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Assessing Potential of Dor River as Small Hydro Project for Lessening Energy Crisis and Enhancing Tarbela Reservoir Life in Khyber Pakhtunkhwa, Pakistan

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Abstract: This study was conducted to design a small hydropower project at Dor River in Abbottabad, Khyber Pakhtunkhwa, Pakistan. The study area is part of the Hazara Basin and contains sedimentary rocks deposited in glaciofluvial, fluvial and marine environments. The suitable locations were chosen for the proposed hydropower project components and shown on geological map of the study area. Rock Mass Rating (RMR) studies were conducted to check the quality of rocks exposed at the selected sites. The rocks were classified as fair rocks with RMR ranging from 48 to 55, which shows that rocks are suitable for construction activities, e.g., tunneling, etc. The rocks of the area were also found suitable for their use as a construction material, which is an additional positive aspect of this study. For potential hydropower evaluation, the discharge of the Dor river was measured using the current meter method. Additionally, the sediment load of the river was determined using Whatman filter papers. The Dor River water discharge is variable, where the maximum water discharge was found in the months of July (6.79 m^3 s^{-1}) and August (6.71 m^3 s^{-1}). Hence, the construction of a small hydropower project on Dor River can be favorably undertaken to produce a plant with low (2.79 MW), average (5.37 MW) and high-power potential (13.16 MW). In suspended sediment load analysis, it was found highest in the months of July and August and lowest in December. Annually, the Dor River takes 7267 tons of sediment to Tarbela Reservoir, which is likely to adversely affect both the life and capacity of the country's currently largest hydropower-producing reservoir located downstream. The construction of the hydropower project proposed in this study will effectively slow the deposition of sediment into Tarbela Reservoir, which in turn will enhance the life of the reservoir positively.

Keywords: energy; rock mass rating (RMR); building materials; power potential; sediment load

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1. Introduction

Energy plays a vital role in building economies and improving people's lifestyles [1]. With the emergence of modern technology, energy has become an essential life commodity as it controls almost all human activities, including home, trade, commerce, business, transportation and agriculture. Energy has the potential to overcome important fundamental social issues such as poverty, food shortage, diseases and paucity of education [2]. Therefore, the provision of sufficient inexpensive and renewable energy is essential for controlling the level of poverty, improving human welfare and raising the standard of living across the world [3,4].

Many people in the world are without electricity. According to a Human Development report [5], for twenty-five years, some 1.3 billion people have had this facility, while more than 1.4 billion people do not have this facility. The leading countries in the world that suffer from severe power shortages and so have to impose and observe multiple long spells of power load shedding include India, Bangladesh, Indonesia, Nigeria, Pakistan, Congo, Ethiopia, Myanmar, Tanzania and Kenya.

As one of the South Asian countries, Pakistan has faced an energy crisis since the time of its independence. The energy supply basis of Pakistan constitutes both the commercial and the non-commercial sectors. At the time of independence, the total population of the country was about 33 million, the total installed generation capacity of electric power was 50 MW [6] and energy consumption by the commercial sector was estimated to be 1.2 million tons oil equivalent (TOE). Currently, Pakistan requires around 15,000 to 20,000 MW of electricity, while that produced through all the available means is only 11,500 MW; thus, a shortage of about 4000 to 9000 MW is usually experienced. This huge power shortfall has to be managed through load shedding, which badly affects the economic growth of the country [7]. Compensation for power generation through other means, e.g., thermal, coal-fired power and oil and gas, is not only expensive but also leads to circular debts and environmental pollution.

Fortunately, Pakistan is gifted with ample water resources with the potential to fulfill its energy requirements, provided they are properly utilized for hydroelectric power generation [8]. Hydroelectric power generation is an economically feasible and environment-friendly means of producing renewable energy. Furthermore, after power production, the reservoir water can also be utilized for other purposes [9]. It is one of the best sources of energy, reportedly better than other renewable and non-renewable energy resources.

In recent years, many advances have been made to develop cost-effective and environmentally sustainable new hydropower projects around the world. For instance, the hydropower potential of the Mat River in Southern Miziram, India, is estimated using a unique technique (Spatial technology and SWAT modeling) coupled with water flow sensing methods for using streams and rivers [10,11]. Klinf et al. [12] used a water balance model to analyze the hydropower potential of rivers in West Africa. Baken et al. [13] worked on small vs. large hydro projects in Norway. Using a GIS-based method, Sammartano et al. [14] identified possible locations for hydropower projects along the Run of River in southwest England. Tsoutsos et al. [15] presented a procedure under which small hydro projects can be constructed and deployed, specifically in nations with complex governmental and statutory systems. Kusre et al. [16] selected streams of 5th order or larger with a bed slope of more than 2% and spaced 500 m apart as viable locations in India's Kopili River. Palomino-Cuya et al. [17] calculated the highest theoretical hydropower potential in South America's La Plata basin using the mean yearly discharge. Fuji et al. [18] calculated hydropower for six distinct rivers in Beppu City Bay, with lengths ranging from 3 to 6 km at sites 500 m from the mouth of each river, while Bayazit et al. [19] identified the places with the most potential along the river by evaluating two scenarios: average precipitation and minimal precipitation. Rojanamon et al. [20] conducted a comprehensive analysis to identify viable locations, taking into account environmental, economic and social issues. Specific site selection parameters, such as the distance between the weir site, powerhouse and surge tank head, were also specified. Yi et al. [21] developed a small hydropower model for Run-of River (RoR) and a storage system, bringing topography, hydrologic and eco-environmental factors into consideration. Zapata-Sierra and Manzano-Agugliaro [22] proposed a methodology of evaluation of hydropower in a Mediterranean climate. Furthermore, the United Nations Industrial Development Organization (UNIDO), the Department of Hydro and Renewable Energy (HRED) and the European Small Hydropower Association (ESHA) produced recommendations to help in the rapid development of small hydro-projects [23–25].

Hence, it is prime time for Pakistan to capitalize on these experiences and consider its water resources for developing small hydropower projects to overcome its severe energy crisis.

Currently, large amount of the electricity in Pakistan is produced from Tarbela and Mangla reservoirs but is insufficient to meet the national energy requirements. Both the capacity and lives of these reservoirs are rapidly decreasing due to the high suspended sediment load in the source rivers. Such a sedimentation issue can be resolved by constructing small-hydropower plants since their design essentially includes desilting tanks for removing sediments of a specified size and quantity [26]. As a result, sediment-free water moves forward into the storage reservoirs so as to enhance their life and power-producing potential.

Presently, the Abbottabad district in Pakistan hosts ~1.182 million people. However, its population is increasing at a high rate. The district very commonly faces power shortages resulting in multiple spells of power load-shedding on a daily basis. Abbottabad is also a hub of educational institutions and industries and hosts tens of quality educational institutions of international repute and many small industries; some of these are higher education institutions internationally known for quality education and research. The continuous load shedding in the area is badly affecting educational and industrial activities currently because electricity plays a key role in running the laboratories, classrooms and related offices where at times uninterruptible power supply is required for weeks. If this fails, the experiments being carried out in the laboratories of higher education institutions or industries do not give the required results, and the quality of work is compromised, so there is a need to explore sources that can overcome these issues. The Dor River flows in the close vicinity of Abbottabad city, carries along a large suspended sediment load and falls into Tarbela reservoir. According to Sabir et al. [7], the Dor River is capable of producing a sufficient amount of hydroelectric energy that can be used locally as a closed system or added to the national grid. This work is designed to evaluate the suitability of Dor River for constructing a small hydro project. The objectives of the current research include (1) designing a small hydro project at Dor River; (2) choosing the suitable locations for the proposed hydropower project components; (3) evaluating the quality of rocks at selected sites through Rock Mass Classification system; (4) determining the hydropower and sedimentation potential of Dor River; (5) and evaluating the effect of Dor River siltation on Tarbela Reservoir. Moreover, the suitability of rocks present in the Dor River area as a construction material was also checked according to standard ASTM procedures, which is one of the additional positive aspects of this study. Currently, in view of the huge increase in demand for construction materials because of the growth in population, it is necessary to carry out prospective research for the exploration of new resources [27]. This work provides a complete assessment of rocks present there, which will help the people to know about the possibility of these rocks for use in the construction industry and for tunneling, etc.

2. Study Area

The study area, situated ~125 km north of Islamabad, is part of the Hazara Basin, Khyber Pakhtunkhwa, Pakistan (Figure 1). The formation of the Hazara basin is reportedly attributed to global and local tectonics caused by the formation and rifting of Rodina, Gondwana, Pangaea and the collision of the India–Eurasia continents [7]. The Abbottabad area, considered to be humid subtropical climate (cfa) following the Koppen–Geiger climate classification. The sedimentary rocks of the area represent glacio-fluvial, fluvial and marine environments [28,29] and overlie metamorphosed and unmetamorphosed sedimentary rocks. The oldest rock unit consists of slates of the Pre-Cambrian Hazara Formation. The area contains the Jurrasic (Samana Suk formation), Cretaceous (Chichali, Lumshiwal and Kawagarh formations), Palaeocene (Hangu and Lockhart formations) and Eocene sequences (the Nammal and Sakessar formations) [29]. The study area is part of the fold-and-thrust belt and thus has experienced extreme deformation resulting in the development of a major thrust faulting system. The major thrust fault present in the vicinity of the study area includes the Bhagnotar thrust along which the Hazara formation is thrust over the Samana Suk formation of the Jurassic age.

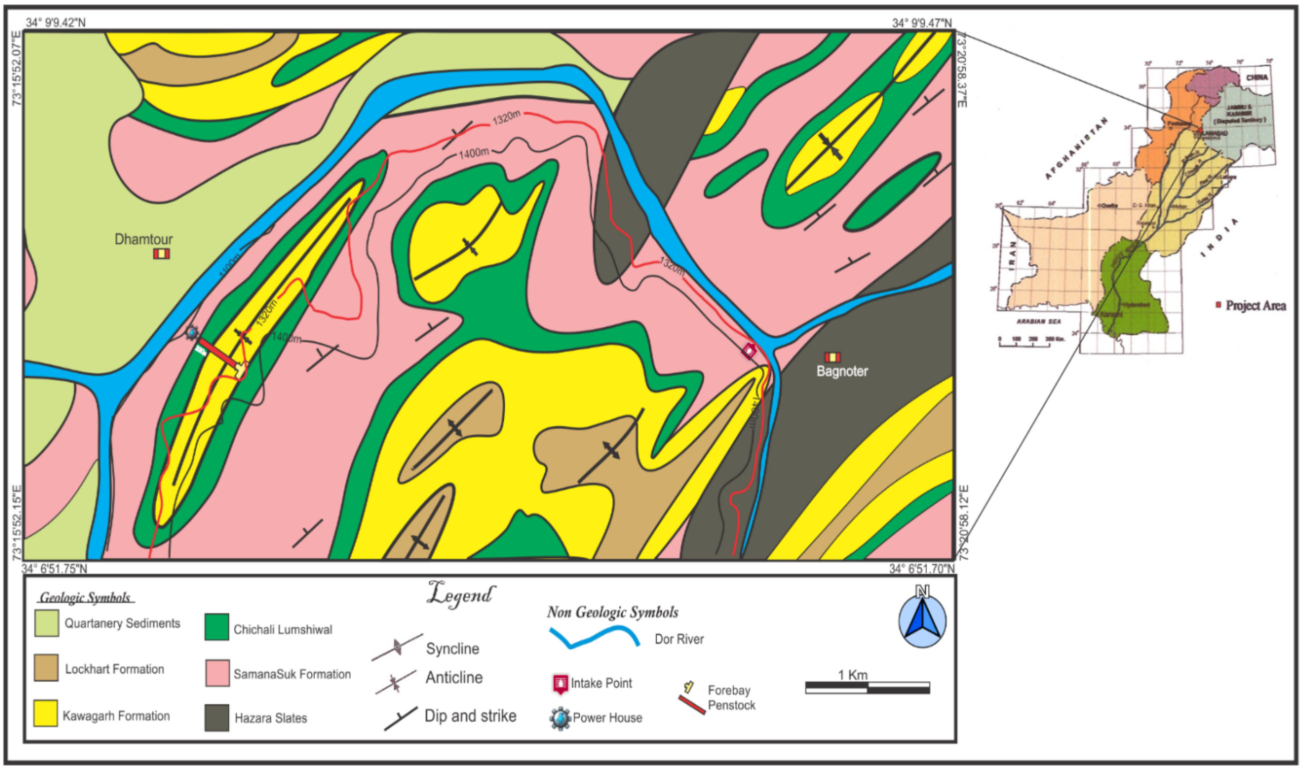


Figure 1. Map showing complete design, geology and parts of proposed hydropower project (After Afridi, 2010) [30].

3. Materials and Methods

Detailed fieldwork was conducted to locate potential sites for the proposed hydropower project components, including intake, power channel, desilting tank, forebay tank, penstock and powerhouse. Next, these sites were shown on the geological map of the area in order to provide a complete design of the proposed hydropower project with the exact locations of its components (Figure 1). The site selected for intake, power channel, desilting tank and the powerhouse of the proposed small hydropower project consists of limestone of the Jurassic Samana Suk Formation. The forebay tank was expected to be located in the fine-grained limestone of the Kawagarh Formation. The penstock was likely to cross shale, sandstone and subordinate limestone of the Chichali Formation. Next, the value of the head was calculated by subtracting the altitude value of intake from the powerhouse's location.

3.1. Rock Mass Rating (RMR)

Rock mass classification is important for a quantitative assessment of rock quality. The mechanical properties of rocks need to be assessed for tunneling, hazards analysis and other constructional activities [31,32]. Rock Mass Rating (RMR) and Basic Quality (BQ) methods are widely used for this purpose [33,34]. In this study, the RMR method revised by Bieniawski in 1989 [35] was adopted (Table 1).

Table 1. Rock Mass Rating Classification System by Bieniawski 1989 [35].

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS									
Parameters			Range Values						
1	Strength of intake rock material	Point-load Strength index	>10 MPa	4–10 MPa	2–4 MPa	1–2 MPa	For this low range–uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100–250 MPa	50–100 MPa	25–50 MPa	5–25 MPa	1–5 MPa	<1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90–100%	75–90%	50–75%	25–50%		<25%	
	Rating		20	17	13	8		3	
3	Spacing of discontinuities		>2 m	0.6–2 m	200–600 mm	60–200 mm		<60 mm	
	Rating		20	15	10	8		5	
4	Condition of discontinuities (See E)		Very rough surface not continuous No separation Unweather wall rock	Slightly rough Surfaces Separation < 1 mm Slightly weathered walls	Slightly Rough surfaces Separation <1 mm Highly weathered-walls	Slickensides surfaces or Gouge <5 mm Continuous		Soft gouge >5 mm thick or Separation >5 mm Continuous	
	Rating		30	25	20	10		0	
5	Ground water	Inflow per 10 m Tunnel length (µm)	None	<10	10–25	25–125		>125	
		(Joint water press)/ (Major principal stress)	0	<0.1	0.1–0.2	0.2–0.5		>0.5	
		General conditions	Completely dry	Damp	Wet	Dripping		Flowing	
	Rating		15	10	7	4		0	
B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)									
Strike and dip orientations			Very favorable	Favorable	Fair	Unfavorable		Very Unfavorable	
Ratings	Tunnels and mines		0	−2	−5	−10		−12	
	Foundations		0	−2	−7	−15		−25	
	Slopes		0	−5	−25	−50			
C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS									
Rating			100 ← 81	80 ← 61	60 ← 41	40 ← 21		‹21	
Class number			I	II	III	IV		V	
Description			Very good rock	Good rock	Fair rock	Poor rock		Very poor rock	
D. MEANING OF ROCK CLASSES									
Class number			I	II	III	IV		V	
Average stand-up time			20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span		30 min for 1 m span	
Cohesion of rock mass (kPa)			›400	300–400	200–300	100–200		<100	
Friction angle of rock mass (degree)			›45	35–45	25–35	15–25		<15	
E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY CONDITIONS									
Discontinuity length (persistence)			<1 m	1–3 m	3–10 m	10–20 m		>20 m	
Rating			6	4	2	1		0	
Separation (aperture)			None	<0.1 mm	0.1–1.0 mm	1–5 mm		>5 mm	
Rating			6	5	4	1		0	
Roughness			Very Rough	Rough	Slightly rough	Smooth		Slicken sided	
Rating			6	5	3	1		0	
Infilling (gouge)			None	Hard Filling < 5 mm	Hard Filling > 5 mm	Soft filling < 5 mm		Soft filling > 5 mm	
Rating			6	4	2	2		0	
Weathering			Un weathered	Slightly weathered	Moderately weathered	Highly weathered		Decomposed	
Rating			6	5	3	1		0	

Table 1. *Cont.*

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip—Dip 45–90°	Drive with dip—Dip 20–45°	Dip 45–90°	Dip 20–45°
Very favorable	Favorable	Very unfavorable	Fair
Drive against dip—Dip 45–90°	Drive against dip—Dip 20–45°	Dip 0–20—Irrespective of strike	
Fair	Unfavorable	Fair	

Rock Mass Rating (RMR) studies were conducted on all the selected sites of hydropower project components for the purpose of knowing if the rocks exposed are capable of construction and tunnel activities of a proposed project or not. The parameters determined for RMR include Rock Quality Designation (RQD), Point Load, Unconfined Compressive Strength, conditions of discontinuities and ground water conditions. The value of RQD was determined by utilizing the formula used by [33] in his study.

$$\text{RQD} = 115 - 3.3\ \text{Jv} \tag{1}$$

where Jv is the total number of joints per cubic meter (volumetric joint).

The ground water and discontinuities conditions were completely determined in the field by using a Geological Hammer, Hand lens, Brunton Campus and measuring tape. The parameters, including persistence, aperture, roughness, infilling and weathering, were evaluated in discontinuities conditions, and for ground water conditions, the rocks were assessed on the base of moisture, i.e., completely dry, damp, wet, dripping and flowing. For Point Load and Unconfined Compressive Strength (UCS), the samples were obtained from intact rocks. The Point Load tests were carried out on 54 mm-diameter cylindrical samples with a length (L) to diameter ratio of 1.2 through the procedure provided in ASTM D 5731-16 [36] standard, while the UCS tests were carried out on cylindrical samples with 54 mm diameter (D) with an L/D ratio of 2.5 using ASTM D 7012 [37] standard. After determining all these parameters, the RMR rating was calculated using Table 1.

3.2. Geotechnical Parameters Analysis

The samples collected for Point Load and Unconfined Compressive Strength (UCS) tests in RMR studies were further tested to check their suitability for use as construction aggregates. The tests, including specific gravity, water absorption, flakiness index, elongation index, abrasion resistance and soundness, were conducted on all collected samples according to ASTM D6473 [38], BS 812.105.1 [39], BS 812.105.2 [40], ASTM C131 [41] and ASTM C88 [42], respectively. The results of these parameters were then compared with international standards to assess their effectiveness in the construction industry.

3.3. Determination of Discharge and Hydropower Generation Potential

For measuring discharge, the velocity of Dor river water was multiplied by its cross-sectional area [43]. The velocity was determined by using the current meter method, while the cross-sectional area of the river was measured by multiplying its depth with width. The current meter used for the purpose of measuring velocity was an OTT Z400 meter. The flow velocity was measured at various subsections of the river. For the purpose of greater accuracy, mean velocity values (i.e., an average of velocities at surface and depth) for each subsection were considered.

The values of river depth and width were also determined at various points depending on variation in the geometry of the river channel. The hydropower potential was evaluated by utilizing the following equation [44]:

$$\text{P} = \eta\text{rgQH} \tag{2}$$

where P = potential in watts; η = hydraulic efficiency of the turbine; r = density of water (kg/m^3 and is equal to 1000); g = acceleration due to gravity (9.8 ms^{-2}); Q = Discharge of river; H = effective pressure head of water across the turbine.

The best turbines can have hydraulic efficiencies in the range of 80 to over 90% [44], so the value of 0.9 (90%) was used in this equation.

Discharge of the river was determined from January 2018 to December 2021, and the month-wise mean value was used for calculating the river hydropower potential and sediment load. The normal distribution curve was also prepared to know about the availability of discharge annually. Statistical analysis of the data was also carried out to assess precision, accuracy and degree of representation of the data by the mean values. The range represents the difference between the highest value and the lowest value. The values of standard deviation and coefficient of variation were determined as follows [45]:

$$S = \sqrt{\Sigma}\left(x - \bar{x}\right)^2/n - 1 \quad (3)$$

where S = standard deviation, x = the each value of the data, $\bar{x}$ = mean, n = total number.

$$CV = \sigma/\mu \quad (4)$$

CV = coefficient of variation, σ = standard deviation, μ = mean

The reason for measuring these values is to know about the amount of variability or dispersion around a mean.

3.4. Determination of Suspended Sediment Concentration

For calculating the suspended sediment concentration, water samples were collected from near the water surface in one-liter bottles. The bottles were locked quickly to avoid contamination. The concentration was determined by adopting the methodology provided by Sabir et al. [46,47]. Each water sample was passed through Whatman filter paper of known weight. The filter paper, along with sediments (if any), was then dried in a thermostatic oven at 105 °C for 30 min. Following cooling down to room temperature, the filter paper plus the sediment were weighed as the final weight. The suspended sediment concentration was then calculated as follows:

$$SSC = Fw - Iw \quad (5)$$

where SSC is Suspended sediment concentration, Fw = Final weight of the filter paper and Iw = Initial known weight of the filter paper.

3.5. Suspended Sediment Load

The suspended sediment concentration values were converted to suspended sediment load as tonnes per day (td-1) with the method used by Sabir et al. [46,47]:

$$SSL = SSC \times Q \times 0.0864 \quad (6)$$

where SSL = suspended sediment load, SSC = suspended sediment concentration (ppm), Q = river discharge and 0.0864 is the equation constant value.

After obtaining the sediment load of every day by using this equation, it was added to obtain the monthly and yearly values.

4. Results and Discussion

4.1. Head

The value of the head was found 220 m, and that is the elevation difference between the intake point and the powerhouse (Figure 1).

4.2. Rock Mass Rating (RMR) Analysis

The results of rock mass characteristics used in the calculation of RMR are shown in Table 2, while the values of measured RMR are shown in Table 3. The RMR is ranged from 48 to 55, showing that the quality of exposed rocks is fair. The value of the RMR is higher in pure limestones, and it is slightly lower in the rocks containing other lithologies with limestones. These lithologies are sandstone, shale and slate (Table 3). The strength of shale and slates is always lower than limestone due to the presence of platy clay minerals in them. That is why the value of RMR is lower in these mixed lithologies as compared to pure limestones. Overall, all the rocks are classified as fair rocks, which means that they are adequate for the construction of proposed hydropower components and for tunneling activities. As these rocks are not yet classified in the literature, so these classification outcomes can also be utilized for additional constructional activities other than the proposed hydropower project.

Table 2. Summary of Rock mass characteristics for determining RMR.

Location	RQD (%)	UCS (MPa)	Point Load (MPa)	Persistence (m)	Aperture (mm)	Roughness	Infilling	Weathering	Ground Water
Intake Point	56–67	61–84	2.5–3	0.5–6	0.1–2.5	Rough- Slightly rough	Hard-Soft	Slight-Moderate	Wet-Dripping
Desilting Tank	54–63	53–78	2–3	0.6–4	0.3–0.9	Rough- Slightly rough	Hard-Soft	Slight-Moderate	Dry–Damp
Power Channel	44–73	41–104	2–3.5	0.2–7	0.1–3	Rough- Slightly rough	Hard-Soft	Slight-Moderate	Dry–Damp
Fore bay Tank	56–62	59–71	2.5–3	0.4–4.5	0.2–0.6	Rough- Slightly rough	Hard-Soft	Slight-Moderate	Dry–Damp
Penstock	49–57	42–60	2–2.5	0.5–6	0.2–0.9	Rough- Slightly rough	Hard-Soft	Slight-Moderate	Dry–Damp
Power House	59–66	66–74	2.5–3	0.4–5	0.3–1.5	Rough- slightly rough	Hard-Soft	Slight-Moderate	Damp-Wet

Table 3. Summary of Rock Mass Rating and Rock Quality.

Location	Lithology	RMR	Rock Quality According to Rock Mass Classification System
Intake Point	Limestone.	55	Fair Rock
Desilting Tank	Limestone.	51	Fair Rock
Power Channel	Predominantly Limestone. Slate, shale and sandstone are also present in some parts but in a very minor percentage.	49	Fair Rock
Forebay Tank	Limestone.	52	Fair Rock
Penstock	Predominantly Limestone. Shale and sandstone are also present in some parts but in a very minor percentage.	48	Fair Rock
Power House	Limestone.	51	Fair Rock

4.3. Geotechnical Parameters Analysis

The measured mean values of water absorption, specific gravity, Los Angeles abrasion, flakiness index, elongation index and soundness for Samana Suk and Kawagarh limestones are shown in Table 4. The values of water absorption are lower than 1%, and according to ASTM 127 [48], the aggregates with water absorption of less than 2.5% can be utilized in cement concrete. Specific gravities of the studied limestones vary from 2.63 to 2.74, whereas the minimum specific gravity requirement for the aggregate usage in cement concrete is 2.60 [48].

Table 4. Geotechnical Parameters of Samana Suk and Kawagarh Limestones.

Studied Parameters	Samana Suk Limestones (Mean Values)	Kawagarh Limestones (Mean Values)
Water Absorption (%)	0.68	0.74
Specific Gravity	2.63	2.74
Loss angles Abrasion Value	16.29	15.85
Flakiness Index	18.75	18.20
Elongation Index	23.15	15.40
Soundness (%)	2.64	2.40

The flakiness index and elongation index are the two most important physical parameters related to the shape of the aggregates. Higher values of these parameters are not suitable in the construction industry. The values of the flakiness index and elongation index vary from 18.20 to 18.75 and 23.15 to 15.40, respectively. The maximum limit of flakiness index is 40% for road and cement concrete according to BS-882, while the limit of elongation index for cement concrete is 25% according to B812 105.2. Los Angeles abrasion values show the resistance of the aggregates; lower values mean that the material is more durable. These values range from 15.25 to 16.29. Material with an abrasion resistance of less than 40% can be utilized as road aggregates [41]. The soundness values are also very low, which means that the aggregates are weather resistant.

Overall, all the obtained values are within the limits of international standards; therefore, these limestones can be used as road and cement aggregates successfully.

4.4. Discharge

The mean discharge values range from 1.44 $m^3 s^{-1}$ to 6.79 $m^3 s^{-1}$ (Figure 2). The minimum discharge of Dor river is 1.44 $m^3 s^{-1}$ in the month of December, and it goes up to 6.71 $m^3 s^{-1}$–6.79 $m^3 s^{-1}$ in the months of August and July, respectively (Figure 2), which is the peak season of power shortage/outage in Abbottabad area. This higher discharge reflects a high amount of precipitation in the form of monsoon rainfall during July and August. This heavy precipitation results in faster run-off, which leads to a rapid increase in water volume in the river channel that, in turn, triggers a sudden surge in discharge. The discharge of Dor River is also high in March (Figure 2; 3.42 $m^3 s^{-1}$). The abnormally high discharge during March indicates the influence of snow melting. Since the catchment area does not have any glaciers that could continuously feed the Dor River, the possibility is that seasonal snowfalls in late winters result in the accumulation of snow that starts melting with a slight increase in temperatures during early spring times.

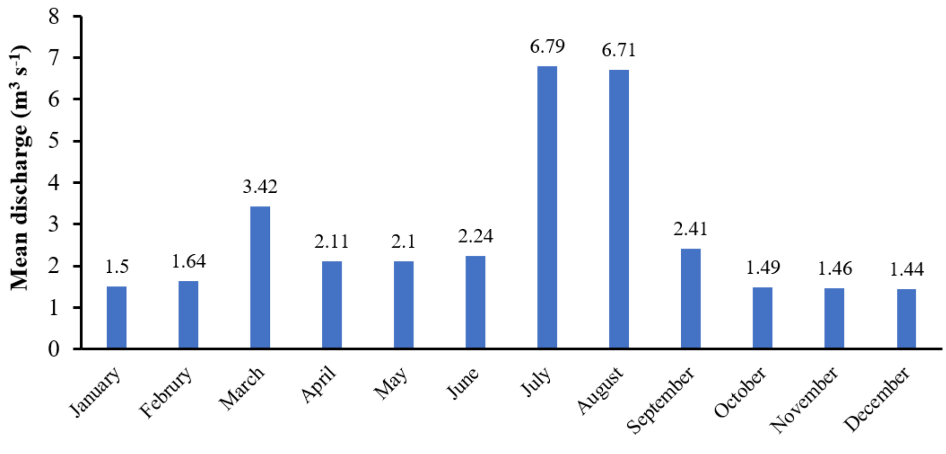
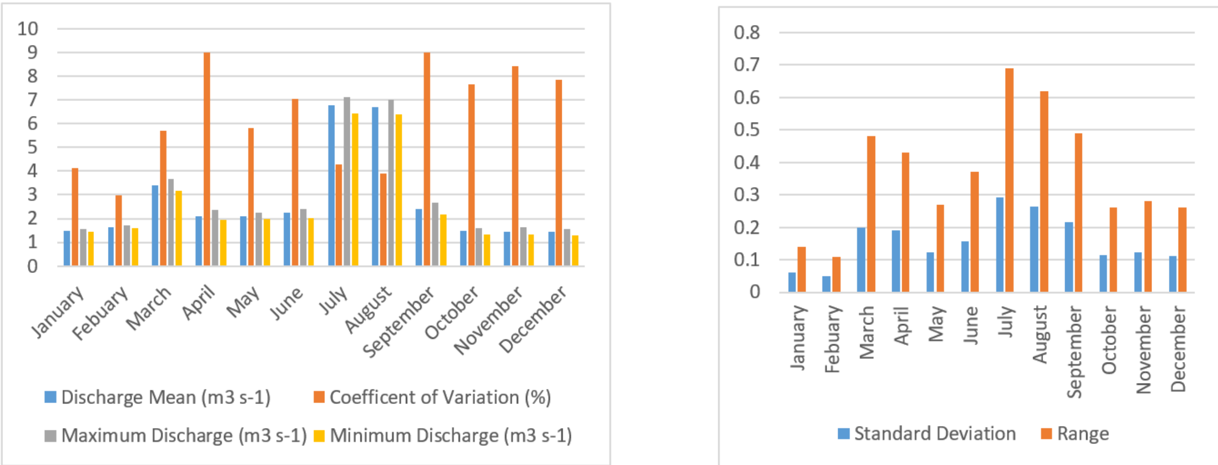


Figure 2. Mean discharge values of Dor River from January 2018 to December 2021.

The statistical analysis results regarding the comparison of Dor River mean discharge with a coefficient of variation, maximum discharge, minimum discharge (Figure 3a), standard deviation and range (Figure 3b) indicate that the mean values are representative of the whole data set and so can be used for estimating hydropower potential and sediment load. The bell curves were also produced to illustrate the actual distribution of the whole data (Figures 4 and 5). The bell curves reveal that all the discharge values are very close to their respective mean values since the degree of variation is very low.

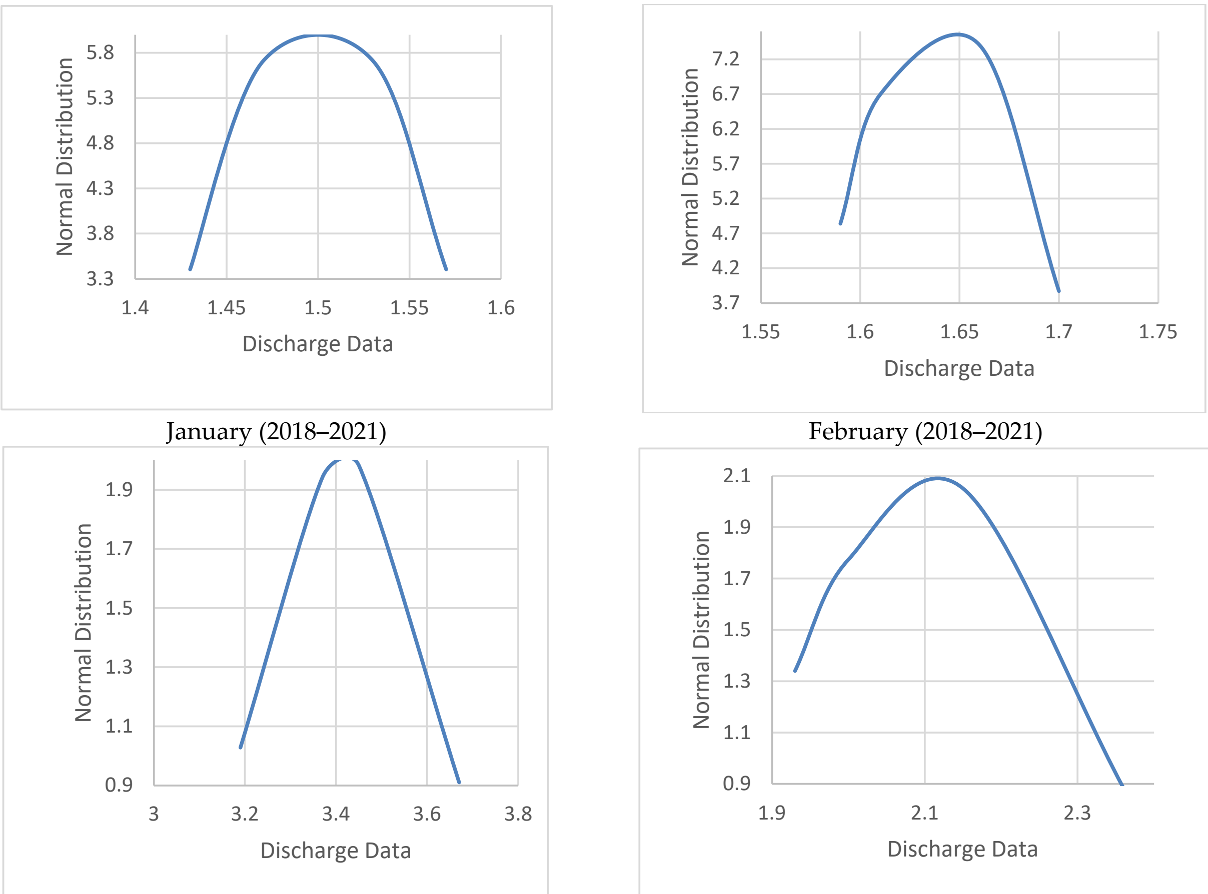
4.5. Hydropower Potential

As shown in Figure 6, the minimum power potential for Dor River is 2.79 MW, which surges to 5.37 MW if the mean discharge value is used. The availability of minimum power potential is 100%, i.e., this power will be accessible throughout the year (Figure 7a). The utmost power capability of the river is about 13 MW, which will be available only in July and August, i.e., during 16% of the year (Figure 7a). The comparison of power potential vs. discharge for Dor River is shown in Figure 7b. These results indicate that the development of a hydropower project over Dor River can meet the major bulk of the power requirement for the Abbottabad area and thus resolve its power outage (load shedding) issue to a large extent.



(**a**) (**b**)

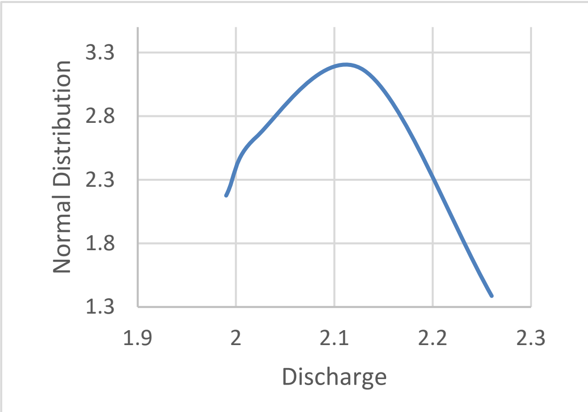
Figure 3. Comparison of Dor River mean discharge with (**a**). coefficient of variation and minimum and maximum discharge (**b**). with standard deviation and range.



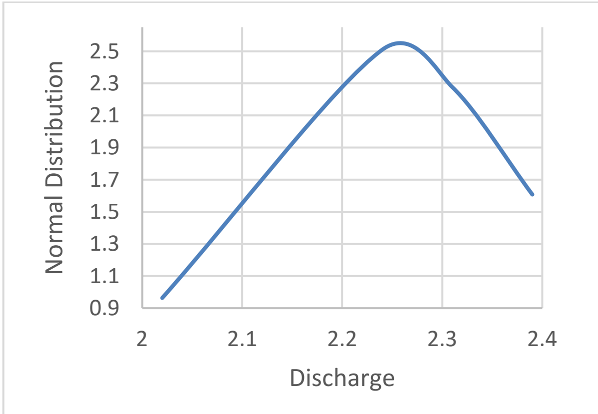
January (2018–2021) February (2018–2021)

March (2018–2021) April (2018–2021)

Figure 4. *Cont.*

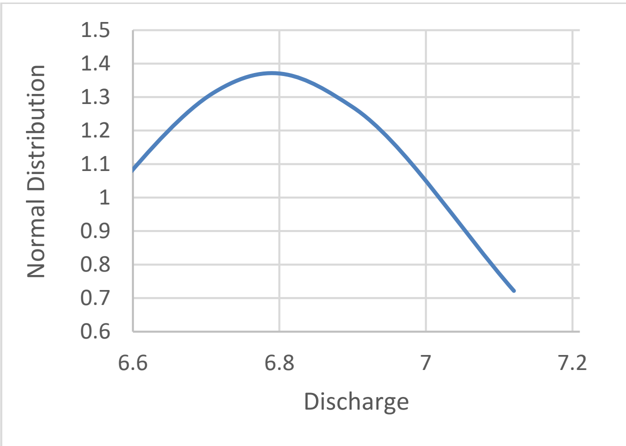


May (2018–2021)

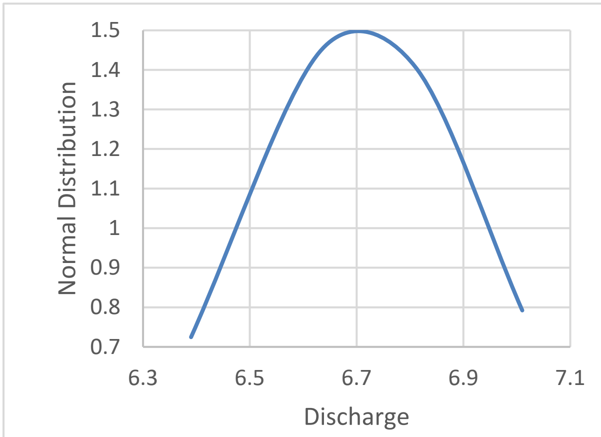


June (2018–2021)

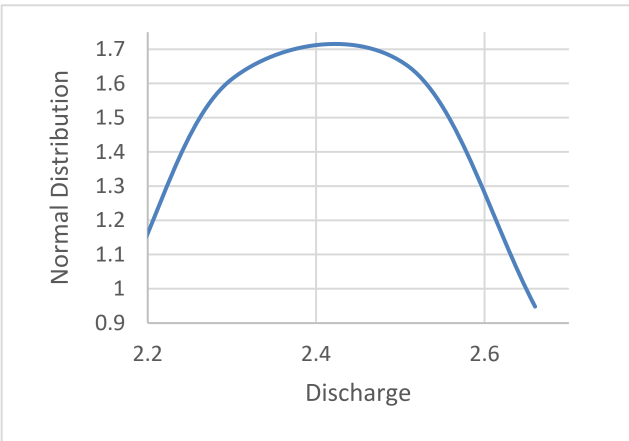
Figure 4. Normal distribution curve/bell curve of Dor River discharge from January to June (2018–2021).



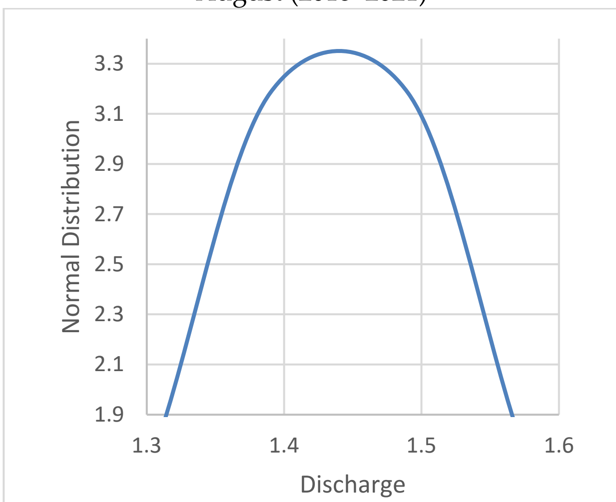
July (2018–2021)



August (2018–2021)

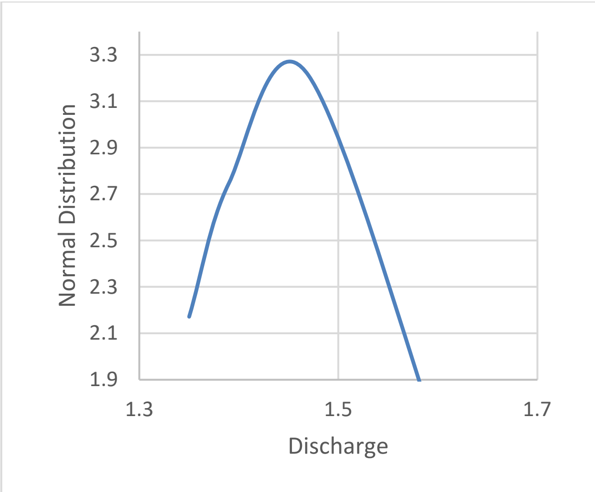


September (2018–2021)

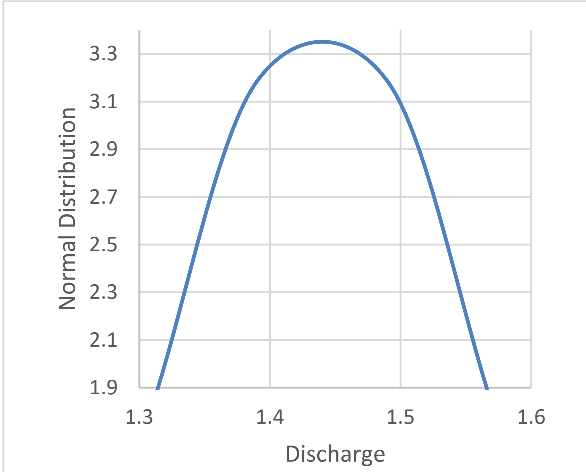


October (2018–2021)

Figure 5. *Cont.*



November (2018–2021)



December (2018–2021)

Figure 5. Normal distribution curve/bell curve of Dor River discharge from July to December (2018–2021).

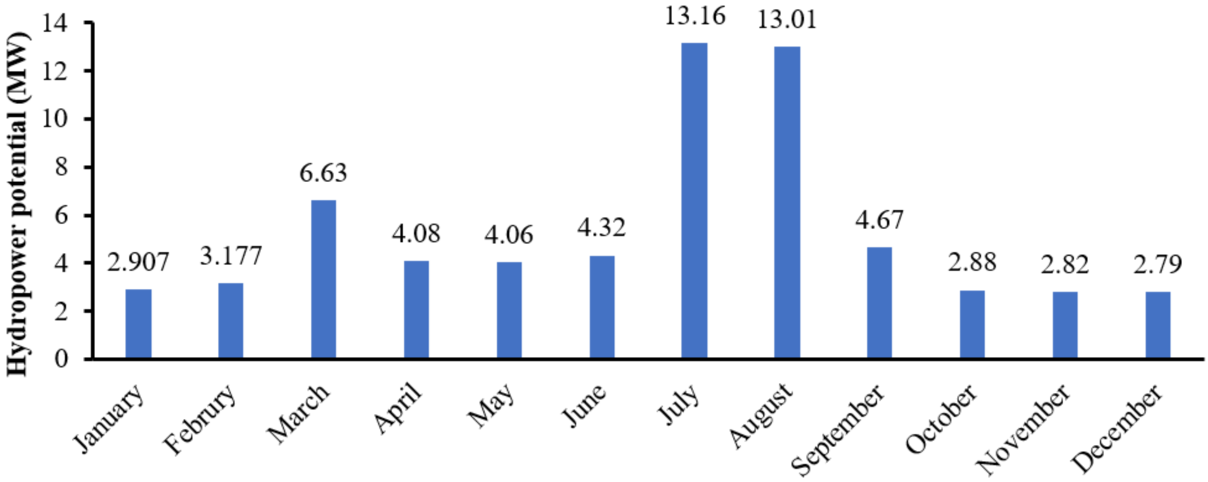
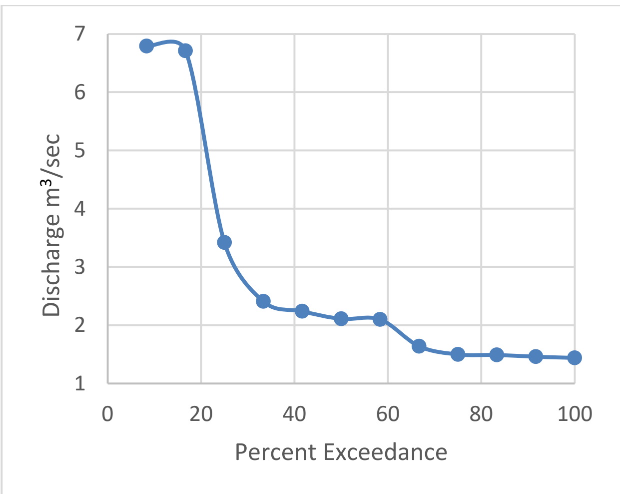
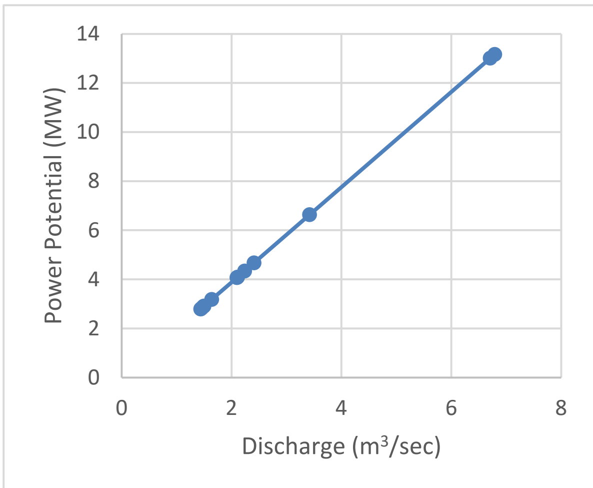


Figure 6. Average hydropower potential in megawatts of Dor River from January 2018 to December 2021.



(**a**)



(**b**)

Figure 7. (**a**) Flow duration curve for Dor River. (**b**) Power potential vs. discharge for Dor River.

4.6. Suspended Sediment Concentration and Load of Dor River

Determination of suspended sediment concentration and load is very important, especially during the designing phase of a hydropower project, since this concentration badly affects the turbines and leads to a reduction in the power potential and life span of the power plant. These finer silt and clay particles also show expansion due to the larger absorption of water [49–53]. The suspended sediment concentration in Dor River ranges from 35 ppm to 100 ppm (Figure 8), while the mean daily suspended sediment load (SSL) values for Dor River are shown in Figure 9. The per month SSL values range from 134 tons to 1797 tons (Figure 10), which means that the river has been carrying a lot of sediments that might have badly affected the life of the country's largest, Tarbela reservoir.

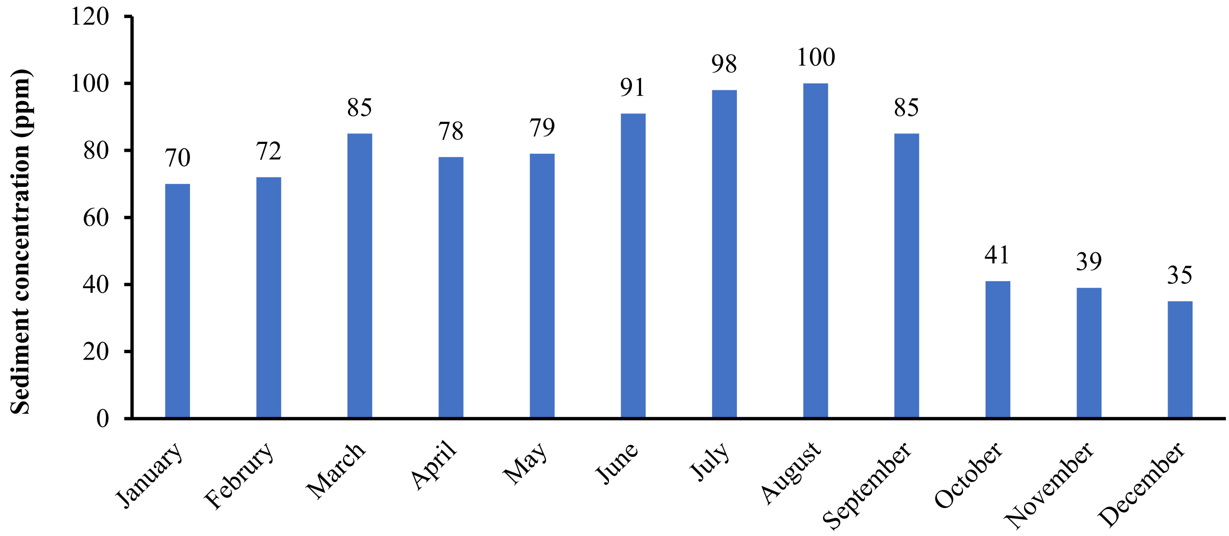


Figure 8. Mean sediment concentration of Dor River from January 2018 to December 2021.

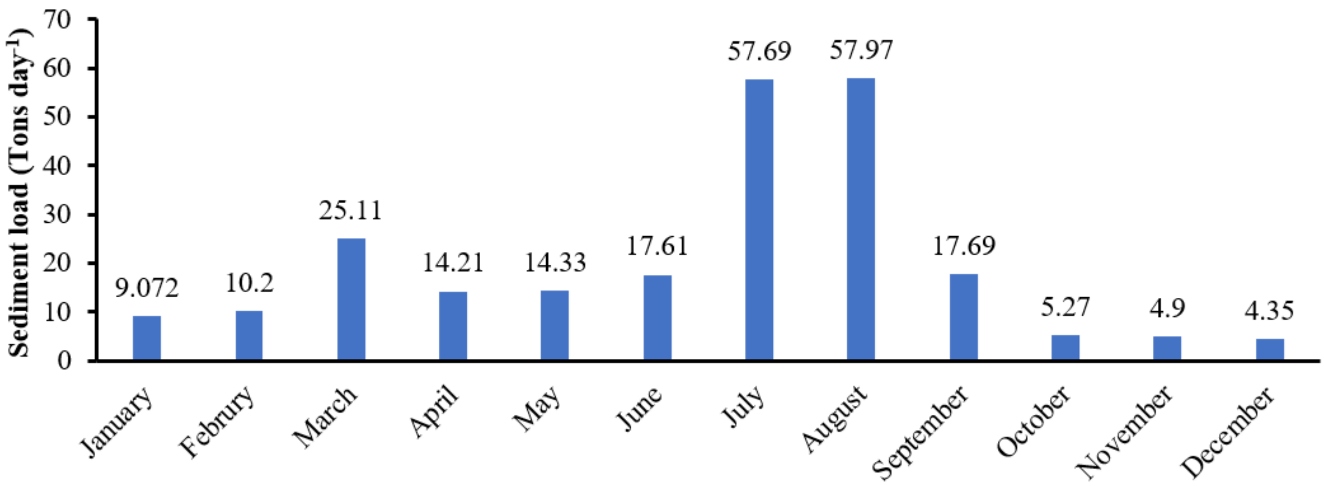


Figure 9. Mean suspended sediment load/day of Dor River from January 2018 to December 2021.

The construction of the proposed hydropower project is likely to enhance the life of this reservoir since the estimated yearly SSL for Dor River is 7267 tons, which is carried downstream and largely deposited in the Tarbela reservoir (Figure 10). The suspended load (silt) consists of fine-grained sediment, including silt and clay-sized particles that settle down and accumulate in the reservoir, diminishing its storage capacity, power generation potential and life. The sediment deposition (silting) gradually reduces the storage capacity and power generation potential of a reservoir. The presence of suspended sediments can also affect the hydraulic turbine machinery by reducing its competency and age. That is why many hydropower plants built on turbid rivers have faced serious turbine-related problems affecting the project's power generation potential.

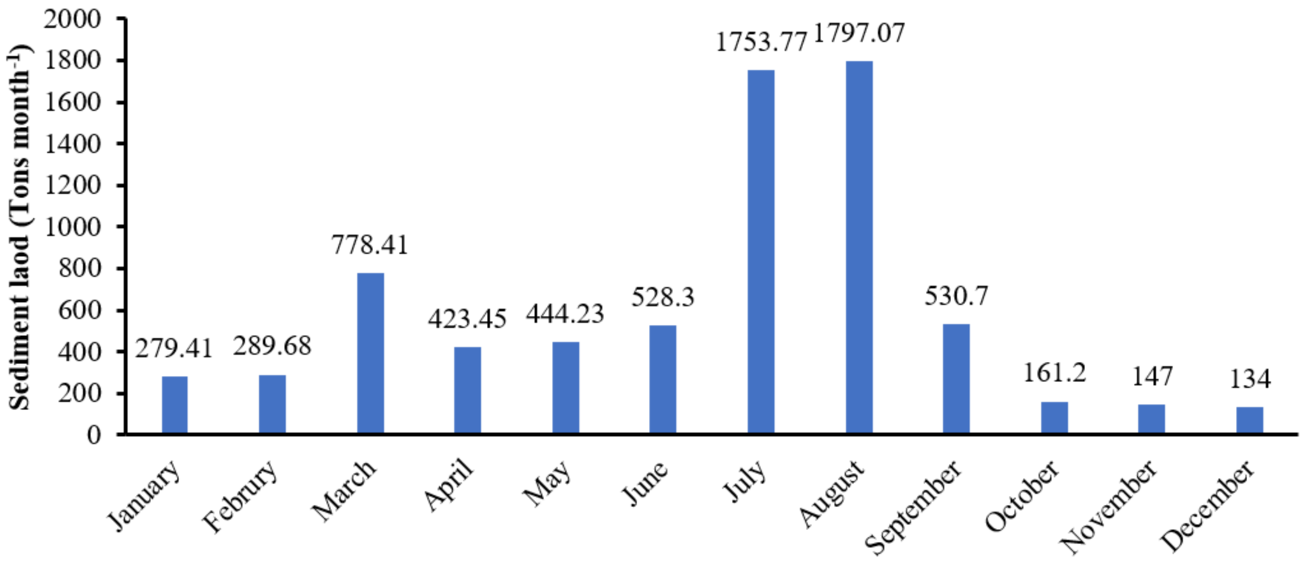


Figure 10. Mean monthly suspended sediment load in Dor River from January 2018 to December 2021.

Currently, Pakistan has two major power-producing reservoirs, namely the Tarbela and Mangla reservoirs. The loss of storage capacity due to sedimentation is unavoidable and will continue to affect the long-term operation of both these reservoirs. Sedimentation surveys have shown that gross storage capacities of the Tarbela and Mangla reservoirs have decreased by up to 28.23% and 20.54%, respectively [54]. That is why the construction of a settling basin is proposed for developing the project under consideration. The settling basin, also known as a de-silting tank, is meant for trapping sediments through the reduction in river velocity before its water enters the penstock. Such a basin can be built near the intake or fore-bay structure. The removal of sediments through de-silting will definitely enhance the storage capacity and life of not only the proposed hydropower project but also the Tarbela reservoir.

5. Conclusions

Pakistan, being an energy deficient country, spends a handsome amount of its precious foreign exchange on buying fuel. A major part of this imported fossil fuel is used to generate electricity to keep Pakistan's wheels running. Indigenous and renewable energy resources are needed to be taken up and constructed on an emergency basis. Along with major hydropower projects such as Tarbela and Bhasha and medium projects such as Warsak, Mangla, etc., mini and micro projects are also worth conducting at this stage. There are countless sites available in northern Pakistan for the purpose. Construction of a small-hydropower project with power as low as 2.79 MW to as much as 13.16 MW can be undertaken on Dor River.

The area studied for the Dor River Hydropower project (DRHPP), promises safe geology and hydrology, and the rocks of the area were classified as "Fair" rocks on the basis of RMR ranging from 48 to 55. The RMR values of the rocks suggest that these are sound for the construction of a proposed hydropower project. Additionally, the rocks present in the area can also be utilized as construction material. As already mentioned, hydrological safety is also assured for the project because there are no hydrological threats encountered. A discharge of one and a half cusecs will safely be available throughout the year.

Depending on the tectonic/geologic history of the region, such as other streams draining the country, the Dor River has manageably high SSL. This does not pose any threat to the project as all other projects suggested, under construction and recently constructed, include de-silting tanks and other sediment preventers. The project, if constructed, will act as a "Check Dam" for Tarbela Reservoir because 7267 tons/year of the calculated silt will be stopped at DRHPP, resultantly increasing Tarbla's life.

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References

1. Liming, H. Financing rural renewable energy. A comparison between China and India. *Renew. Sustain. Able Energy Rev.* **2009**, *13*, 1096–1103. [CrossRef]
2. Khan, A.N.; Toheeda, B.; Sher, M. Energy Crisis in Pakistan: Causes and Consequences. *Abasyn J. Soc. Sci.* **2012**, *4*, 341–363.
3. Asif, M. *Energy Crisis in Pakistan—Origins: Challenges and Sustainable Solutions*; Oxford University Press: Karachi, Pakistan, 2011; Volume 1.
4. Kapitonov, I.A. Legal support for integration of renewable energy sources in the energy law of the countries from the international legal position. *Kuwait J. Sci.* **2019**, *46*, 68–75.
5. Klugman, J. *Human Development Report on Sustainability and Equity: A Better Future for All*; United Nations Development Programme: New York, NY, USA, 2011.
6. Government of Pakistan. *Policy Framework and Package of Incentives for Private Sector Hydel Power Generation Projects in Pakistan*; Ministry of Water and Power: Jurisdiction, Pakistan, 1995; pp. 1–18.
7. Sabir, M.A.; Shah, S.H.A.; Habib, U. Establishment of hydroelectric microgrids, need of the time to resolve energy shortage problems. In Proceedings of the 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), Johor Bahru, Malaysia, 4–6 April 2017; pp. 16–21. [CrossRef]
8. Mirza, U.K.; Ahmad, N.; Majeed, T.; Harijan, K. Hydropower use in Pakistan: Past, present and future. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1641–1651. [CrossRef]
9. Patel, S.U.; Pakale, P.N. Study on power generation by using cross flow water turbine in micro hydro power plant. *Int. J. Res. Eng. Technol.* **2015**, *4*, 1–4.
10. Pandey, A.; Lalrempuia, D.; Jain, S.K. Assessment of hydropower potential using spatial technology and SWAT modelling in the Mat River, southern Mizoram, India. *Hydrol. Sci. J.* **2015**, *10*, 1651–1665. [CrossRef]
11. Othman, A.; Khairudin, W.M.; Othman, J.; Ghani, M.A.; Shakir, A.; Saudi, M. Water flow measuring methods in small hydropower for streams and rivers-A study. *Int. J. Appl. Eng. Res.* **2017**, *12*, 14484–14489.
12. Kling, H.; Philipp, S.; Martin, F. Regional Assessment of the Hydropower Potential of Rivers in West Africa. *Energy Procedia* **2016**, *97*, 286–293. [CrossRef]
13. Bakken, H.T.; Sundt, H.; Ruud, A.; Harby, A. Development of Small Versus Large Hydropower in Norway—Comparison of Environmental Impacts. *Energy Procedia* **2012**, *20*, 185–199. [CrossRef]
14. Sammartano, V.; Liuzzo, L.; Freni, G. Identification of Potential Locations for Run-of-River Hydropower Plants Using a GIS-Based Procedure. *Energies* **2019**, *12*, 3446. [CrossRef]
15. Tsoutsos, T.; Maria, E.; Mathioudakis, V. Sustainable siting procedure of small hydroelectric plants: The Greek experience. *Energy Policy* **2007**, *35*, 2946–2959. [CrossRef]
16. Kusre, B.C.; Baruah, D.C.; Bordoloi, P.K.; Patra, S.C. Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). *Appl. Energy* **2010**, *224*, 298–309. [CrossRef]
17. Cuya, D.G.P.; Brandimarte, L.; Popescu, I.; Alterach, J.; Peviani, M. A GIS-based assessment of maximum potential hydropower production in La Plata basin under global changes. *Renew. Energy* **2013**, *50*, 103–114. [CrossRef]
18. Fujii, M.; Tanabe, S.; Yamada, M.; Mishima, T.; Sawadate, T.; Ohsawa, S. Assessment of the potential for developing mini/micro hydropower: A case study in Beppu City, Japan. *J. Hydrol. Reg. Stud.* **2017**, *11*, 107–116. [CrossRef]
19. Bayazıt, Y.; Bakı¸s, R.; Koç, C. An investigation of small scale hydropower plants using the geographic information system. *Renew. Sustain. Energy Rev.* **2017**, *67*, 289–294. [CrossRef]
20. Rojanamon, P.; Chaisomphob, T.; Bureekul, T. Application of geographical information system to site selection of small runof-river hydropower project by considering engineering/economic/environmental criteria and social impact. Renew. *Sustain. Energy Rev.* **2009**, *13*, 2336–2348. [CrossRef]

21. Yi, C.S.; Lee, J.H.; Shim, M.P. Site location analysis for small hydropower using geo-spatial information system. *Renew. Energy* **2010**, *35*, 852–861.
22. Zapata-Sierra, A.J.; Manzano-Agugliaro, F. Proposed methodology for evaluation of small hydropower sustainability in a Mediterranean climate. *J. Clean. Prod.* **2019**, *214*, 717–729. [CrossRef]
23. UNIDO. *Small Hydropower Technical Guidelines*; UNIDO: Vienna, Austria, 2019.
24. Department of Hydro and Renewable Energy. *Standards/Manuals/Guidelines for Small Hydro Development*; Department of Hydro and Renewable Energy: Roorkee, India, 2014.
25. ESHA. *Guide on How to Develop a Small Hydropower Plant*; European Small Hydropower Association (ESHA): Brussels, Belgium, 2004.
26. Mishra, S.; Singal, S.K.; Khatod, D.K. Sizing and Quantity Estimation for Desilting Tank of Small Hydropower Projects—An Analytical Approach. *Int. J. Green Energy* **2013**, *10*, 574–587. [CrossRef]
27. Roberts, F.L.; Kandhal, P.S.; Brown, E.R.; Lee, D.Y.; Kennedy, T.W. *Hot Mix Asphalt Materials, Mixture Design, and Construction*; National Asphalt Pavement Association Education Foundation: Lanham, MD, USA, 1991.
28. Umar, M.; Sabir, M.A.; Farooq, M.; Khan, M.M.S.S.; Faridullah, F.; Jadoon, U.K.; Khan, A.S. Stratigraphic and sedimentological attributes in Hazara basin lesser Himalya, north Pakistan: Their role in deciphering minerals potential. *Arab. J. Geosci.* **2015**, *8*, 1653–1667. [CrossRef]
29. Akhtar, S.; Rahim, Y.; Hu, B.; Tsang, H.; Ibrar, K.M.; Ullah, M.F.; Bute, S.I. Stratigraphy and Structure of Dhamtaur area, District Abbottabad, Eastern Hazara, Pakistan. *Open J. Geol.* **2019**, *9*, 57–66. [CrossRef]
30. Afridi, A.G.K. *Revalidation of Geological Map of Nathiagali Quadrangle, Abbottabad and Mansehra District, Khyber Pakhtunkhwa and Parts of Rawalpindi and Muzafarabad Districts, Pakistan Geological Survey of Pakistan*; Ministry of Petroleum and Natural Research: Islamabad, Pakistan, 2010; Lahore Geol Map Ser 3:9.
31. Ma, K.; Liu, G. Three-Dimensional Discontinuous Deformation Analysis of Failure Mechanisms and Movement Characteristics of Slope Rockfalls. *Rock Mech. Rock Eng.* **2022**, *55*, 275–296. [CrossRef]
32. Ma, K.; Ren, F.; Huang, H.; Yang, X.; Zhang, F. Experimental investigation on the dynamic mechanical properties and energy absorption mechanism of foam concrete. *Constr. Build. Mater.* **2022**, *342*, 127927. [CrossRef]
33. Nathaniel, K.A. RMR- A System for characterizing Rock Mass Classification: A Case Study from Garhwal Himalaya, Uttarakhand. *J. Geol. Soc. India* **2007**, *79*, 627–640.
34. Liu, Q.; Liu, J.; Pan, Y.; Kong, X.; Hong, K. A case study of TBM performance prediction using a Chinese rock mass classification system—Hydropower Classification (HC) method. *Tunn. Undergr. Space Technol.* **2017**, *65*, 140–154. [CrossRef]
35. Beiniawski, Z.T. *Engineering Rock Mass Classification*; Willey & Sons: New York, NY, USA, 1989; p. 251.
36. *ASTM D5731-16*; Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications. ASTM International: West Conshohocken, PA, USA, 2016.
37. *ASTM D7012-14*; Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. ASTM International: West Conshohocken, PA, USA, 2014.
38. *ASTM D6473*; Standard Test Method for Specific Gravity and Absorption of Rock for Erosion Control. ASTM International: West Conshohocken, PA, USA, 2010.
39. *BS 812.105.1*; Methods for Determination of Flakiness Index. British Standard Institute: London, UK, 1985.
40. *BS 812.105.2*; Methods for Determination of Elongation Index. British Standard Institute: London, UK, 1990.
41. *ASTM C131*; Standard Test Method for the Resistance to Degradation of Small-Size Coarse Aggregates by Abrasion and Impact in the Los Angeles Machine. ASTM International: West Conshohocken, PA, USA, 1996.
42. *ASTM C88-13*; Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate. ASTM International: West Conshohocken, PA, USA, 2005.
43. URL. Available online: https://www.micro-hydro-power.com/how-to-measure-water-flow.htm (accessed on 1 August 2022).
44. Paish, O. Small hydro power: Technology and current status. *Renew. Sustain. Energy Rev.* **2002**, *6*, 537–556. [CrossRef]
45. Lane, D. *Introduction to Statistics*; OpenStax College (Rice University): Houston, TX, USA, 2003.
46. Sabir, M.A.; Rehman, S.S.; Umar, M.; Waseem, A.; Farooq, M.; Khan, A. The Impact of Suspended Sediment Load on Reservoir Siltation and Energy Production: A Case Study of the Indus River and Its Tributaries. *Pol. J. Environ. Stud.* **2013**, *22*, 219–225.
47. Sabir, M.A. Evaluation of Surface Water Resources and Sediment Load in Indus and Swat Kohistan. Ph.D. Thesis, University of Peshawar, Peshawar, Pakistan, 2002.
48. *ASTM C127*; Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate. ASTM International: West Conshohocken, PA, USA, 2007.
49. Shah, S.H.A.; Arif, M.; Sabir, M.A.; Iqbal, J. In-situ stabilization of clays with lime, dolerite and quartzite powders. *Acta Geodyn. Geomater.* **2020**, *3*, 341–352. [CrossRef]
50. Shah, S.H.A.; Arif, M.; Sabir, M.A.; Rehman, Q. Impact of Igneous Rock Admixtures on Geotechnical Properties of Lime Stabilized Clay. *Civil. Environ. Eng.* **2020**, *16*, 329–339. [CrossRef]
51. Shah, S.H.A.; Arif, M.; Rehman, Q.; Manzoor, F. Utilization of dolerite waste powder *for* improving geotechnical parameters of compacted clay soil. *Open Geosci.* **2021**, *13*, 1523–1535. [CrossRef]
52. Shah, S.H.A.; Arif, M.; Sabir, M.A.; Tanoli, J.I.; Asma, S.; Lodhi, H.T. The effect of weathering on the appropriateness of granite for clay stabilization. *Acta Geotech. Slov.* **2022**, *65*, 48–56.

53. Rehman, Q.; Ahmed, W.; Waseem, M.; Khan, S.; Farid, A.; Shah, S.H.A. Geophysical investigations of a potential landslide area in Mayoon, Hunza District, Gilgit-Baltistan, Pakistan. *Rud. Geološko-Naft. Zb.* **2021**, *36*, 127–141. [CrossRef]
54. Haq, I.; Abbas, S.T. Sedimentation of Tarbela and Mangla Reservoirs. In *Proceedings of the 70th Annual Conference of the Pakistan Engineering Congress*; Pakistan Engineering Congress: Lahore, Pakistan, 2006.