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Hydro Power Potential of Swat River Catchment, Pakistan; a Dendrochronological Approach

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Abstract

This project has been devised to get a larger series of hydrology data through a dendrochronological approach and utilize it for hydropower evaluation of the Swat River catchment. For the purpose of dendrochronological analysis, Tree-ring samples were collected using increment borers and measured by Velmax measuring system. The previous hydrological data ranging from 23 to 55 years of the same tributaries were collected from Water and Power Development Authority, Pakistan and Pakhtunkhwa Energy Development Organization (PEDO). Both dendrochronological and obtained hydrological data have been applied to reconstruct the long-term hydrological data of more than 200 years. The reconstructed hydrological data has been used for hydel power potential estimation of all studied tributaries. The current investigation presented the same pattern of flow rate and power potential in existing and reconstructed hydrological data with minor variances. The findings of this research demonstrate that reconstructed hydrological data can be obtained by using existing hydrological and dendrochronological data, and it can act as the best source to measure the expected flow rate and hydropower potential.

Keywords

Hydrology, Dendrochronology, Discharge, Power potential

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Introduction

The world is facing an energy crisis due to the increase in population and global urbanization (Khan and Zaidi, 2015). The prime needs of human beings living on earth are water and electricity (Zaidi and Khan, 2018). These days, the excess use of fossil fuels as a source of energy has created so many environmental issues that could threaten life on the planet (Reddy et al., 2006). The combustion of fossil fuels for energy generation releases huge quantities of greenhouse gas emissions into the environment, causing global warming and sea level to rise and thereby causing the misery of human society (Qureshi and Akıntuğ, 2014). To handle this serious issue, it is necessary to adopt ways of energy production that are renewable and environmentally friendly, including wind, solar and hydroelectric. Apparently, hydropower is the most common form of renewable energy option (OECD/IEA, 2010). It is possible to use water supplies for irrigation purposes and even use them in the form of hydropower to generate electricity (Liming, 2009).

Pakistan is a country rich in mountainous areas and optimum water resources in the form of rivers and streams; it has been reported that Pakistan has a hydel power potential of 75000 MW (Sabir et al., 2017). According to the safest estimation, a power potential of approximately 42000 MW from water resources is reported by Mirza et al., 2008. These water resources are scattered throughout the country, out of which ~50% are present in the Khyber Pakhtunkhwa Province of Pakistan mountain regions. For the construction of hydropower projects, it is very important to have long-term data on water discharge and velocity for the purpose of safe design (Shah et al, 2022a). This data acquisition is time-consuming and takes years to acquire the required data. For the solution to this serious concern, scientists are now using a dendrochronological approach to assess the archaeological, biological, hydrological, entomological, geomorphological, seismological, and chemical conditions of the past (Sabir et al., 2016).

Dendrochronology is a "young science" and has been expanding rapidly worldwide, and so far, substantial progress has been made since the pioneering work of champion et al. (1965). This young interdisciplinary science involves annual tree rings that are dependent on water availability in the area for the roots of trees. The growth rate of tree rings throws a direct light on the water availability, and the difference in available water amount affects tree growth that is recorded in the annual tree rings (Meko et al., 2001; Liu et al., 2007; and Garland et al., 2012). The missing data and the data of previous centuries may be reconstructed using dendrochronological techniques depending on the age of available trees (Meko et al. 2001; Liu et al. 2007).

Swat being a part of the Kohistan Himalayas (Chaudhry and Ghazanfar, 1995), is a potential area of Khyber Pakhtunkhwa with enormous power potential. This area is drained by the Swat River and its tributaries network with high head differences in small areas of their courses, making it more prominent for power generation. The Swat River feeds the Kabul River, which is a direct tributary of the Indus River. Indus River falls in the Arabian Sea near Karachi, As the Swat River originates in Pakistan and feeds the Kabul River within the country, becoming fully undisputed among neighbouring nations. So due to anticipated future conflicts on hydrological possessions, it is the prime time for Pakistan to pay attention to its aboriginal resources. If properly used, hydrological tools will support Swat's recovery after the traumatic episode of law and order sitting in recent years (Sabir et al., 2014). This research work is designed to reconstruct the hydrological data of swat river catchment for more than two hundred years with the help of studying annual tree rings through dendrochronological techniques and utilizing available hydrological data. The reconstructed hydrological data is applied for hydropower potential determination of swat river tributaries. This research provides the basic methodology for reconstructing the maximum hydrological data for designing hydropower projects through dendrochronological techniques, which will save time and help the countries construct the hydropower projects in a short time.

Geology of the Study Area

Regarding the area's geology, the area hosts different well-known rock units. The Ushu river originates in the Deshai Diorites of the Cretaceous age and drains the Kohistan Batholith and Kohistan Ladakh Batholith of the Cretaceous age. The river unites with the Gabral River to form the Swat River in the Silurian Granitic Plutons at Kalam. Being on the western side of the Ushu River, the Gabral River also follows the same geology other than Kohistan Ladakh Batholith. Swat River stretches for 240 km from source to mouth. It originates in the Hindu Kush ranges and joins the Kabul River near Charsadda, Khyber Pakhtunkhwa, Pakistan. Accommodating both previously discussed tributaries, the Swat river at Kalam drains the same geological units. However, as regards the geology of the Swat district rocks of the Dir and Kohistan Groups, Jijal and Chilas complexes are also exposed in the area (Fig. 1).

Materials and Methods

Samples Collection:

Swat district of Khyber Pakhtunkhwa province, the study area (latitude: 34° 44' 57.3756" N and longitude: 72° 21' 25.4268" E) is about 200 km NE of Peshawar, Pakistan (Badar et al., 2017) (Fig. 1). Increment borers were used for taking tree ring samples from the study area, which were then tagged and stored in plastic straws, normally used for drinking purposes (Fig. 2 and Fig. 3). The complete flow diagram of the methodology section is shown in Fig 4. The field parameters, including the degree of damage, canopy density, circumference, breast height diameter, tree elevation, and soil cover properties, were considered properly during tree ring sampling.

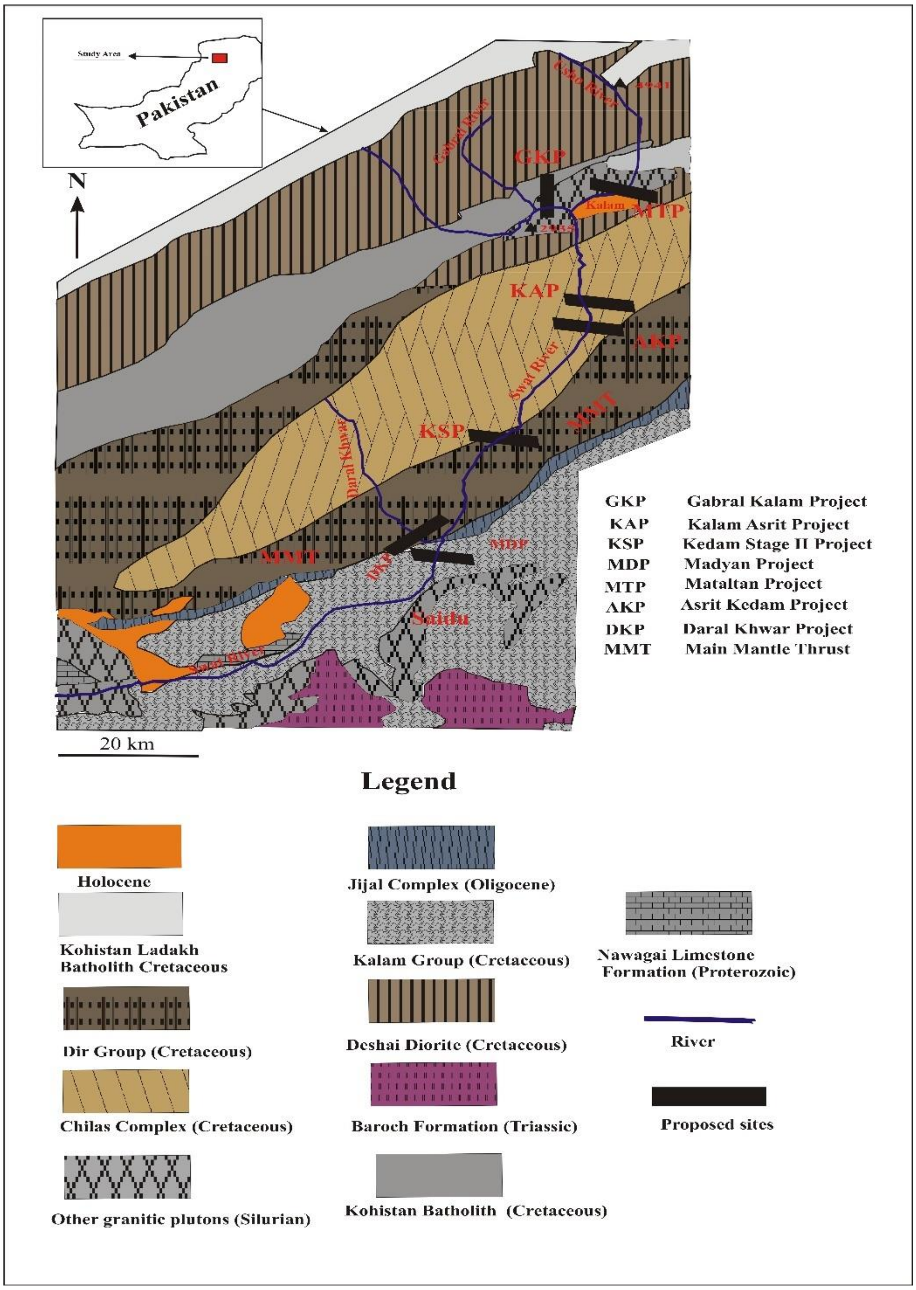

Fig.1. *Map showing the study area and major geological units presented in the area (Tahirkheli, 1996).*

Fig.2. *Collection of Tree ring sample using an Increment borer.*

Fig. 3. *Storage of Tree ring samples in plastic straw for studying under stereo zoom microscope.*

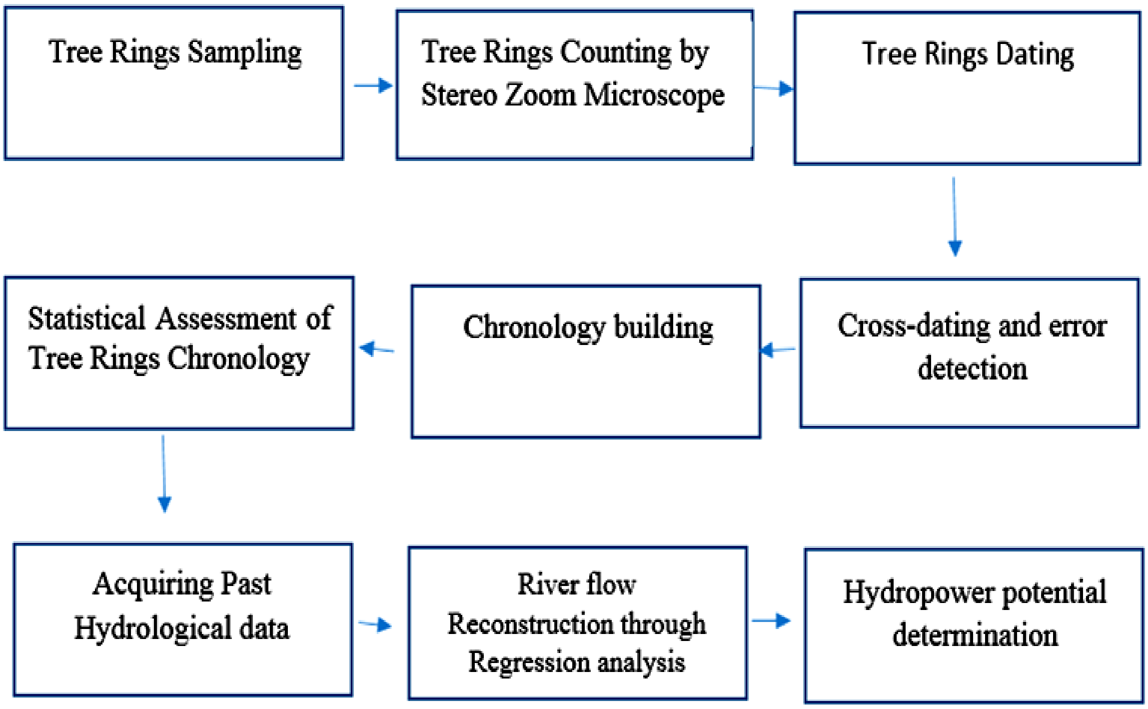

Fig 4: *Flow diagram of the methodology used.*

After obtaining tree ring samples, each ring of the core was counted under the stereo zoom microscope. The age of the tree was obtained by counting the tree rings of the core samples under a stereo zoom microscope and assigned to the calendar year of their formation, shown in Fig. 5.

Fig. 5. *Tree Ring Dating with the help of the microscope.*

Measurement of the Tree-Ring Samples:

After dating the tree-ring series to the exact calendar year of their formations, the thickness of each ring was measured to the nearest 0.01 mm precision with Velmax measuring system attached to a computer. The individual rings were determined by moving the core samples on the sliding stage under a Velmex measuring system connected to the PC having TSAP (Time Series Analysis and Presentation Software) with professional 0.62 ©2002-2008, a computer program. The measurements were recorded on the computer afterwards. The growth structure of the target species was calculated by measuring the gap between the widths of the annual rings.

Cross-dating and error detection:

Cross-dating is the most basic technique used in the dendrochronological study (Panyushkina, 2011). It involves the matching of patterns of ring widths from one tree to corresponding patterns for the same years from another tree, as shown in Fig. 6. All the tree cores collected for dendrochronological analysis were cross-dated, and the errors were detected and removed by using a computer program, COFECHA software.

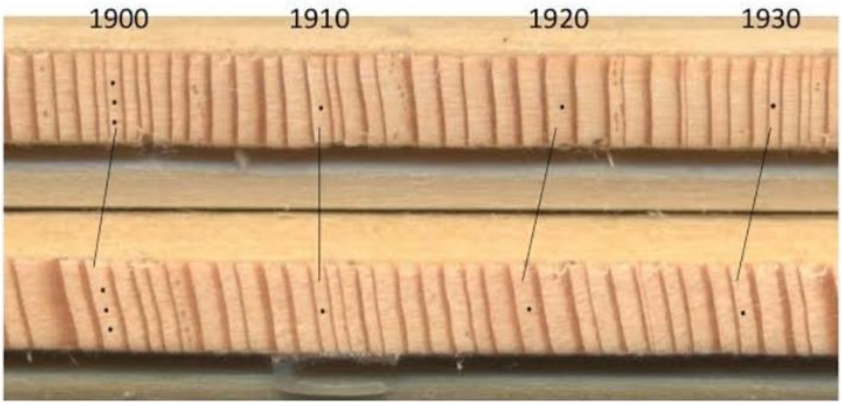

Fig. 6. Cross-*dating between two trees sample.*

Chronology building:

The modified ring-width data was standardized by using the computer program ARSTAN software (Cook, 1985). It eliminated growth trends associated with age, stand dynamics and climate. Three types of chronologies, including residual, standard and Arstan, were produced using ARSTRAN software (Table 1). Moreover, the auto-regressive (AR modelling) was also done through ARSTAN program to remove any auto-correlation effects.

Tab 1. Representation of tree chronology.

(1)Standard Chronology	(2)Residual Chronology	(3)Artsan Chronology
1.344	1.144	1.383
0.903	0.711	0.94
0.813	0.87	0.834
0.81	0.923	0.823
0.945	1.054	0.948
0.876	0.908	0.876
1.527	1.591	1.517
1.047	0.745	1.055
1.158	1.133	1.166

Statistical Assessment Tree Ring Chronology

To describe site chronologies, various statistical parameters were calculated for standard and residual chronologies. These were Standard Deviation, Mean sensitivity, Autocorrelation, Signal-to-noise ratio, Mean series correlation, Expressed population signal and percentage of variance explained by the first eigenvector of the chronologies. A tree species with a low auto-correlation, a high mean sensitivity and a high standard deviation has good potential for dendroclimatological study.

Past Hydrological data:

Past 23-55 years, Gabral River, Ushu River and Kalam River data was obtained from Water and Power Development Authority (WAPDA) and Pakhtunkhwa Energy Development Organization (PEDO), Pakistan.

River flow reconstruction through regression analysis

The analysis started with the calculation of the discharge coefficients of rivers for which the discharge was available (23 to 55 years) using SPSS software. For the further reconstruction (1750 to 2015) of discharge for each river, such as Kalam River, Usho River, and Gabral River, the Tree Ring Chronologies and the calculated coefficients were used. The hydrological data were regressed against the meteorological parameters in individual month-wise regression and collective month-wise regression analysis.

The coefficient of determination

The coefficient of determination is a single summary number that explains how much variation in one variable (Y) is described by variation in another variable (X). It is represented by R-Square. Here we use it as a testing tool for regression analysis. The higher the R-square value better would be the prediction. Its value ranges from 0 to 1.

General equation:

The general equation for multiple linear regressions is:
$Y = B0 + B1X1 + B2X2 + B3X3 + \cdots \ldots\ldots BnXn ---$ (1) (Montgomery, Peck, & Vining, 2012)

The general regression equation is modified according to the requirement.

Modified equation:

$$Q = B0 + B1C + -------------- (2)$$ (Masood et al., 2009)

Where

Q = River flow in m^3/s

B_0 = Constant coefficient or intercept

B_1 = Coefficient or intercept for the Tree ring chronologies

The values of B_0 and B_1 were determined for individual months by using individual month-wise regression and also as a combination for the whole data by using collective month-wise regression analysis *using SPSS Software*.

Evaluation of Hydel Power Potential

The power potential of the three tributaries of the Swat River was estimated after the collection of hydrological data. Head was estimated with the help of 1:50000 topographic sheets, which was confirmed later on by GPS. The general properties of rocks and soils were also observed in the area, which are very important before starting any construction project (Shah et al., 2020a; Shah et al., 2020b; Shah et al., 2021, Shah et al, 2022b). Power potential was estimated by the following formula:

$$P = Qgh/1000$$

Whereas Q is the discharge or flow rate (m^3/s), h is the hydraulic head (m) and g is the acceleration due to gravity (9.8 m/s) (Paish, 2002).

Results

The results of individual month-wise regression and collective month-wise regression analysis using SPSS Software are shown in Tables 2 to Table 6, while the values of discharge and hydropower potential of all investigated rivers are shown in Table 7 and Table 8.

Tab 2: Individual month-wise regression coefficients for each month of the year, Ushu River at Usho area

S.NO	Month	B0	B1	R2	Remarks
1	Jan	2.4215	1.5	0.494	Average
2	Feb	2.511	1.093	0.42	Average
3	Mar	3.616	0.72	0.126	Weak
4	Apr	5.1582	6.884	0.144	Weak
5	May	35.353	-3.568	0.626	Good
6	Jun	51.5208	0.562	0.58	Good
7	Jul	63.497	10.175	0.513	Good
8	Aug	47.0016	12.083	0.552	Good
9	Sep	24.692	6.368	0.237	Weak
10	Oct	9.402	0.648	0.684	Good
11	Nov	5.784	0.0254	0.647	Good
12	Dec	2.675	2.0216	0.602	Good

Tab 3. Individual month-wise regression coefficients for each month of the year, Kalam River

S.NO	Month	B0	B1	R2	Remarks
1	Jan	11.724	3.834	0.61	Good
2	Feb	14.26	0.28	0.54	Good
3	Mar	16.926	0.988	0.208	Weak
4	Apr	39.531	12.449	0.211	Weak
5	May	141.707	-3.77	0.301	Weak
6	Jun	237.43	-4.3076	0.312	Weak
7	Jul	143.12	105.29	0.401	Average
8	Aug	143.369	10.711	0.351	Weak
9	Sep	96.181	-19.29	0.411	Average
10	Oct	32.389	2.8	0.303	Weak
11	Nov	28.009	-5.353	0.215	Weak
12	Dec	21.614	-4.012	0.21	Weak

Tab 4. Individual month-wise regression coefficients for each month of the year, Gabral River

S.NO	Month	B0	B1	R2	Remarks
1	Jan	2.548	1.337	0.664	Good
2	Feb	3.548	0.457	0.272	Good
3	Mar	5.117	0.823	0.422	Average
4	Apr	14.716	-2.941	0.371	Weak
5	May	52.524	-21.007	0.335	Weak
6	Jun	63.978	-11.991	0.64	Good
7	Jul	71.557	-17.449	0.521	Good
8	Aug	50.572	-15.151	0.664	Good
9	Sep	30.3492	-12.054	0.27	Weak
10	Oct	11.986	3.247	0.152	Weak
11	Nov	7.695	-1.922	0.35	Weak
12	Dec	4.928	-0.329	0.305	Weak

Tab 5. Multiple linear regressions model summary output from SPSS Software

Regression Statistics	Gabral River	Ushu River	Kalam River
Multiple R	.987	.950	.775
R square	.975	.902	.610
Adjusted R square	.900	.701	.765

Tab 6. Resultant coefficients of the variable used in multiple linear regression models.

Coefficients	Gabral River	Ushu River	Kalam River
Intercept (B0)	26.359	21.1367	77.192
Tree-Ring Chronology (B1)	-6.888	-1.669	8.301

Tab 7. The average monthly flow rate of Ushu, Kalam, and Gabral Rivers of previous and reconstructed hydrological data.

Reconstructed hydrological data in m^3/s (1750-2015)				**Previous hydrological data in m^3/s**		
Months	**Ushu River**	**Kalam River**	**Gabral River**	**Ushu River**	**Kalam River**	**Gabral River**
January	3.835	14.988	5.748	3.797	15.019	5.713
February	3.645	13.749	5.217	3.447	13.767	5.201
March	4.279	16.797	6.504	4.157	16.818	6.530
April	11.982	48.277	17.078	11.418	47.914	17.116
May	31.820	128.538	46.107	30.815	129.046	45.773
June	54.981	234.438	74.539	56.336	239.578	74.169
July	56.550	243.693	81.183	58.710	249.351	79.540
August	38.240	159.630	57.095	39.776	162.700	56.578
September	18.508	76.230	28.549	19.296	77.870	28.391
October	8.693	34.403	11.949	8.861	34.814	11.796
November	5.739	5.739	9.135	5.733	5.733	9.209
December	4.511	4.511	6.294	4.510	4.510	6.210

Tab 8. The average monthly Power potential of Ushu, Kalam, and Gabral Rivers in Megawatts of previous and reconstructed hydrological data

	Reconstructed hydrological data in MW (1750-2015)			Previous hydrological data in MW		
Months	**Ushu River**	**Kalam River**	**Gabral River**	**Ushu River**	**Kalam River**	**Gabral River**
January	9.470	23.501	9.576	9.378	23.550	9.517
February	9.001	21.559	8.691	8.513	21.587	8.664
March	10.568	26.338	10.835	10.266	26.370	10.879
April	29.591	75.698	28.452	28.197	75.129	28.515
May	78.582	201.547	76.814	76.100	202.345	76.258
June	135.780	367.599	124.181	139.127	375.659	123.566
July	139.655	382.111	135.251	144.990	390.982	132.514
August	94.437	250.300	95.120	98.941	255.114	94.259
September	45.707	119.529	47.562	47.654	122.100	47.299
October	21.468	53.945	19.907	21.882	54.589	19.652
November	14.173	34.677	15.218	14.158	35.101	15.342
December	11.142	26.938	10.485	11.137	27.258	10.345

Discussion

This research work was designed to reconstruct the hydrological data of the Swat river catchment with the help of annual tree-rings' study, using dendrochronological techniques and available hydrological data. Hydrology data from more than two centuries was reconstructed and used for the estimation of hydropower potential. Very few variations were observed in the reconstructed hydrological data and the obtained data from PEDO and WAPDA, Pakistan (Tables 7 and 8). This small difference shows the effectiveness of dendrochronological techniques for acquiring long-term hydrological data in hydropower projects, which is impossible through the current practice techniques. This dendrochronological approach will help the engineers to design and construct the hydropower projects in a very short time, which is the major contribution and novelty of this research work.

The values of discharge were found to be higher in all tributaries, including Ushu, Kalam and Gabral, from May to August in both reconstructed and past data of more than two centuries and 23 to 55 years, respectively (Table 7). However, the discharges were found moderate in April and September and lower in other months. The high discharge values may be due to the glacial melting and flooding because the temperature values are always higher in these months (Cook et al., 2013). The heavy rainfalls, along with moderate temperature, may likely be the cause of normal discharge in September and August. The lower temperature and snowfalls can be the basis for lower water flow in all other months. It has been observed that snow cover extent, temperature index, precipitation and geomorphology have a major effect on stream runoff in swat catchment areas. The similar trend of discharge in the obtained and reconstructed data of more than two centuries means that no specific climate change occurred in the Swat area in the studied past. Both data have an almost equal trend of flow rate, which shows that previous data can be used to fill the gaps in the annual flow rate of the rivers, and this data can also provide important information in future planning regarding micro hydropower projects.

Monthly power potential is estimated from the past and reconstructed hydrological data of Ushu, Kalam, and Gabral River. Table 8 represents the monthly mean value of power potential, which shows approximately the same pattern in both data types. The values of power potential are higher from May to August, moderate in April and September and lower in other months. This difference is due to the variation in discharge values (Table 7). The higher the discharge, the more hydropower potential will be.

In figures (7 and 8) both reconstructed and past data were also compared with already calculated data of Sabir et al. (2014) for the same area with minimal difference. This small difference will make this study more reliable and applicable.

To take advantage of water resource management, it is necessary to understand the climatic/societal impacts on changes in streamflow runoff continuously for long-term water-cycle studies (Sing et al., 2009), and this work will help the planners to acquire long-term data by adopting the dendrochronological approach to know about these impacts in more depth.

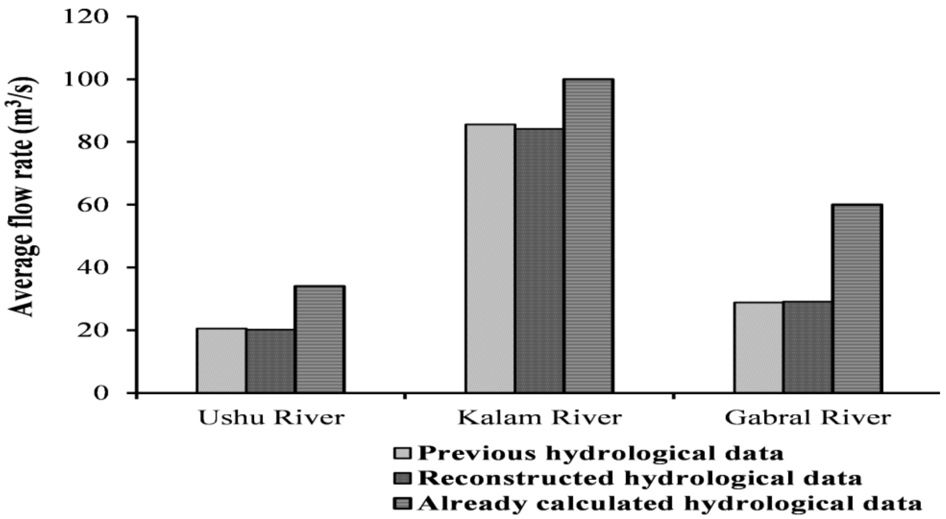

Fig. 7. Comparison of annual flow rate between previous, reconstructed and already calculated hydrological data in Sabir et al., 2014.

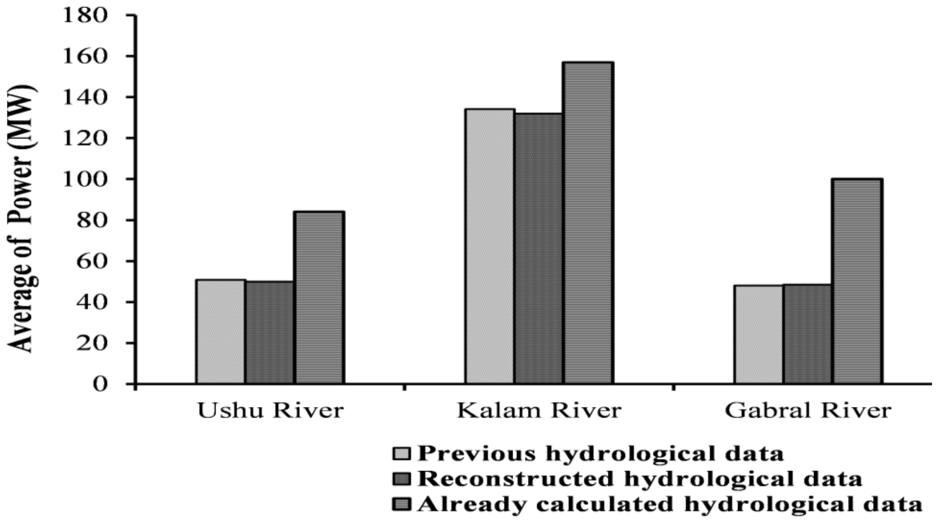

Fig. 8. Comparison of power potential between previous, reconstructed and already calculated hydrological data in Sabir et al., 2014.

Conclusions

The study proved that dendrological data could be used to obtain long-term hydrological data in order to estimate the power potential of respective streams. Long-term reconstructed hydrological data, using dendrochronology, can be used as the best estimate of expected flow rates of Swat River tributaries in the future, but the continuation of strong interdecadal variability in the future, like that found in the past which can be used for the identification of potential hydropower sites. Correct assessment of hydropower potential at a site requires realistic information on topography (particularly elevation) and flows, followed by careful analysis of these data. The energy sector can use this study technique to better utilize available resources for selecting suitable sites for small hydropower plants with high power potential in a cost-effective manner. It is suggested that further research intended to inform hydropower-related policymaking needs to consider future hydropower potential under climate change. This may be based on fine-resolution analysis, which will influence the long-term role of hydropower in future energy systems.

References

Badar, M. A., Hussain, S., Niaz, S., and Rehman, S. 2017. X-ray diffraction study of emerald from Mingora and Charbagh deposits, Swat valley. Northwest Pakistan. *Journal of Himalayan Earth Science*, 50(1), 13-24.

Champion, S.H., Seth, S.K., and Khattak, G.M. 1965. E book on Forest types of Pakistan. *Pakistan Forest Institute*.

Chaudhry, M.N. and Ghazanfar, M.A.1995. Review of the geology of northwest Himalaya. *Journal of Chicago*, 6(6), 537-556.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization. *Doctoral dissertation*, University of Arizona.

Cook, E.R., Krusic, P.J. and Jones, P.D. 2003. Dendroclimatic Signals in Long Tree-Ring Chronologies from the Himalayas of Nepal. *International Journal of Climatology*, 23, 26-29.

Garland, N. A., Grissino-Mayer, H.D., Deagan, K., Harley, G. L. and Waters, G. 2012. Dendrochronological dating of wood from the fountain of Youth Park archaeological site (8SJ31), St. Augustine, Florida, USA. *Tree-Ring Research*, 68(1), 69-78.

Holmes, R.L.1983. Program COFECHA user's manual. *Laboratory of Tree-Ring Research*. The University of Arizona, Tucson.

Khan, M. and Zaidi, A.Z. 2015. Run-of-river hydropower potential of Kunhar River, Pakistan. *Pakistan Journal of Meteorology*, 12(23), 25-32.

Liming, H. 2009. Financing rural renewable energy: a comparison between China and India. *Renewable and Sustainable Energy Reviews*, 13(5), 1096-1103.

Liu, Y. and Gupta, H.V. 2007. Uncertainty in hydrologic modeling: Toward an integrated data assimilation framework. *Water resources research*, 43(7), 1-18.

Meko, D.M., Therrell, M.D., Baisan, C.H. and Hughes, M.K. 2001. Sacramento river flow reconstructed to ad 869 from tree rings 1. Jawra. *Journal of the American Water Resources Association*, 37(4), 1029-1039.

Meko, D.M., Woodhouse, C.A., Baisan, C.A., Knight, T., Lukas, J.J., Hughes, M.K. and Salzer, M.W. 2007. Medieval drought in the upper Colorado River Basin. *Geophysical Research Letters*, 34(10), 1-5.

Montgomery, D.C., Peck, E.A. and Vining, G.G. (2012). Introduction of linear regression analysis, Edition 5, John Wiley & Sons.

Maqsood, A., Shah, S.M.S., Malik, M.A., Khan, G.D., Gul, S. and Haq, I. (2009). Collective & Individual month-wise data management approach on the data collected in Kalam (Swat) through multiple regression analysis. *Sarhad J. Agric*, 25 (4), 557-561.

Mirza, U.K., Ahmad, N., Majeed, T. and Harijan, K. 2008. Hydropower use in Pakistan: past, present and future. Renewable and Sustainable Energy. Renewable and Sustainable Energy Reviews, 12(6), 1641-1651.

OECD/IEA. 2010. Hydropower Essentials. International Energy Agency. *Nepal Geological society*, 12, 7–9.

Paish, O. 2002. Small hydro power: technology and current status. *Renewable and sustainable energy reviews*, 6(6), 537-556.

Panyushkina I.P. 2011. Dendrochronology. McGraw Hill Encyclopedia of Science & Technology, 11th Edition, The University of Arizona.

Qureshi, F.U. and Akıntuğ, B. 2014. Hydropower potential in Pakistan. 11th *International Congress on Advances in Civil Engineering*, Istanbul, Turkey.

Reddy, V.R., Uitto, J.I., Frans, D.R. and Matin, N. 2006. Achieving global environmental benefits through local development of clean energy? The case of small hilly hydel in India. *Energy policy*, 34(18), 4069-4080.

Sabir, M.A., Rehman, S.S., Umar, M., Waseem, A., Farooq, M. and Irshad, M. 2014. Assessment of hydro power potential of Swat, Kohistan Himalayas: A solution for energy shortfall in region. *Water resources*, 41(5), 612-618.

Sabir, M.A., Umar, M., Farooq, M. and Faridullah, F. 2016. Computing soil creep velocity using dendrochronology. *Bulletin of Engineering Geology and the Environment*, 75(4), 1761-1768.

Sabir, M.A., Shah, S.H.A. and Habib, U. (2017): Establishment of hydroelectric microgrids, need of the time to resolve energy shortage problems, 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), Johor Bahru, 16-21. DOI: 10.1109/PGSRET.2017.8251794.

Singh, M., Mishra, V.D., Thakur, N. K., Kulkarni, A.V. and Singh, M. 2009. Impact of climatic parameters on statistical stream flow sensitivity analysis for hydro power. *Journal of the Indian Society of Remote Sensing*, 37(4), 601-614.

Shah, S.H.A., Arif, M., Sabir, M.A., Iqbal, J. 2020a. In-situ stabilization of clays with lime, dolerite and quartzite powders. *Acta Geodynamica et Geomaterialia*, 3(199), 341–352.

Shah, S.H.A., Arif, M., Sabir, M.A., Rehman, Q. 2020b. Impact of igneous rock admixtures on geotechnical properties of lime stabilized clay. *Civil and Environmental Engineering*, 16, 329–339.

Shah, S.H.A., Arif, M., Rehman, Q., Manzoor, F. 2021. Utilization of dolerite waste powder *for*. improving geotechnical parameters of compacted clay soil. Open Geosciences, 13(1), 1523–1535.

Shah, S.H.A., Tanoli, J.I., Habib, U., Rehman, Qu., Ali, E., Mohamed, A. 2022a. Assessing Potential of Dor River as Small Hydro Project for Lessening Energy Crisis and Enhancing Tarbela Reservoir Life in Khyber Pakhtunkhwa, Pakistan. Water. 2022, 14(17):2683. https://doi.org/10.3390/w14172683.

Shah, S.H.A., Habib, U., Mohamed, A., Aziz, M., Rehman, Qu., Saleem, A. 2022b. Laboratory and In Situ Stabilization of Compacted Clay through Granite Waste Powder. Sustainability, 14(21):14459. https://doi.org/10.3390/su142114459