTAR PRADESH

Although PSP projects are operational in India, there are none in Uttar Pradesh (UP). With an ambitious solar policy recently released by the Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA) that aims to install 22 GW of solar projects by 2027, the role of PSPs is paramount to stabilise the intermittent PV output. The aim of this study is to assess the PSP potential in UP and identify prospective sites for PHS stations using Geographic Information Science (GIS) analyses. The results of this study will benefit the planning of PSP facilities in UP.

This study includes a detailed analysis of two different topologies as described in Table 6.

Table 6: Brief Description of Topologies

Sr. No.	Topology	Details
1	Using Existing Reservoirs	Linking two existing reservoirs with one or several penstock(s), and adding a powerhouse to transform them into a PSP
2	Developing One Reservoir	Transformation of one existing lake or reservoir to PSP by detecting a suitable site for a second reservoir. The second reservoir could be on a flat or non-sloping area, by digging or building shallow dams, on a depression, or in a valley. Even the second reservoir (mostly lower) can be a large river providing sufficient inflow in the PSP.

Off-river, closed-loop[8], pumped hydro schemes offer several advantages over conventional open-loop[9] pumped storage solutions. The upper reservoirs are situated on hills or plateaus instead of river valleys, providing additional power generation heads. Moreover, the reservoirs are smaller in size, typically ranging from tens to hundreds of hectares, resulting in reduced environmental impact and lower construction costs, since large flood events can be managed more easily. These projects are also often located away from main rivers, eliminating the need for extensive dam and spillway structures and desilting chambers. Consequently, closed-loop projects can be completed more rapidly and at a lower cost than traditional PSPs. These projects have the potential to meet the future energy needs of India without affecting existing water and irrigation systems or river basins. They are also expected to play a significant role in achieving the country's renewable energy capacity addition target.

5.1 METHODOLOGY

The geographic information systems (GIS) platform ArcGIS version 10.5 was utilised to pinpoint prospective locations. This platform relies on algorithms with predefined search criteria to identify potential sites. In this regard, the following steps were followed:

1. **Extraction of DEM**: To identify the potential PSP sites, a Digital Elevation Model (DEM) derived from Shuttle Radar Topography Mission (SRTM) satellite data with 30 m spatial resolution was used to

8 A closed-loop system in pumped storage is a type of system where the water used in the upper and lower reservoirs is recycled, and no water is released into the environment.

9 In an open loop system in pumped storage, water is drawn from an external source, such as a river or lake, and pumped into the upper reservoir to generate electricity during peak demand.

visualise the topographic relief of the entire state. It is observed that the smaller part of southern UP covering Mirzapur, Sonbhadra, and Chandauli under the Vindhya Range and plateau exhibits a good number of natural sites where PSP development is possible as seen in Figure 7.

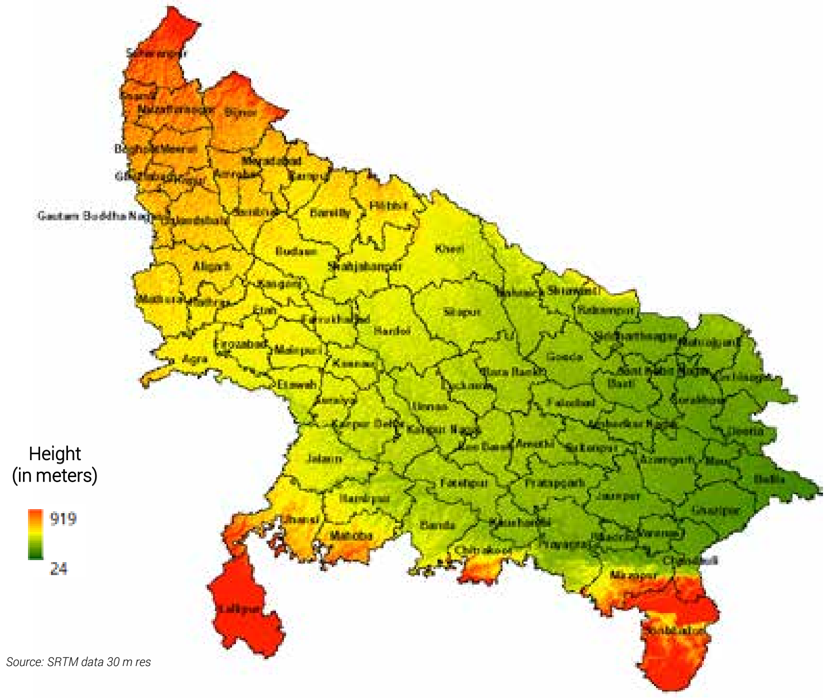

Figure 7: Altitude map of Uttar Pradesh (SRTM data 30m resolution)

2. **Extraction of waterbodies**: Waterbodies extracted from satellite images were further classified into two categories i.e., perennial and intermittent keeping in view the continuous availability of water to support the PSP system as can be observed in Figure 8. Also, Survey of India (SOI) topographic maps/ toposheets (F44E13, F44F1, G44Q12, G44W9, G44W10 to G44W 16, G44X2 to G44X8 for Sonbhadra and G44Q8, G44Q16, G44R4, G44W1 to G44W6 and G44W13 for Mirzapur district and G44R3, G44R7, G44R8, G44X1 and G44X5 for Chandauli district) were used for comparison/validation of waterbodies.

Figure 8: Waterbodies in Uttar Pradesh (Satellite data)

3. **Assessment of catchment/watershed**: The entire region of the three districts was analysed for topographic characteristics using Survey of India (SOI) toposheets. The analysis involved contour intervals (20-meter interval), stream network, and direction, as well as probable catchment areas along drainage lines. The purpose of this analysis was to identify suitable locations for developing new water bodies (topology 2) and maximise the PSP capacity.

The elevation profile of existing waterbodies was calculated along with the aerial distance between two perennial waterbodies. In this regard, the 3D surface model was created in GIS to visualise the potential pumped hydro-energy storage (PHES) sites with their respective interconnections.

5.2 KEY CRITERIA FOR FAVOURABLE SITES

The key criteria for selecting pumped storage potential sites can vary depending on the specific context and goals of the project. However, some common criteria included in the analysis are as follows:

- Presence of a large head is desirable
- Minimum conflicts with indigenous, environmental, social, heritage and agricultural and land management aspects
- Minimum conflicts with human settlements
- Appropriate geological characteristics
- Around 85 percent of the stored water is available for use
- Ensuring sites that have rainfall exceeding annual evaporation in most years to ensure top-up water requirements are minimal

5.3 TOPOLOGY 1 – USING EXISTING RESERVOIRS

As mentioned previously, this topology includes PHS sites based on linking two existing reservoirs. Key constraints for this topology are mentioned in Table 7. The potential PSP capacity is dependent on the capacity of the upper reservoir.

Table 7: Key Constraints for Potential Assessment

Description	Values
Maximum distance between reservoirs	20 kms
Minimum upper reservoir area	0.05 sq km
Average depth of the reservoir	20 m

The energy estimation can be carried out using

$E = \rho g h V \eta$

Where:

E= Energy available (Joules)

ρ= density (1000 kg/m3)

g= acceleration due to gravity (9,8 m/s2)

h= average head (m)

V= Volume of upper reservoir (m3)

η= generation efficiency (assumed as 90 percent)

Here, the volume of the upper reservoir is calculated based on the assumption of the average depth of the reservoir to be 20 m, and the area of the reservoir is calculated using the GIS tool. Figure 9 captures the potential PSP sites under the first topology. As shown in the figure, the majority of sites are present in Chandauli, Mirzapur, and Sonbhadra regions.

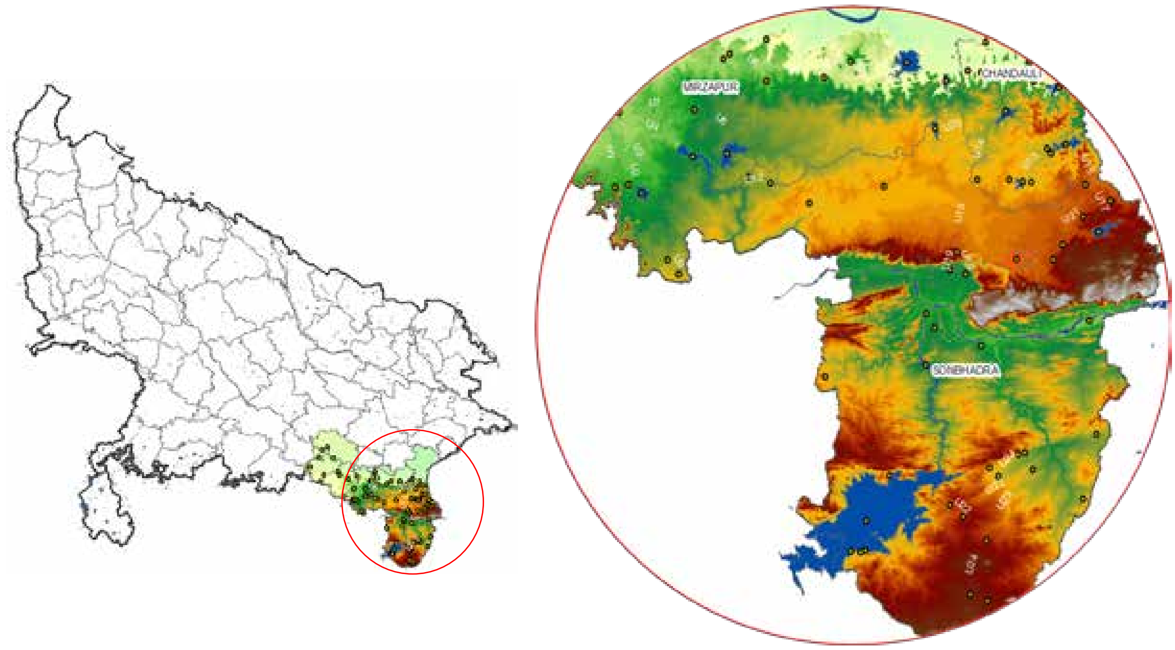

Figure 9: Potential PSP sites in UP under the first topology

Moreover, each site was further deep-dived to furnish other parameters such as head, reservoir area, and the average distance between the reservoirs. The upper reservoir is marked with the character 'U' and the lower reservoir is marked with the character 'L'. Figure 10 and Figure 11 provide a typical 3D representation of a few sites to provide a better understanding of the parameters assessed.

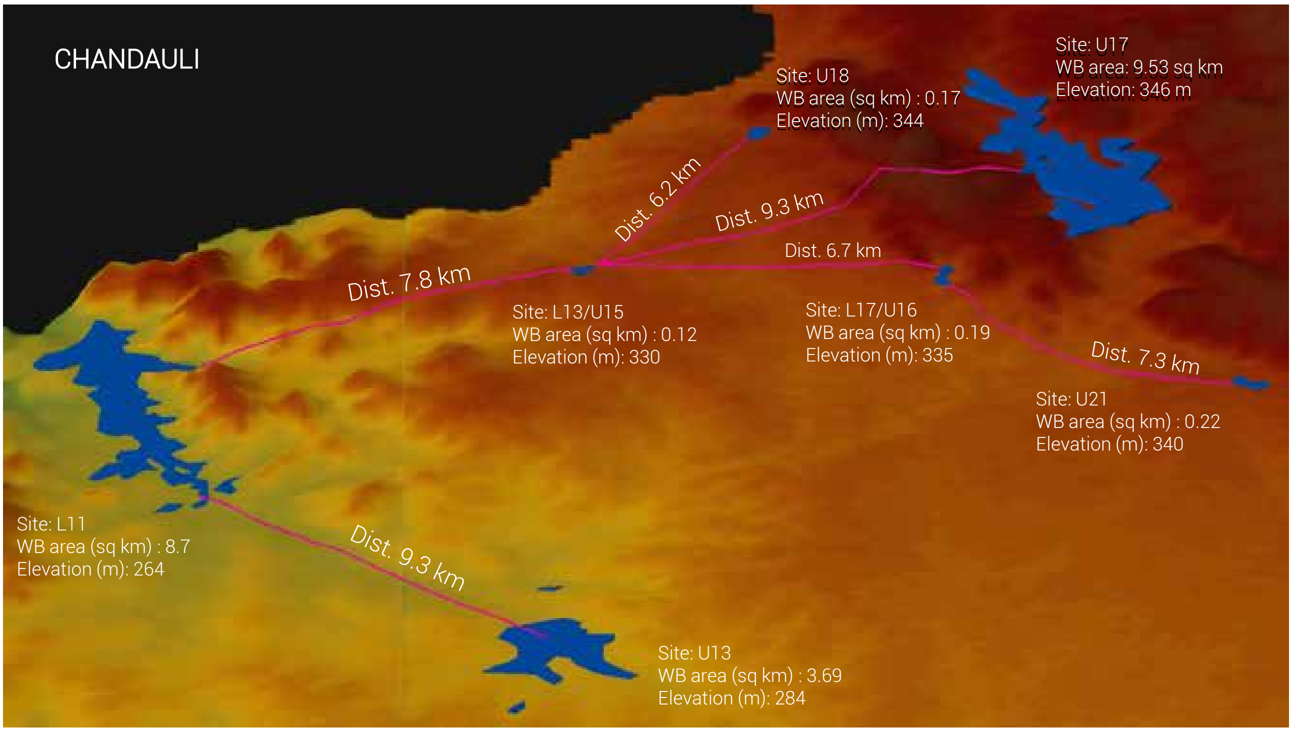

Figure 10A: Detailed 3D maps for select favourable sites in Chandauli region

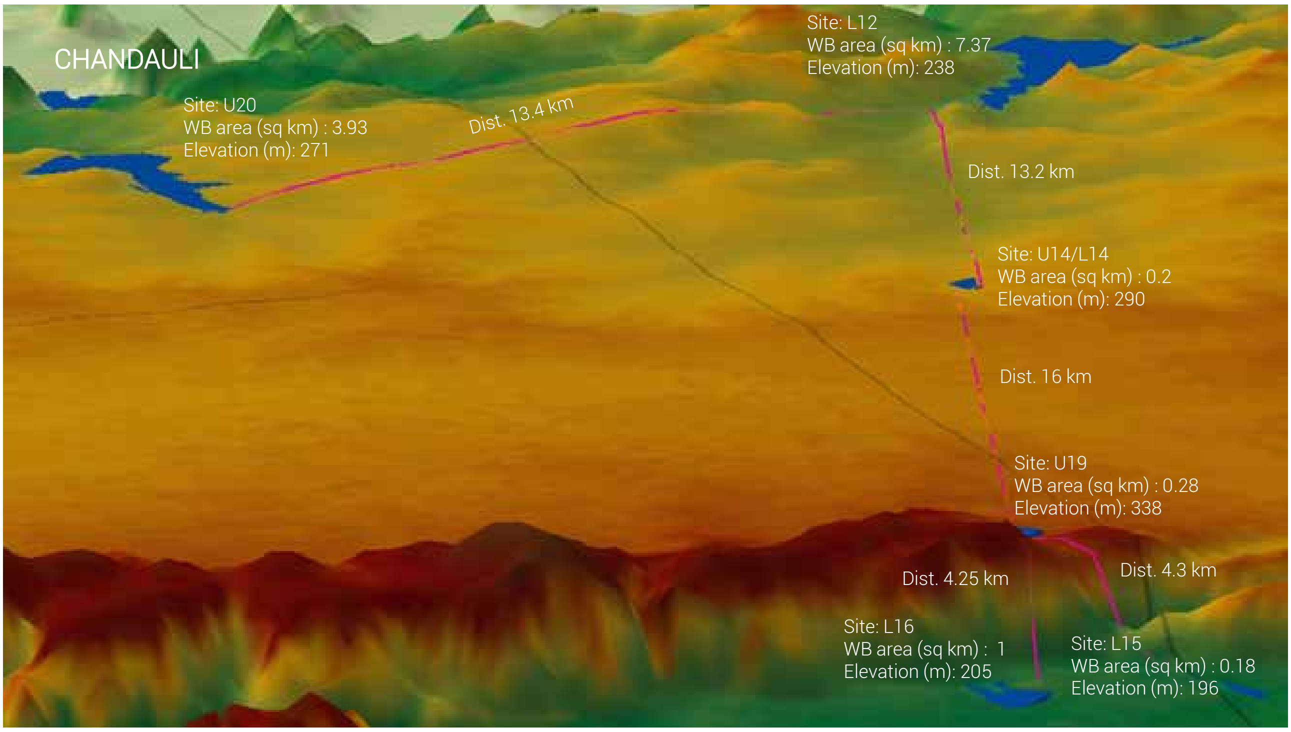

Figure 10B: Detailed 3D maps for select favourable sites in Chandauli region

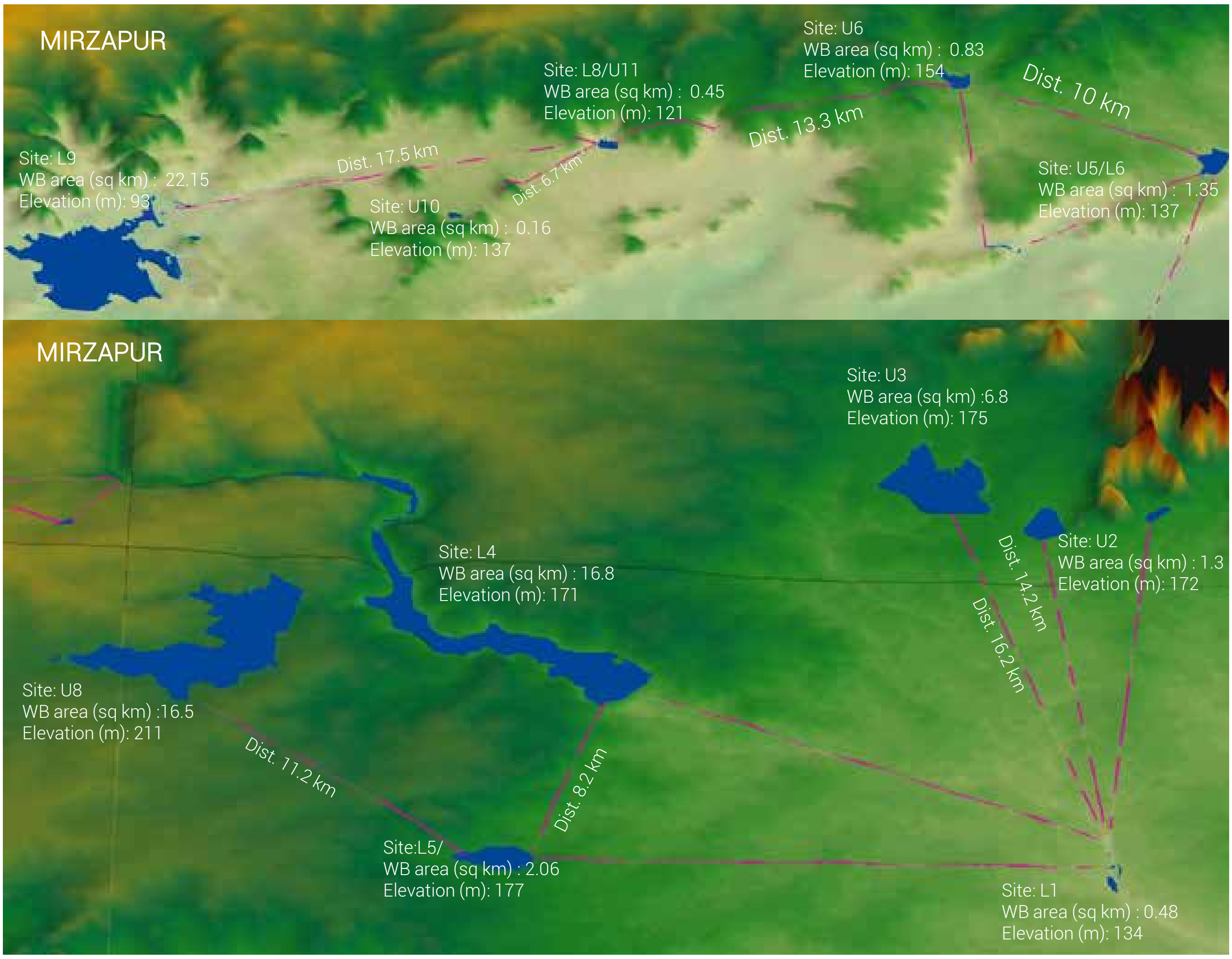

Figure 11: Detailed 3D maps for select favourable sites in Mirzapur region

Table 8 enlists all suitable sites for PSP development under the first topology in UP along with precise latitude and longitude details. There are around 24 such sites. The maximum head discovered between the upper and lower reservoir is around 142 meters between U19 and L15. In terms of capacity, U4 has the highest PSP capacity of 30.5 GWh with a reservoir area of around 16.82 sq. km.

Table 8: List of all suitable sites under the first topology in UP

S. No.	Upper Reser-voir	Lower Reser-voir	UR_ Eleva-tion (m)	LR_ Eleva-tion (m)	Head (m)	UR_Area (Sq m)	UR_ Area (Sq km)	LR_Area (Sq m)	LR_ Area (Sq km)	Length/ Dis-tance (Km)	UR_ Lat-itude	UR_ Longi-tude	LR_ Lati-tude	LR_ Longi-tude	High Poten-tial (GWh)	Low Poten-tial (GWh)
1.00	U1	L1	177.00	134.00	43.00	2,57,213.00	0.26	4,84,409.00	0.48	14.84	24.79	82.25	24.94	82.26	0.54	0.54
2.00	U2	L1	172.00	134.00	38.00	13,05,792.80	1.31	4,84,409.00	0.48	14.22	24.79	82.28	24.94	82.26	2.43	2.43
3.00	U3	L1	175.00	134.00	41.00	68,86,877.10	6.89	4,84,409.00	0.48	16.21	24.77	82.31	24.94	82.26	13.84	13.84
4.00	U4	L1	171.00	134.00	37.00	1,68,18,043.40	16.82	4,84,409.00	0.48	15.62	24.83	82.45	24.94	82.26	30.49	30.49
5.00	U5	L2	137.00	81.00	56.00	13,58,478.20	1.36	96,258.70	0.10	8.63	25.05	82.52	25.13	82.57	3.73	
6.00	U5	L3	137.00	93.00	44.00	13,58,478.20	1.36	3,61,277.50	0.36	8.30	25.05	82.52	25.08	82.61		2.93
7.00	U6	L3	154.00	93.00	61.00	8,32,321.30	0.83	3,61,277.50	0.36	9.05	24.99	82.61	25.08	82.62	2.49	
8.00	U7	L4	177.00	171.00	6.00	20,60,774.00	2.06	1,68,18,043.40	16.82	8.23	24.94	82.44	24.83	82.45		0.61
9.00	U7	L1	177.00	134.00	43.00	20,60,774.00	2.06	4,84,409.00	0.48	16.87	24.94	82.44	24.94	82.26	4.34	
10.00	U8	L5	211.00	177.00	34.00	1,65,33,093.90	16.53	20,60,774.00	2.06	11.19	24.85	82.52	24.94	82.44	27.54	27.54
11.00	U6	L6	154.00	137.00	17.00	8,32,321.30	0.83	13,58,478.20	1.36	9.99	24.99	82.61	25.05	82.52		0.69
12.00	U9	L7	263.00	250.00	13.00	1,38,336.20	0.14	1,08,613.40	0.11	3.93	24.61	82.39	24.64	82.37	0.09	0.09
13.00	U6	L8	154.00	121.00	33.00	8,32,321.30	0.83	4,59,904.70	0.46	13.32	24.99	82.61	25.00	82.75		
14.00	U10	L8	137.00	121.00	16.00	1,60,171.40	0.16	4,59,904.70	0.46	6.68	25.03	82.81	25.00	82.75	0.13	0.13
15.00	U11	L9	121.00	93.00	28.00	4,59,904.70	0.46	2,21,54,364.20	22.15	17.45	25.00	82.75	25.03	82.95	0.63	0.63
16.00	U12	L10	249.00	241.00	8.00	3,06,698.80	0.31	82,209.30	0.08	4.99	24.79	82.62	24.80	82.57		0.12
17.00	U13	L4	241.00	171.00	70.00	82,209.30	0.08	1,68,18,043.40	16.82	3.20	24.80	82.57	24.83	82.45		0.28

S. No.	Upper Reser-voir	Lower Reser-voir	UR_ Eleva-tion (m)	LR_ Eleva-tion (m)	Head (m)	UR_Area (Sq m)	UR_ Area (Sq km)	LR_Area (Sq m)	LR_ Area (Sq km)	Length/ Dis-tance (Km)	UR_ Lat-itude	UR_ Longi-tude	LR_ Lati-tude	LR_ Longi-tude	High Poten-tial (GWh)	Low Poten-tial (GWh)
18.00	U12	L4	249.00	171.00	78.00	3,06,698.80	0.31	1,68,18,043.40	16.82	6.59	24.79	82.62	24.83	82.45	1.17	
19.00	U13	L11	284.00	264.00	20.00	36,89,137.40	3.69	87,02,490.10	8.70	9.34	24.78	83.21	24.85	83.32	3.62	
20.00	U14	L12	290.00	238.00	52.00	1,99,095.80	0.20	73,79,482.20	7.38	13.29	24.79	83.11	24.92	83.18	0.51	0.51
21.00	U15	L11	330.00	264.00	66.00	1,17,683.00	0.12	87,02,490.10	8.70	7.86	24.77	83.36	24.85	83.32	0.38	0.38
22.00	U16	L13	335.00	330.00	5.00	1,90,962.30	0.19	1,17,683.00	0.12	6.73	24.70	83.36	24.77	83.36	0.05	0.05
23.00	U17	L13	346.00	330.00	16.00	95,34,382.10	9.53	1,17,683.00	0.12	9.23	24.68	83.41	24.77	83.36	7.47	7.47
24.00	U18	L13	344.00	330.00	14.00	1,74,125.50	0.17	1,17,683.00	0.12	6.21	24.74	83.42	24.77	83.36	0.12	0.12
25.00	U19	L14	338.00	290.00	48.00	2,80,591.70	0.28	1,99,095.80	0.20	16.05	24.64	83.06	24.79	83.11		0.66
26.00	U19	L15	338.00	196.00	142.00	2,80,591.70	0.28	1,89,769.70	0.19	4.32	24.64	83.06	24.60	83.07	1.95	
27.00	U19	L16	338.00	205.00	133.00	2,80,591.70	0.28	9,90,718.00	0.99	4.26	24.64	83.06	24.60	83.04		
28.00	U20	L12	271.00	238.00	33.00	39,30,250.70	3.93	73,79,482.20	7.38	13.49	24.89	83.01	24.92	83.18	6.36	6.36
29.00	U21	L17	340.00	335.00	5.00	2,17,775.40	0.22	1,90,962.30	0.19	7.39	24.65	83.31	24.70	83.36	0.05	0.05
30.00	U22	L18	352.00	270.00	82.00	1,96,582.00	0.20	2,82,372.30	0.28	11.31	24.11	83.06	24.19	83.14		
31.00	U23	L18	294.00	270.00	24.00	1,07,091.40	0.11	2,82,372.30	0.28	2.12	24.20	83.12	24.19	83.14		0.13
32.00	U23	L19	294.00	256.00	38.00	1,07,091.40	0.11	2,53,120.90	0.25	6.62	24.20	83.12	24.23	83.19		
33.00	U24	L19	270.00	256.00	14.00	2,82,372.30	0.28	2,53,120.90	0.25	6.19	24.19	83.14	24.23	83.19		0.19
34.00	U24	L20	270.00	245.00	25.00	2,82,372.30	0.28	2,27,863.20	0.23	7.70	24.19	83.14	24.23	83.21		
35.00	U22	L21	352.00	248.00	104.00	1,96,582.00	0.20	1,90,348.50	0.19	18.66	24.11	83.06	24.20	83.23	1.00	
36.00	U23	L21	353.00	248.00	105.00	1,21,760.30	0.12	1,90,348.50	0.19	18.41	24.06	83.11	24.20	83.23	0.63	
37.00	U24	L22	406.00	353.00	53.00	1,37,214.80	0.14	1,21,760.30	0.12	12.52	23.95	83.07	24.06	83.11	0.36	
38.00	U22	L23	352.00	330.00	22.00	1,96,582.00	0.20	82,347.80	0.08	4.11	24.11	83.06	24.13	83.03		0.21

5.4 TOPOLOGY 2 – DEVELOPING ONE RESERVOIR

As mentioned previously, this topology includes linking the existing reservoirs or rivulets with a newly built reservoir, which can be enclosed with a wall structure similar to a dam. Key constraints for this topology are the same as Topology 1. Figure 12 displays the potential PSP sites under the second topology. As can be seen in the figure, the majority of sites are present in Chandauli, Mirzapur, and Sonbhadra regions.

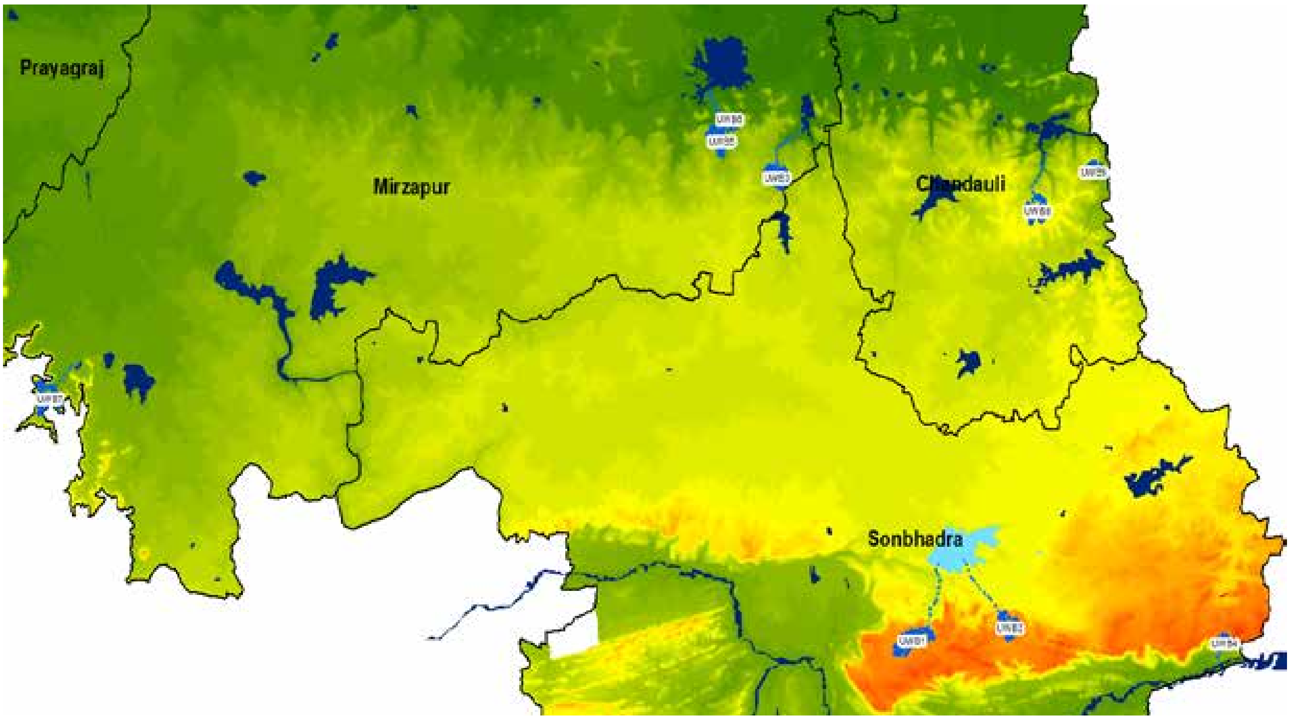

Figure 12: Potential PSP sites in UP under the second topology

Moreover, each site was further deep-dived to furnish other parameters such as head, reservoir area, and the average distance between the reservoirs. The upper reservoir is marked with the character 'UWB' and the lower reservoir is marked with the character 'LWB'. Figure 13 provides a typical 3D representation of a few sites to provide a better understanding of the parameters assessed along with the region to create the upper reservoir.

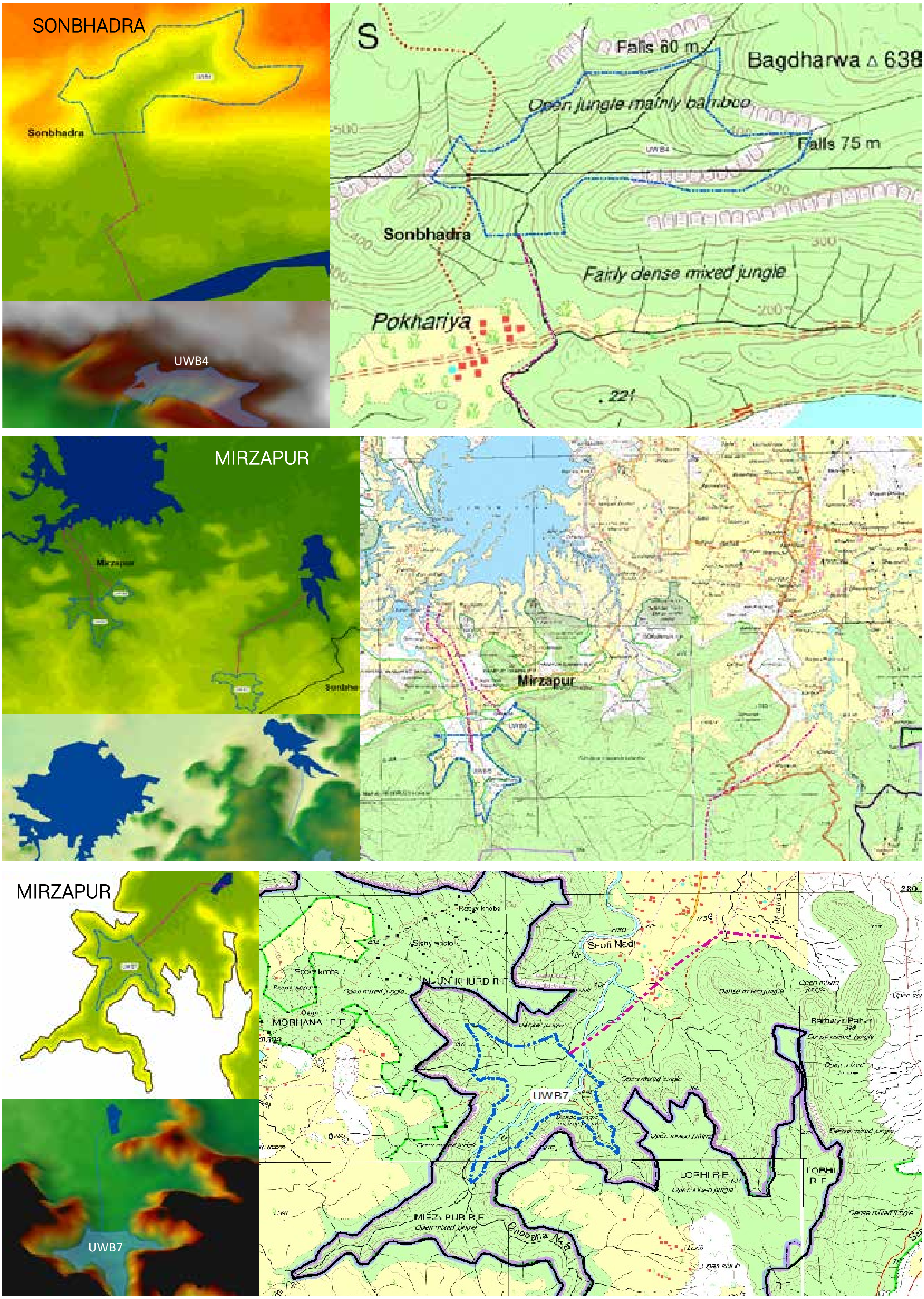

Figure 13: Detailed 3D maps for select favourable sites in Sonbhadra and Mirzapur region

Table 9 lists out of all suitable sites for PSP development under the second topology in UP along with precise latitude and longitude details. There are around nine such sites. The maximum head discovered between the upper and lower reservoir is around 161 meters between UWB1 and LWB1. The potential assessment was done on similar lines to Topology 1. In terms of capacity, UWB1 has the highest PSP capacity of 33.7 GWh with a reservoir area of around 4.23 sq. km.

Table 9: List of all suitable sites under the second topology in UP

S. No	Upper Reser-voir	Lower Reser-voir	UR_Eleva-tion (m)	LR_Eleva-tion (m)	Head (m)	UR_Area (Sq km)	LR_Area (Sq km)	Length/ Distance (Km)	UR_Lati-tude	UR_Longi-tude	LR_Lati-tude	LR_Longi-tude	Potential (GWh)
1	UWB8	LWB6	272.00	14.00	158.00	3.21	7.69	5.17	24.91	83.28	24.95	83.29	24.85
2	UWB9	LWB6	192.00	135.00	57.00	1.20	7.69	0.62	24.93	83.35	24.93	83.36	3.34
3	UWB1	LWB1	475.00	314.00	161.00	4.23	19.35	6.79	24.55	83.16	24.61	83.18	33.37
4	UWB2	LWB1	421.00	314.00	107.00	2.08	19.35	6.58	24.57	83.24	24.62	83.20	10.89
5	UWB4	LWB3	205.00	151.00	54.00	1.17	River	1.81	24.54	83.47	24.52	83.48	3.10
6	UWB5	LWB4	122.00	97.00	25.00	2.23	22.15	4.23	24.97	82.94	25.01	82.93	2.74
7	UWB3	LWB2	212.00	102.00	110.00	1.92	3.07	5.56	24.94	83.00	24.98	83.04	10.36
8	UWB6	LWB4	127.00	97.00	30.00	0.60	22.15	3.61	24.98	82.95	25.01	82.93	0.89
9	UWB7	LWB5	185.00	177.00	8.00	2.51	0.25	3.83	24.76	82.22	24.79	82.25	0.98

6 EXAMINING IMPACTS OF PSPs

Though there are certain critical impacts of PSPs on flora and fauna, careful planning and management can help mitigate these impacts and ensure that these projects are developed in an environmentally sustainable manner.

6.1 IMPACT ON HUMAN SETTLEMENTS

Pumped storage projects offer several advantages, including their ability to provide reliable energy and facilitate the integration of renewable energy into the power grid. However, it's important to note that these projects can also have significant impacts on communities living in the area. The construction of large reservoirs and related infrastructure can lead to displacement of people and disruption of their livelihoods, resulting in social and economic upheaval. To minimise these negative impacts, it is essential to carefully select project sites that are located away from densely populated areas. Based on Figure 14, areas such as Chandauli, Mirzapur, and Sonbhadra, which have the lowest population density in Uttar Pradesh, would be the most suitable for the development of pumped storage projects. By doing so, the potential for disruption of human settlements can be minimised.

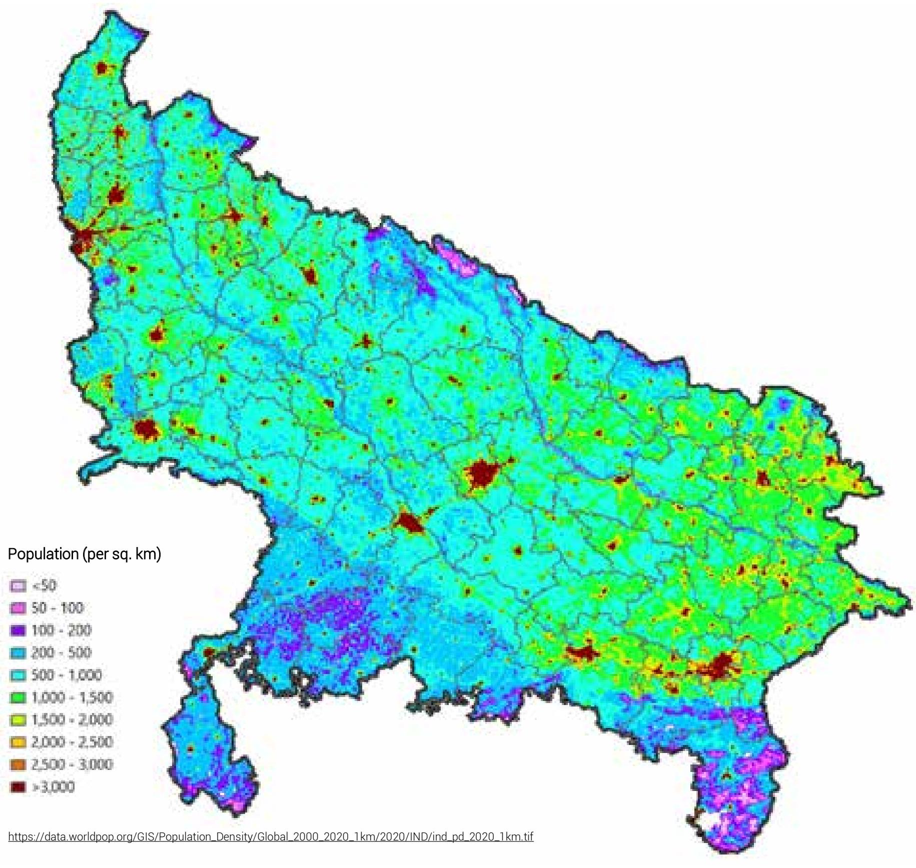

Figure 14: Population density map of UP[10]

10 https://data.worldpop.org/GIS/Population_Density/Global_2000_2020_1km/2020/IND/ind_pd_2020_1km.tif

6.2 IMPACT ON ENVIRONMENT

The construction of pumped storage projects can have significant impacts on forest ecosystems and surrounding habitats, particularly through the construction of large dams and reservoirs. This can lead to the displacement of wildlife and changes to surrounding habitats, ultimately resulting in a loss of biodiversity and having negative impacts on endangered species. Additionally, the creation of reservoirs may lead to conversion of natural resources, such as wetlands or forests, into artificial water bodies, thereby disrupting the essential ecosystem services such as carbon sequestration, water purification and flood regulation, they provide. Finally, the development of large dams and associated infrastructure may contribute to increased soil erosion and sedimentation, causing harm to nearby wetlands and aquatic ecosystems and deteriorate water quality and habitats. Therefore, it is critical to carefully consider the location of pumped storage projects and to avoid constructing them in ecologically sensitive areas. As can be seen in Figure 15, majority of sites identified in this report lie outside protected regions and are thus suitable for further exploration.

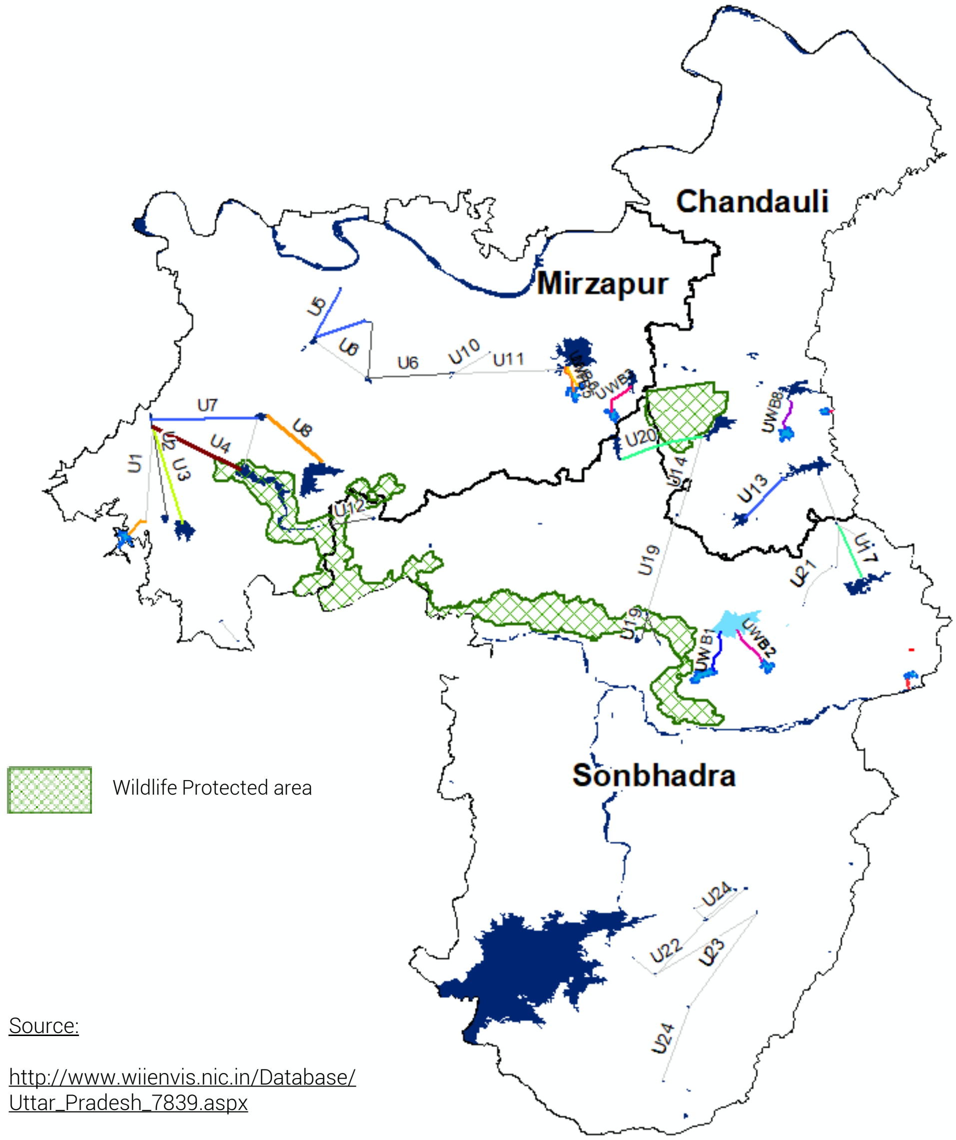

Figure 15: Wildlife protected area near the proposed sites[11]

11 http://www.wiienvis.nic.in/Database/Uttar_Pradesh_7839.aspx

6.3 IMPACT ON THE PROJECT INFRASTRUCTURE

Pumped storage projects should be sited away from high seismic zones and flood-prone areas due to the potential risks posed to the safety and stability of the associated infrastructure. Among these risks are ground shaking, displacement, and liquefaction, which can lead to infrastructure failure and negative environmental impacts, endangering human settlements and causing damage to property. To ensure safety, selecting suitable sites for pumped storage projects requires thorough consideration of seismic and flood hazards, including geotechnical and seismic hazard assessments, flood hazard assessments, and consultation with local communities and stakeholders. In this regard, potential sites outside high seismic zones and flood-prone areas, as illustrated in Figure 16, could be viable alternatives for pumped storage projects.

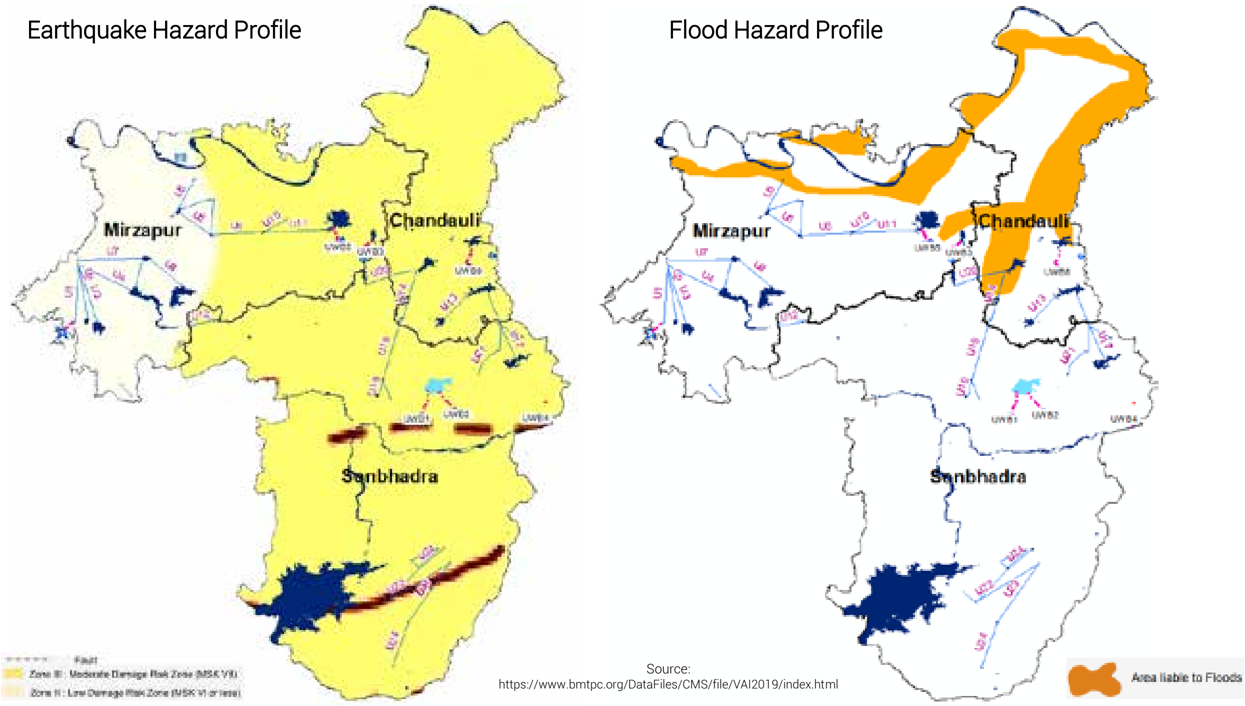

Figure 16: Seismic zone profile near the proposed sites[12]

12 https://www.bmtpc.org/DataFiles/CMS/file/VAI2019/index.html

7 RESULTS

UP has many potential sites for PSPs. Our initial survey found about 33 sites – the district and territory breakdown are shown in the table below. PSP potential under the first topology is ranging 96.45 GWh to 109.91 GWh and the second topology is 90.51 GWh. Figure 17 represents the location of each site for each topology along with their respective capacities.

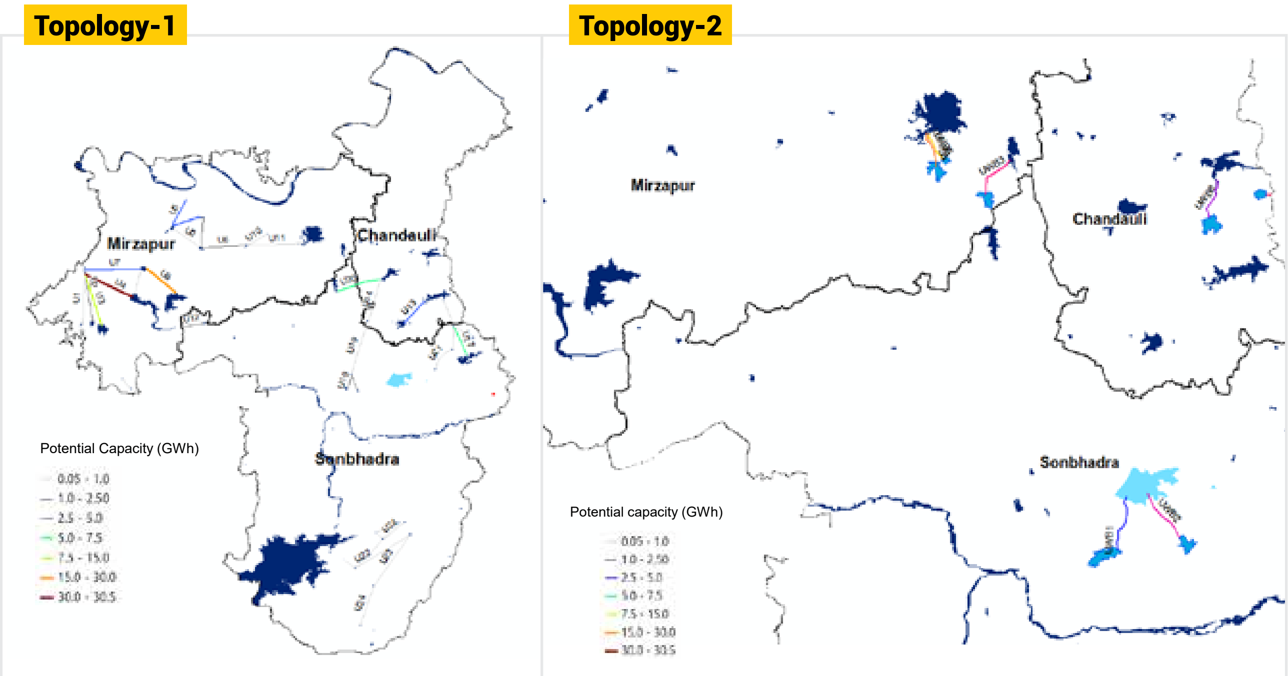

Figure 17: Capacity-wise representation of each PSP site

Each site has an energy storage potential between 0.05 and 33.37 Gigawatt hours (GWh). The sites identified so far have a combined energy storage potential ranging between 186.96 GWh to 200.42 GWh. To provide perspective to this number, the energy storage capacity required for 2029-30 as per the recently released Optimal Generation Mix Report is 336.4 GWh. Of this, around 128.15 GWh will be from PSP and the remaining from BESS.

Around 140.3 GWh of capacity is located in low impact regions. Table 10 and Table 11 provide details on identified sites based on their level of impact where light green colour indicates lower impact on the flora and fauna.

Table 10: Colour coding of sites under topology 1 based on their level of impact

S. No.	Upper Rese-rvoir	Lower Reser-voir	UR_ Elevation (m)	LR_ Elevation (m)	Head (m)	UR_ Lati-tude	UR_ Longit-ude	LR_ Lati-tude	LR_ Longi-tude	Earthquake Hazard (Damage Risk Zone)	Wildlife Sanc-tuaries	Flood Hazard	High Poten-tial (GWh)	Low Poten-tial (GWh)
1	U1	L1	177.00	134.00	43.00	24.79	82.25	24.94	82.26	Low	No	No	0.54	0.54
2	U2	L1	172.00	134.00	38.00	24.79	82.28	24.94	82.26	Low	No	No	2.43	2.43
3	U3	L1	175.00	134.00	41.00	24.77	82.31	24.94	82.26	Low	No	No	13.84	13.84
4	U4	L1	171.00	134.00	37.00	24.83	82.45	24.94	82.26	Low	Inside Wildlife Protected area	No	30.49	30.49
5	U5	L2	137.00	81.00	56.00	25.05	82.52	25.13	82.57	Low	No	Area liable to floods	3.73	
6	U5	L3	137.00	93.00	44.00	25.05	82.52	25.08	82.61	Low	No	No		2.93
7	U6	L3	154.00	93.00	61.00	24.99	82.61	25.08	82.62	Low	No	No	2.49	
8	U7	L4	177.00	171.00	6.00	24.94	82.44	24.83	82.45	Low	No	No		0.61
9	U7	L1	177.00	134.00	43.00	24.94	82.44	24.94	82.26	Low	No	No	4.34	
10	U8	L5	211.00	177.00	34.00	24.85	82.52	24.94	82.44	Low	No	No	27.54	27.54
11	U6	L6	154.00	137.00	17.00	24.99	82.61	25.05	82.52	Low	No	No		0.69
12	U9	L7	263.00	250.00	13.00	24.61	82.39	24.64	82.37	Low	No	No	0.09	0.09
13	U6	L8	154.00	121.00	33.00	24.99	82.61	25.00	82.75	Low	No	No		
14	U10	L8	137.00	121.00	16.00	25.03	82.81	25.00	82.75	Moderate	No	No	0.13	0.13
15	U11	L9	121.00	93.00	28.00	25.00	82.75	25.03	82.95	Moderate	No	No	0.63	0.63
16	U12	L10	249.00	241.00	8.00	24.79	82.62	24.80	82.57	Moderate	Inside Wildlife Protected area	No		0.12
17	U13	L4	241.00	171.00	70.00	24.80	82.57	24.83	82.45	Moderate	No	No		0.28
18	U12	L4	249.00	171.00	78.00	24.79	82.62	24.83	82.45	Moderate	No	No	1.17	
19	U13	L11	284.00	264.00	20.00	24.78	83.21	24.85	83.32	Moderate	No	No	3.62	
20	U14	L12	290.00	238.00	52.00	24.79	83.11	24.92	83.18	Moderate	Inside Wildlife Protected area	Area liable to floods	0.51	0.51
21	U15	L11	330.00	264.00	66.00	24.77	83.36	24.85	83.32	Moderate	No	No	0.38	0.38
22	U16	L13	335.00	330.00	5.00	24.70	83.36	24.77	83.36	Moderate	No	No	0.05	0.05
23	U17	L13	346.00	330.00	16.00	24.68	83.41	24.77	83.36	Moderate	No	No	7.47	7.47
24	U18	L13	344.00	330.00	14.00	24.74	83.42	24.77	83.36	Moderate	No	No	0.12	0.12
25	U19	L14	338.00	290.00	48.00	24.64	83.06	24.79	83.11	Moderate	Inside Wildlife Protected area	No		0.66
26	U19	L15	338.00	196.00	142.00	24.64	83.06	24.60	83.07	Moderate	Inside Wildlife Protected area	No	1.95	
27	U19	L16	338.00	205.00	133.00	24.64	83.06	24.60	83.04	Moderate	Inside Wildlife Protected area	No		

S. No.	Upper Rese-rvoir	Lower Reser-voir	UR_ Elevation (m)	LR_ Elevation (m)	Head (m)	UR_ Lati-tude	UR_ Longit-ude	LR_ Lati-tude	LR_ Longi-tude	Earthquake Hazard (Damage Risk Zone)	Wildlife Sanc-tuaries	Flood Hazard	High Poten-tial (GWh)	Low Poten-tial (GWh)
28	U20	L12	271.00	238.00	33.00	24.89	83.01	24.92	83.18	Moderate	Inside Wildlife Protected area	Area liable to floods	6.36	6.36
29	U21	L17	340.00	335.00	5.00	24.65	83.31	24.70	83.36	Moderate	No	No	0.05	0.05
30	U22	L18	352.00	270.00	82.00	24.11	83.06	24.19	83.14	Moderate	No	No		
31	U23	L18	294.00	270.00	24.00	24.20	83.12	24.19	83.14	Moderate	No	No		0.13
32	U23	L19	294.00	256.00	38.00	24.20	83.12	24.23	83.19	Moderate	No	No		
33	U24	L19	270.00	256.00	14.00	24.19	83.14	24.23	83.19	Moderate	No	No		0.19
34	U24	L20	270.00	245.00	25.00	24.19	83.14	24.23	83.21	Moderate	No	No		
35	U22	L21	352.00	248.00	104.00	24.11	83.06	24.20	83.23	Moderate	No	No	1.00	
36	U23	L21	353.00	248.00	105.00	24.06	83.11	24.20	83.23	Moderate	No	No	0.63	
37	U24	L22	406.00	353.00	53.00	23.95	83.07	24.06	83.11	Moderate	No	No	0.36	
38	U22	L23	352.00	330.00	22.00	24.11	83.06	24.13	83.03	Moderate	No	No		0.21

Table 11: Color coding of sites under topology 2 based on their level of impact

S. No	Upper Reser-voir	Lower Reser-voir	UR_ Eleva-tion (m)	LR_ Eleva-tion (m)	Head (m)	UR_ Area (Sq km)	LR_ Area (Sq km)	Length/ Distance (Km)	UR_ Lati-tude	UR_ Longi-tude	LR_ Lati-tude	LR_ Longit-ude	Earth-quake Hazard	Wildlife Sanc-tuaries	Flood Hazard	Poten-tial (GWh)
1	UWB8	LWB6	272.00	114.00	158.00	3.21	7.69	5.17	24.91	83.28	24.95	83.29	Moderate	No	Area liable to floods	24.85
2	UWB9	LWB6	192.00	135.00	57.00	1.20	7.69	0.62	24.93	83.35	24.93	83.36	Moderate	No	No	3.34
3	UWB1	LWB1	475.00	314.00	161.00	4.23	19.35	6.79	24.55	83.16	24.61	83.18	Moderate	No	No	33.37
4	UWB2	LWB1	421.00	314.00	107.00	2.08	19.35	6.58	24.57	83.24	24.62	83.20	Moderate	No	No	10.89
5	UWB4	LWB3	205.00	151.00	54.00	1.17	River	1.81	24.54	83.47	24.52	83.48	Moderate	No	No	3.10
6	UWB5	LWB4	122.00	97.00	25.00	2.23	22.15	4.23	24.97	82.94	25.01	82.93	Moderate	No	No	2.74
7	UWB3	LWB2	212.00	102.00	110.00	1.92	3.07	5.56	24.94	83.00	24.98	83.04	Moderate	No	No	10.36
8	UWB6	LWB4	127.00	97.00	30.00	0.60	22.15	3.61	24.98	82.95	25.01	82.93	Moderate	No	No	0.89
9	UWB7	LWB5	185.00	177.00	8.00	2.51	0.25	3.83	24.76	82.22	24.79	82.25	Moderate	No	No	0.98

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