GEO-SPATIAL ASSESSMENT OF WATER QUALITY AND SEDIMENTATION TRENDS FOR SUSTAINABLE POWER PRODUCTION IN TARBELA RESERVOIR, PAKISTAN

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THE GLOBAL GOALS

Agenda Outline

7 AFFORDABLE AND CLEAN ENERGY

Ensure access to affordable, reliable, sustainable and modern energy for all.

01 CASE FOR CLEAN ENERGY

02 BENEFITS OF CLEAN ENERGY

03 INTRODUCTION TO SOUTH ASIA

04 CLEAN ENERGY IN PAKISTAN

05 HYDROPOWER PROJECTS IN PAKISTAN

06 ENERGY CRISIS IN PAKISTAN

07 INTRO OF TARBELA DAM

THE GLOBAL GOALS

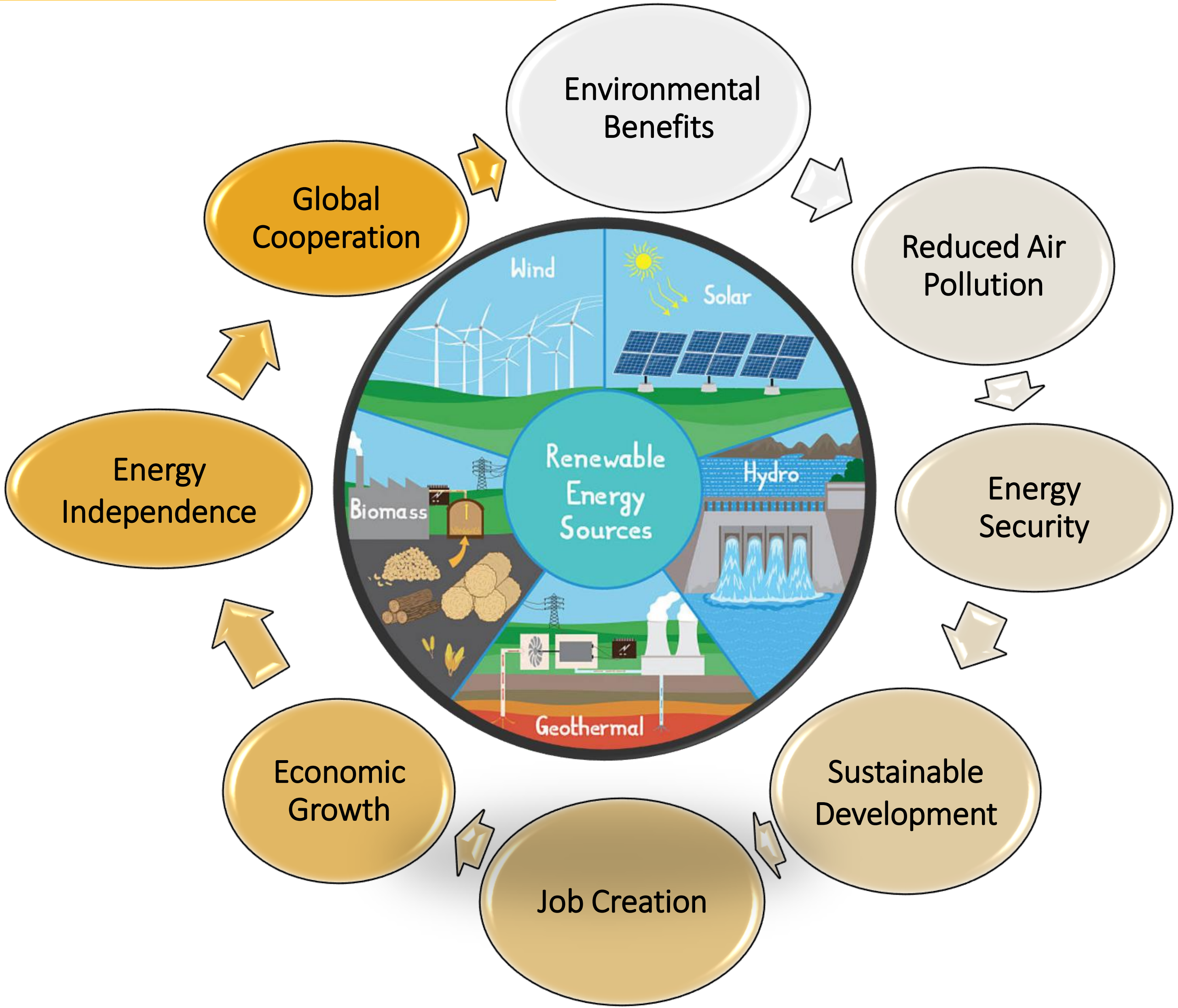
Agenda Outline

7 AFFORDABLE AND CLEAN ENERGY

SIGNIFICANCE OF CLEAN ENERGY

Renewable energy sources, such as wind and solar, emit little to no greenhouse gases, are readily available and in most cases cheaper than coal, oil or gas. [1]

BENEFITS OF CLEAN ENERGY



PHYSICAL GEOGRAPHY OF SOUTH ASIA

South Asia is a subregion of Asia that consists of eight countries: Afghanistan, Bangladesh, Bhutan, India, Pakistan, Nepal, Sri Lanka, and the Maldives.[12]

It is bounded by the Himalayas, Hindu Kush, and Karakoram mountains in the north, and the Indian Ocean and the Bay of Bengal in the south.[12]

It has a diverse physical geography that includes plains, plateaus, deserts, islands, and rivers.[12]

The physical geography of South Asia influences its climate, natural resources, agriculture, biodiversity, and human settlement patterns.[12]

The Indo-Gangetic Plain is one of the most fertile and densely populated regions in the world.[12]

PHYSICAL GEOGRAPHY OF SOUTH ASIA

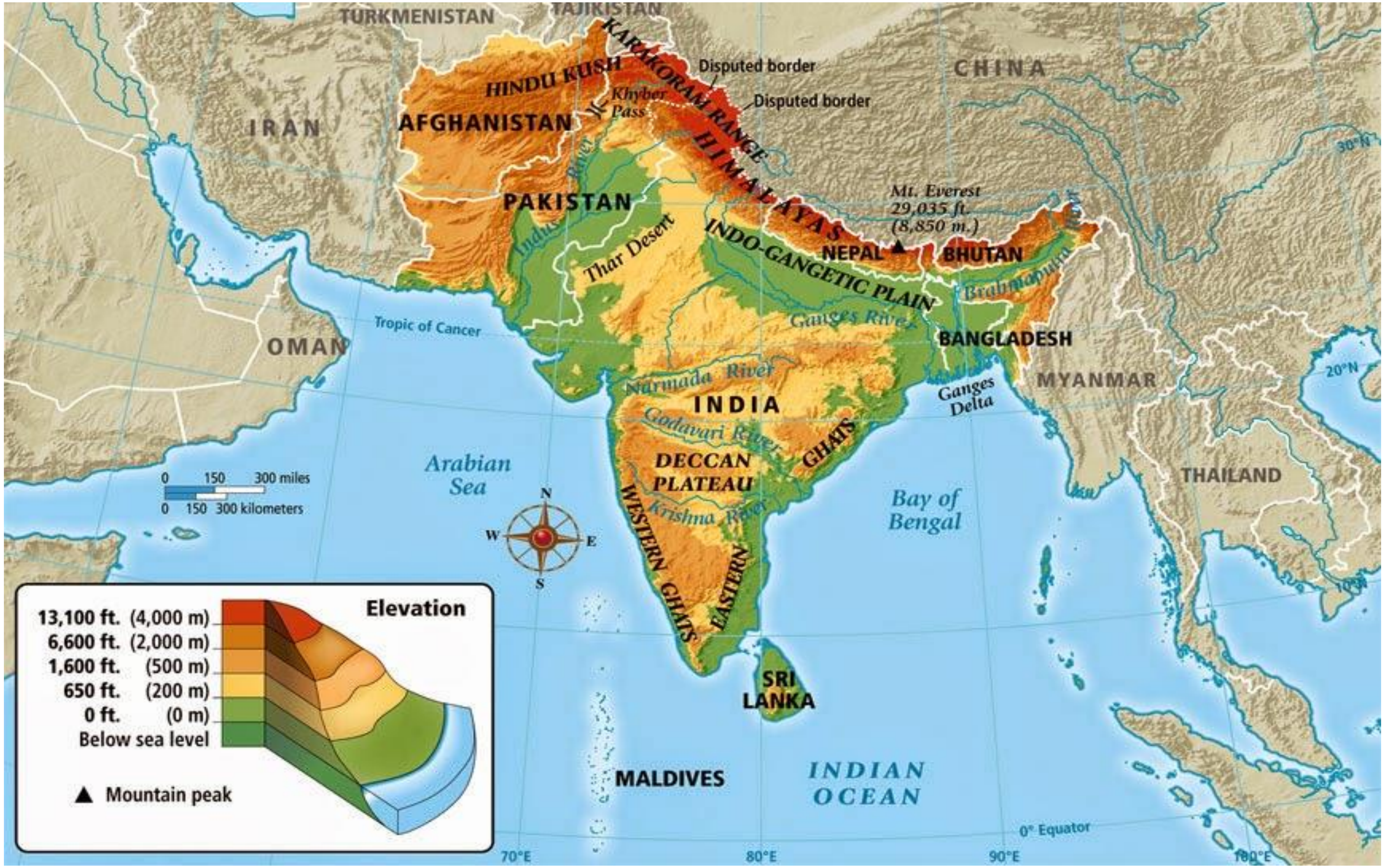
The Deccan Plateau is a large volcanic plateau that has a dry and semi-arid climate with rich mineral resources and endemic species. [12]

The island countries of Sri Lanka and the Maldives have a tropical climate with high humidity and rainfall. They have diverse ecosystems such as coral reefs, mangroves, wetlands, and forests. [12]

The Thar Desert is the largest desert in South Asia that has a hot and arid climate with scarce rainfall and vegetation. It is also rich in salt deposits, gypsum, and lignite. [12]

INTRODUCTION TO

South Asia



Source: 1.bp.blogspot.com

HUMAN RESOURCES SIGNIFICANCE OF SOUTH ASIA

South Asia: As of 2022 its population is 1.9 billion people, which is about 24% of the world's population.[11]

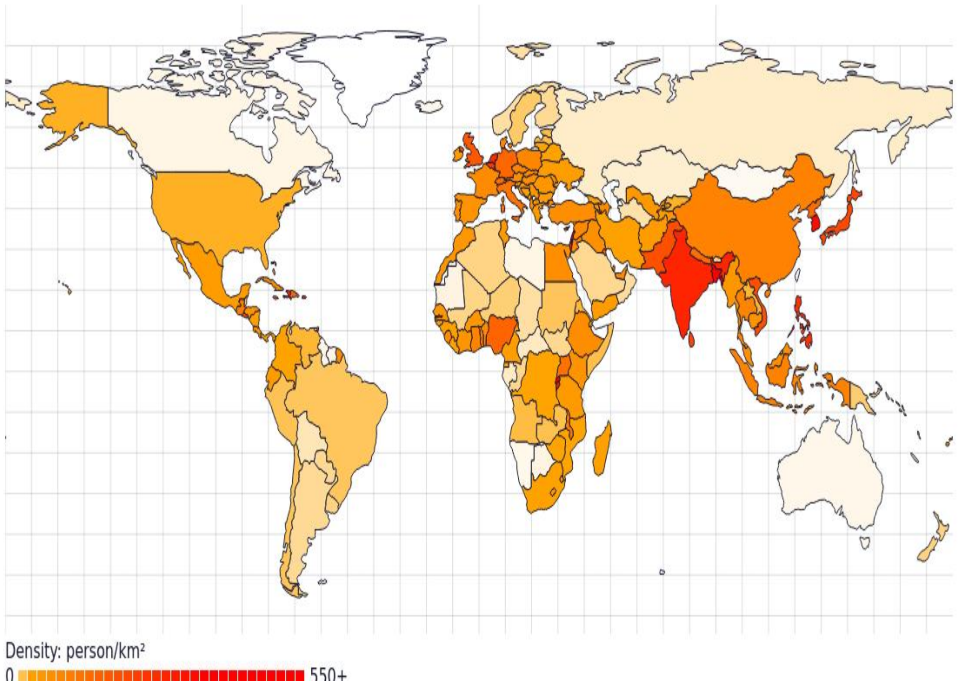
Highest growth rate: Its one of the fastest growing regions in terms of population growth rate, which is projected to reach 2.4 billion by 2050.[11]

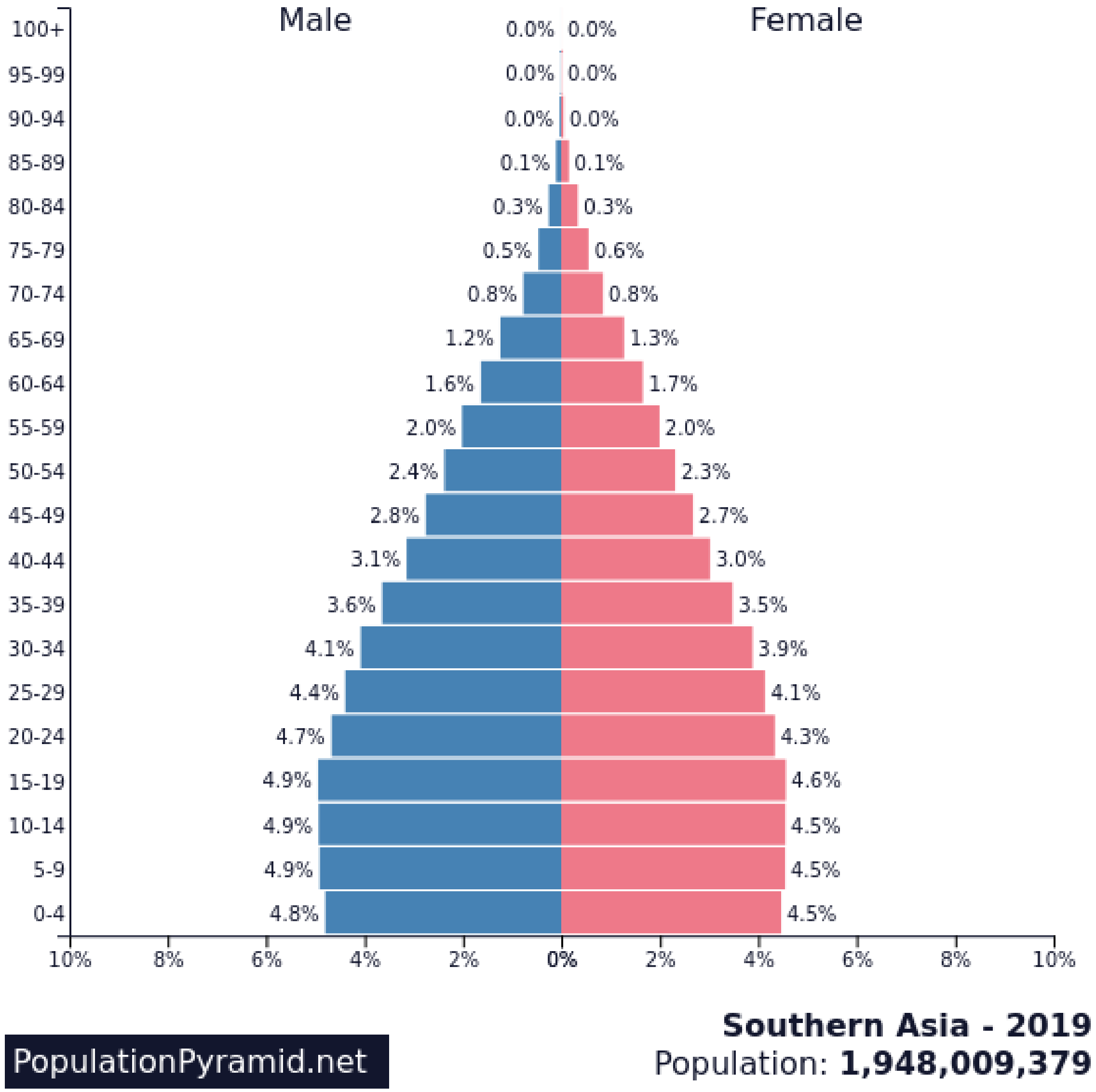
Youthful workforce: Abundant young and working-age population, fostering innovation and economic potential. [11]

Diverse skills: A varied populace contributes to creativity and expertise across sectors. [11]

Education progress: Advancements, especially in IT, engineering, and healthcare professions. [11]

POPULATION DENSITY





Source: Population Pyramid.net

HUMAN RESOURCES SIGNIFICANCE OF SOUTH ASIA

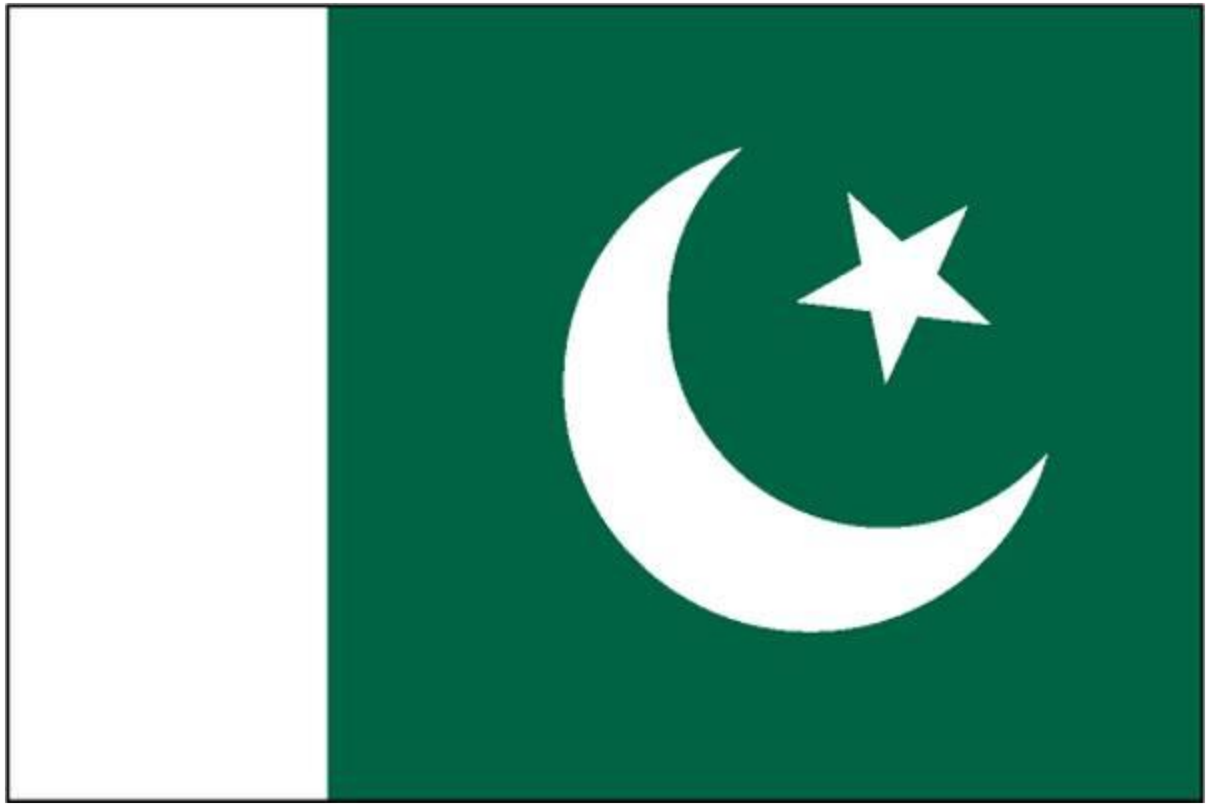
Labor force: A substantial workforce fuels agriculture, manufacturing, and services. [11]

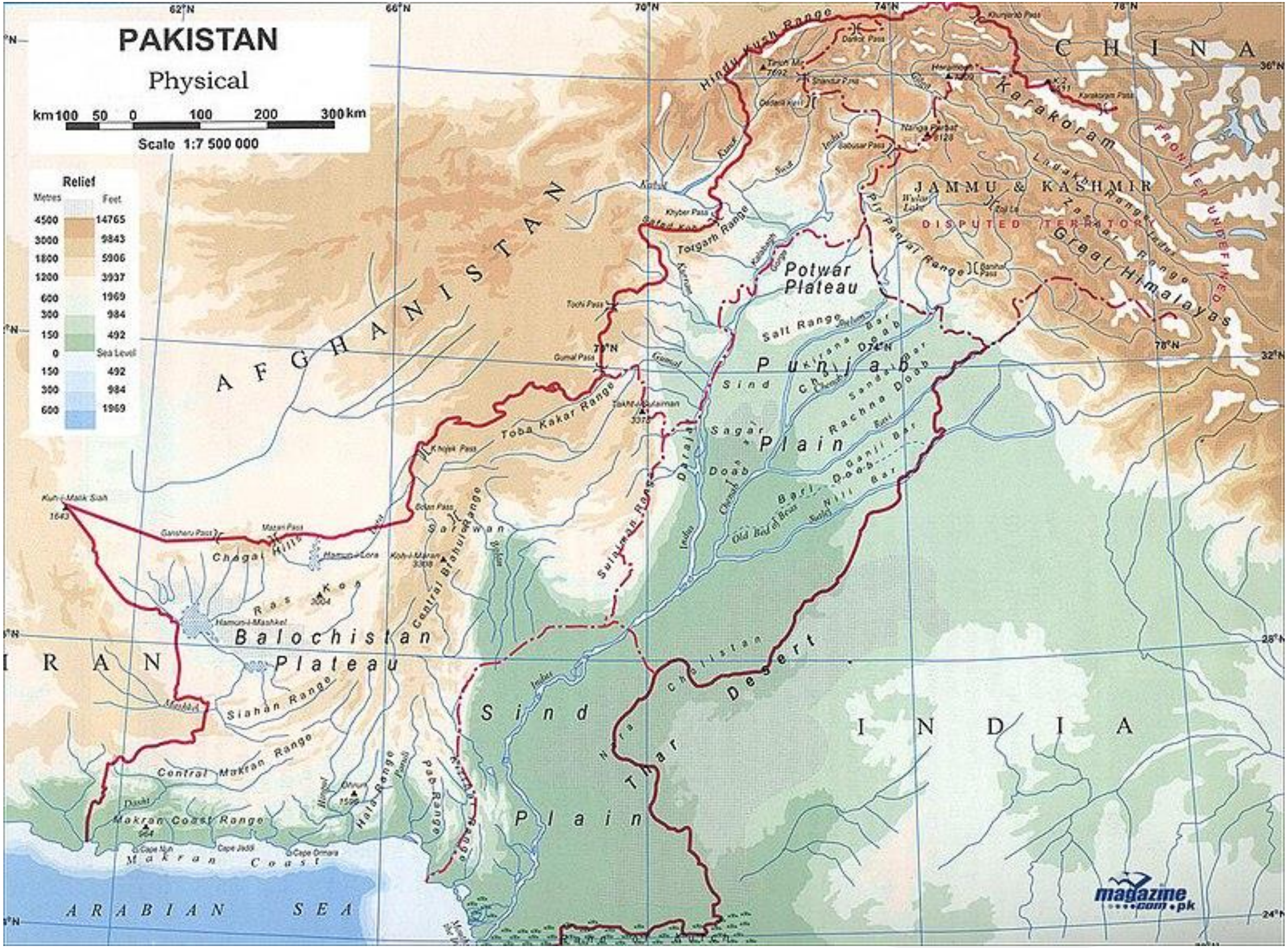
Urbanization's impact: Rapid urban growth alters resource distribution, necessitating effective planning. [11]

Gender equality: Empowering women in the workforce is critical for South Asia's human capital growth. [11]

Global presence: South Asians working abroad contribute significantly through remittances. [11]

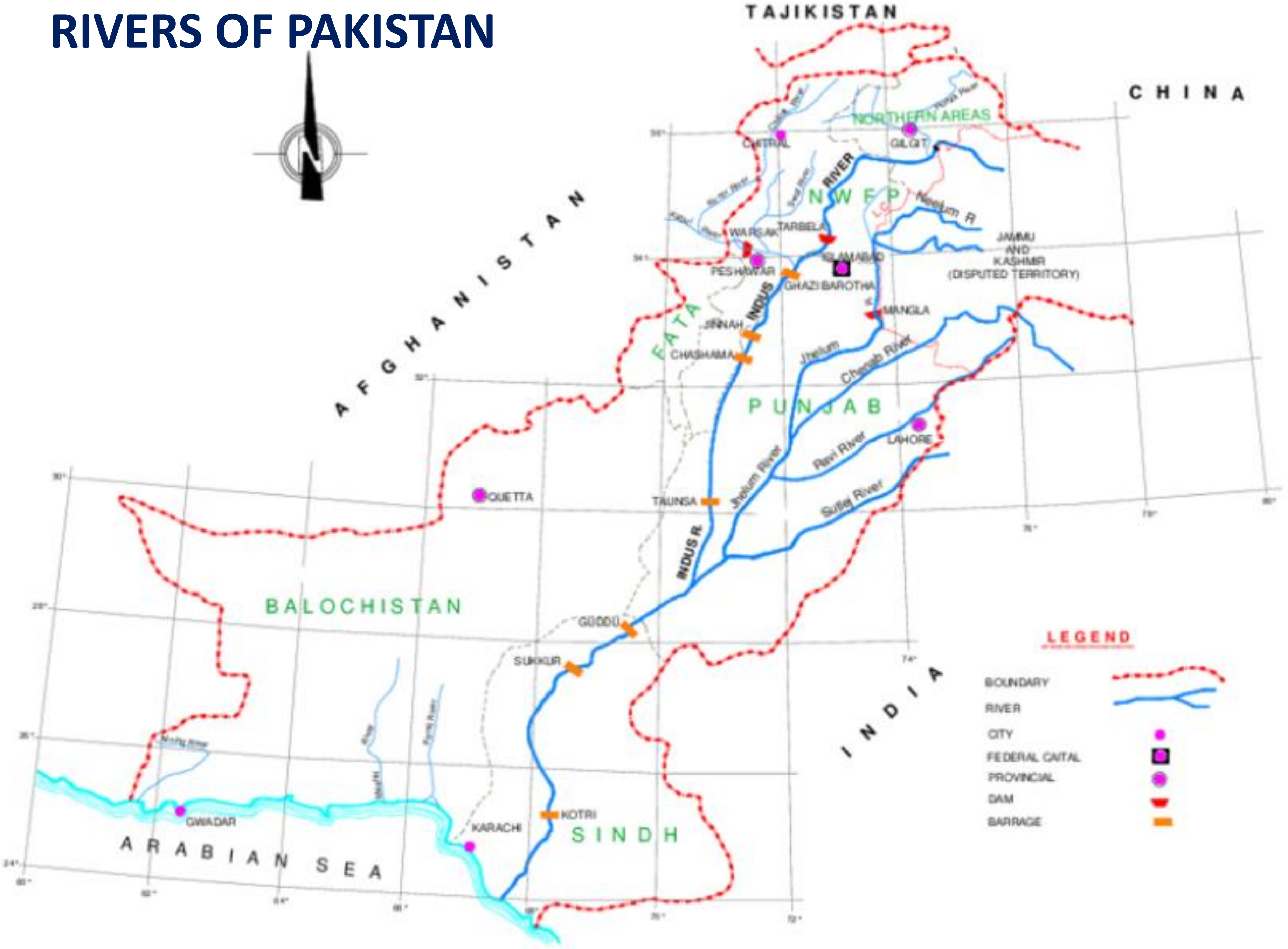
PAKISTAN





Source: FEP Atlas

RIVERS OF PAKISTAN



Source: Majeed et al., 2008

IMPLEMENTATION OF CLEAN ENERGY DEVELOPMENT IN PAKISTAN

Pakistan's goal: 60% renewable energy by 2030, including hydro.[13,14]

Urgent need: Expand solar and wind (VRE) for at least 30% capacity by 2030. [13]

Benefits: Clean energy lowers costs, boosts security, and reduces emissions.[13]

Government actions: Policies, incentives, and renewable energy targets.[14,15]

Successes: Wind farms, solar plants, and small hydro projects.[15]

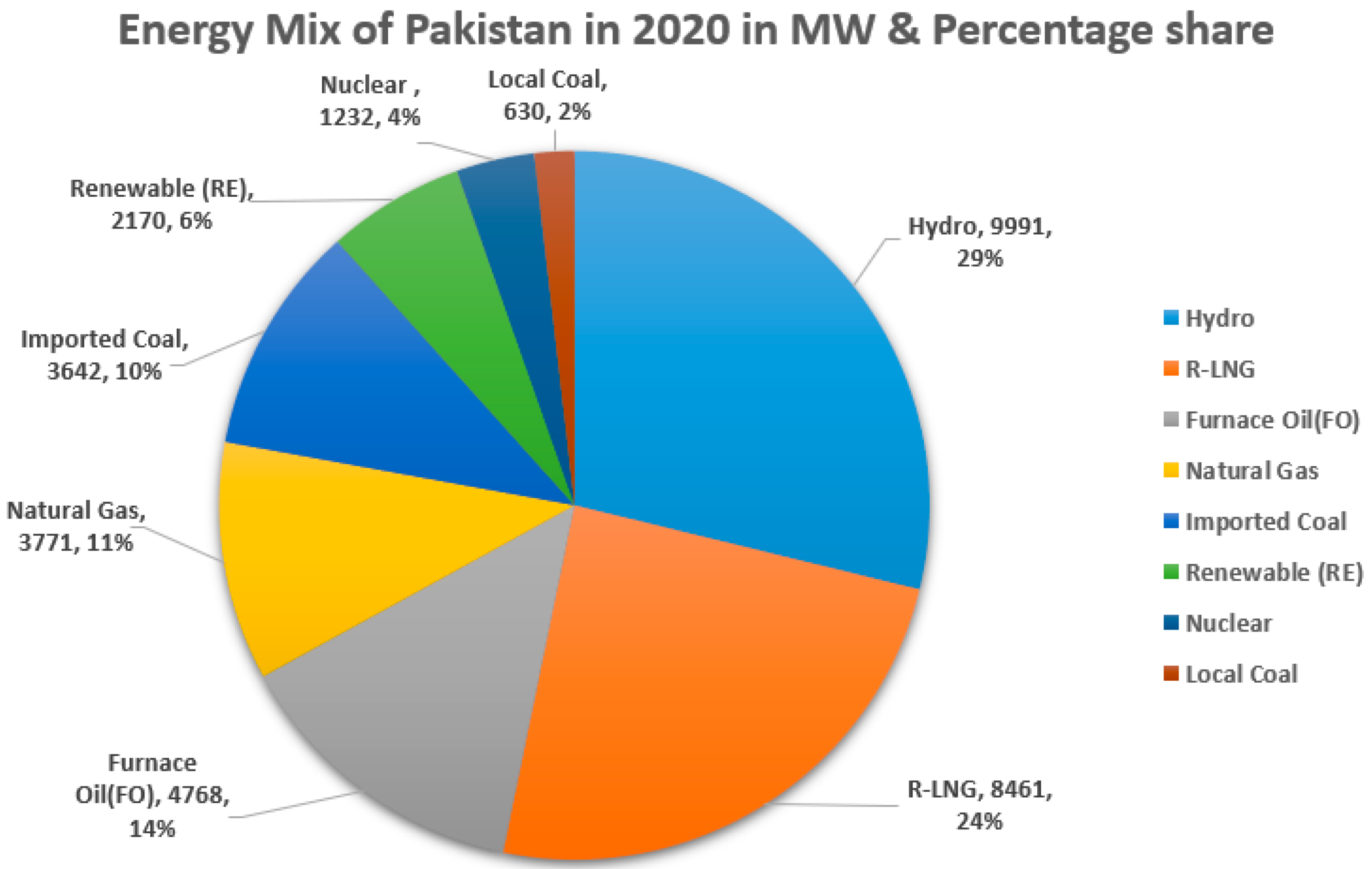
IMPLEMENTATION OF CLEAN ENERGY DEVELOPMENT IN PAKISTAN

Investment opportunities: Attracting domestic and foreign investors.[15]

Partnerships: Public-private collaborations for clean energy projects.[15]

Efficiency measures: Promoting sustainable energy alongside renewables.[15]

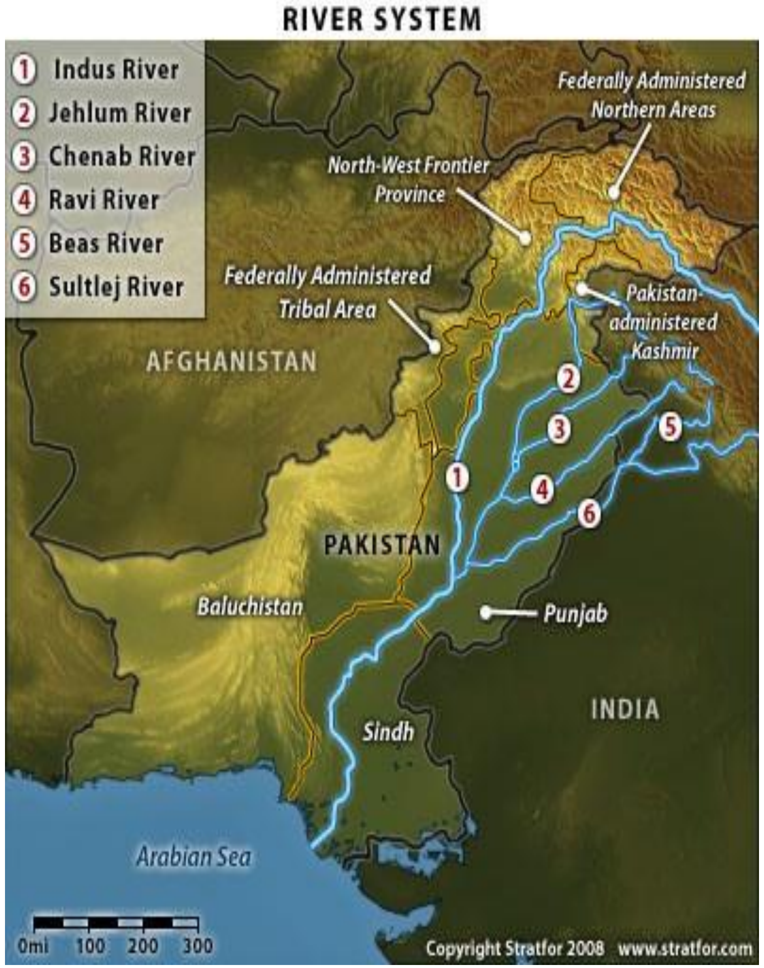
Paris Agreement: Clean energy helps Pakistan meet international commitments.[13]



Source: Durrani et al., 2021

Clean Energy Resources in Pakistan

- Pakistan's total hydropower potential is estimated at around **60,000 MW.** [16,17]
- Currently, only about **16% (approximately 7,320 MW)** of this potential is exploited. [16,18]
- Hydropower is a clean energy source, producing no greenhouse gas emissions or air pollution. [16,18]
- Untapped hydropower potential is mainly concentrated in the mountainous **north** along the **Indus and Jhelum rivers.** [16,18]



Hydropower Renewable Energy Sources in Pakistan

TARBELA DAM

Tarbela Dam is situated on the Indus River in Khyber Pakhtunkhwa province, Pakistan. [19]

It is one of the largest earth-filled dams globally, with a substantial storage capacity of about 11.62 billion cubic meters. [20]

The dam's power station has an installed capacity of approximately 3,478 MW, making it a significant hydroelectric power producer. [20,21]

HR Wallingford

Hydropower Renewable Energy Sources in Pakistan

MANGLA DAM

Located in Azad Kashmir on the Indus River. [22,24]

It is the sixth-largest dam in the world. [22,24]

Storage capacity of approximately 7.4 billion cubic meters. [23,24]

The dam's power station has an installed capacity of about 1,000 MW. [23,24]

Source: Blogspot.com

Hydropower Renewable Energy Sources in Pakistan

GHAZI BAROTHA DAM

Situated near Attock in Punjab province on the Indus River. [25]

Storage capacity of about 8.78 million cubic meters. [25]

Power station installed capacity of around 1,450 MW. [25]

This Project holds the record for the biggest concrete lined channel in the world. [25]

Source: Blogspot.com

Hydropower Renewable Energy Sources in Pakistan

WARSAK DAM

Located near Peshawar in Khyber Pakhtunkhwa province on the Kabul River. [25]

Storage capacity of about 0.35 billion cubic meters. [25]

Power station installed capacity of approximately 243 MW. [25]

This project is playing a vital role in the development of the country by providing cheap power to the National Grid. [25]

Source: Blogspot.com

Hydropower Renewable Energy Sources in Pakistan

DIAMER BHASHA DAM

Located on the Indus River, between Kohistan (KPK) and Diamer of Gilgit-Baltistan region in Pakistan. [25]

The dam site is situated about 315 kilometers upstream of Tarbela Dam. [25]

Under construction with an expected storage capacity of approximately 7.3 million acre-feet (about 9 billion cubic meters). [25]

A hydropower generation capacity of about 4,500 MW once completed. [25]

Source: Daily Pakistan

TARBELA DAM

TARBELA DAM

Built as part of the Indus Basin Project to mitigate the impact of ceding three eastern rivers to India under the 1960 Water Treaty (Ravi, Sultej, and Beas). [32]

It's one of the world's largest earth-fill dams located on the Indus River in Khyber Pakhtunkhwa, about 130 kilometers north of Islamabad.[33]

Built in 1970 and completed in 1974 under the supervision of Pakistan's Water and Power Development Authority . [34]

Its reservoir capacity is 11.62 million acre-feet. [35]

Built to improve Pakistan's low-cost hydroelectric power generation, flood control, and agricultural water storage systems. [36]

Provides 50% of total irrigation releases and 30% of total power and energy needs in Pakistan.[34]

The Indus River transports massive amounts of sediments, which deposit in the reservoir and are the primary cause of the decrease in storage volume. [36]

However, its experiencing sedimentation issues, which are reducing its storage capacity, electricity output, and lifetime. [34]

Due to significant sediment influx from the upstream catchment area, it has lost approximately 30% of its storage capacity and 15% of its power generation potential. [34]

Source: HR Wallingford

TARBELA DAM FACTS AND ISSUES

3,750 MW installed capacity

Tarbela Dam has five main tunnels with tunnels 1, 2, and 3 equipped with powerhouses that have a combined generation capacity of 3,470 MW.

The dam's efficiency is being challenged due to increased sedimentation rates, causing a rapid advancement of the sediment delta.

The completion of the fourth extension in 2018 increased the installed capacity of the dam to 4,888 MW.

There are plans for a fifth extension, which is expected to raise the installed capacity to 6,298 MW once completed.

Cont.

Earthquake activity could potentially liquefy the sediments, leading to blockage of low-level outlets and power intake channels.

The underwater delta is advancing at a rapid pace towards the main embankment dam

The dam's current considered life is 85 years, but the usable storage capacity will continue to decrease with time.

PROBLEM STATEMENT

01

Pakistan is facing a severe energy crisis with a shortfall **of 7000 MW** in the energy sector.

02

Economic activities related to the China-Pakistan Economic Corridor (CPEC) are expected to lead to a significant rise in energy demand, especially in the and commercial sectors, **by 136% and 414%** respectively till 2030, compared to 2013.

03

Despite having vast hydropower potential, the country has not fully utilized it for energy production.

04

Efficient management of current mega power projects is crucial to address the energy crisis and meet the growing energy demands.

05

Investing in and optimizing hydropower projects can play a vital role in meeting the energy needs and reducing dependency on other energy sources.

Media Highlights

THE EXPRESS TRIBUNE
TODAY'S PAPER | JULY 30, 2023 | ADVERTISE

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Tarbela failed 'seven times' during power breakdown

Musadik-led body missed deadline to complete probe

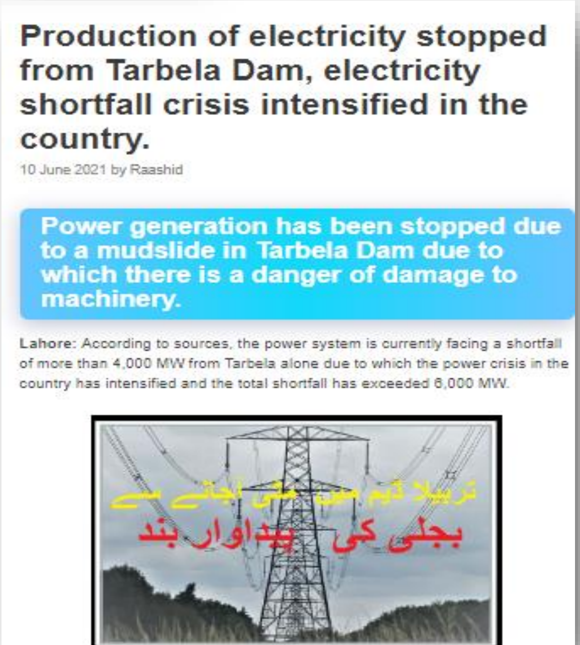
Our Correspondent | February 08, 2023

Massive power outage in Pakistan plunges whole country into darkness

By Euronews, AP and AFP with APTN • Updated: 10/01/2021

A malfunction at one of Pakistan's main power stations set off a chain reaction that shut down other power stations across the country, leaving millions in darkness.

A major technical fault in Pakistan's power generation and distribution system caused a massive power outage that plunged the country into darkness overnight, the energy minister said.



Production of electricity stopped from Tarbela Dam, electricity shortfall crisis intensified in the country.

10 June 2021 by Raashid

Power generation has been stopped due to a mudslide in Tarbela Dam due to which there is a danger of damage to machinery.

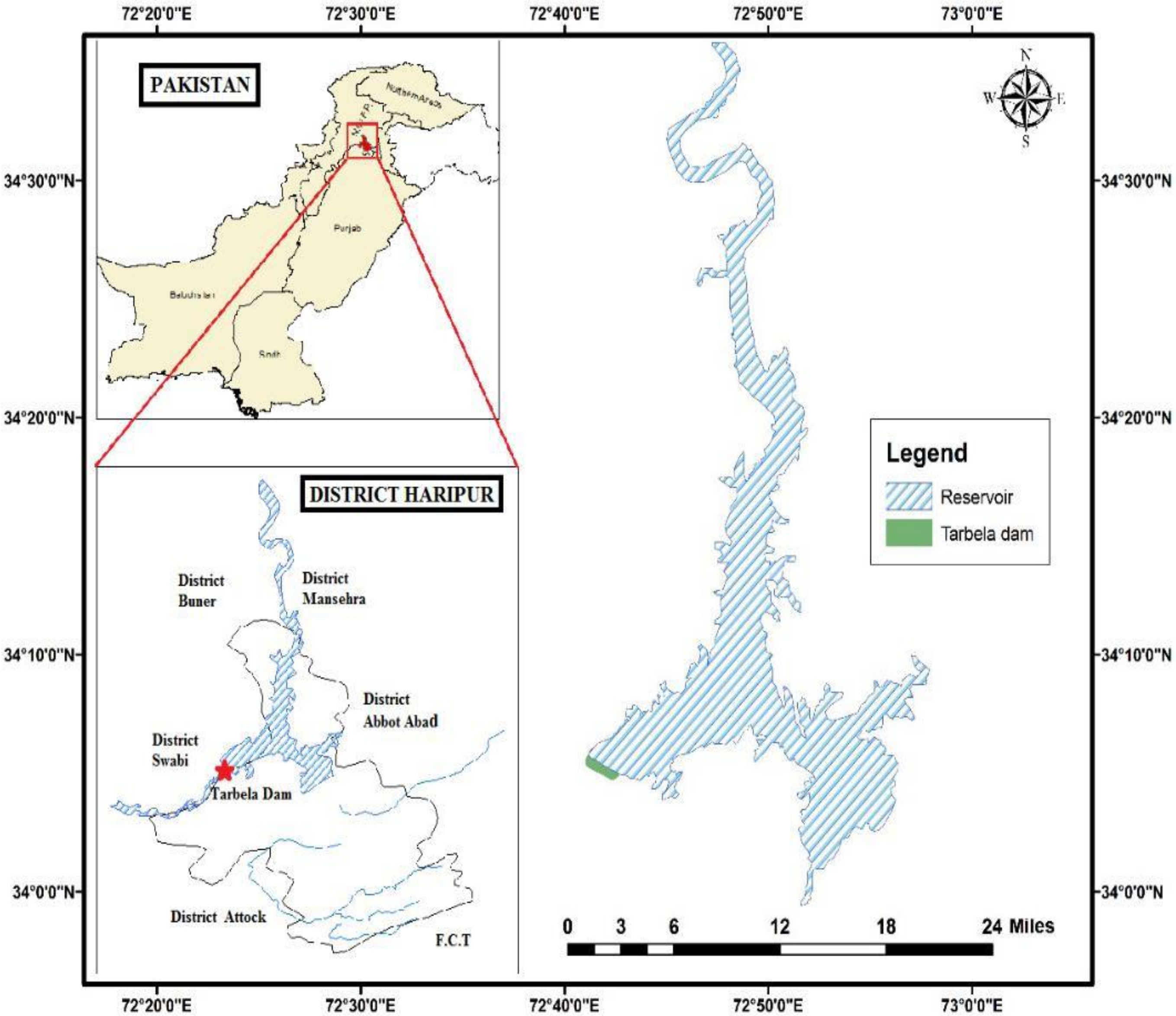
Lahore: According to sources, the power system is currently facing a shortfall of more than 4,000 MW from Tarbela alone due to which the power crisis in the country has intensified and the total shortfall has exceeded 6,000 MW.

OBJECTIVES OF STUDY

- Monitoring Tarbela reservoir's water quality
- Analysis of underwater delta pivot point advancement

Study Site

Study Area Map

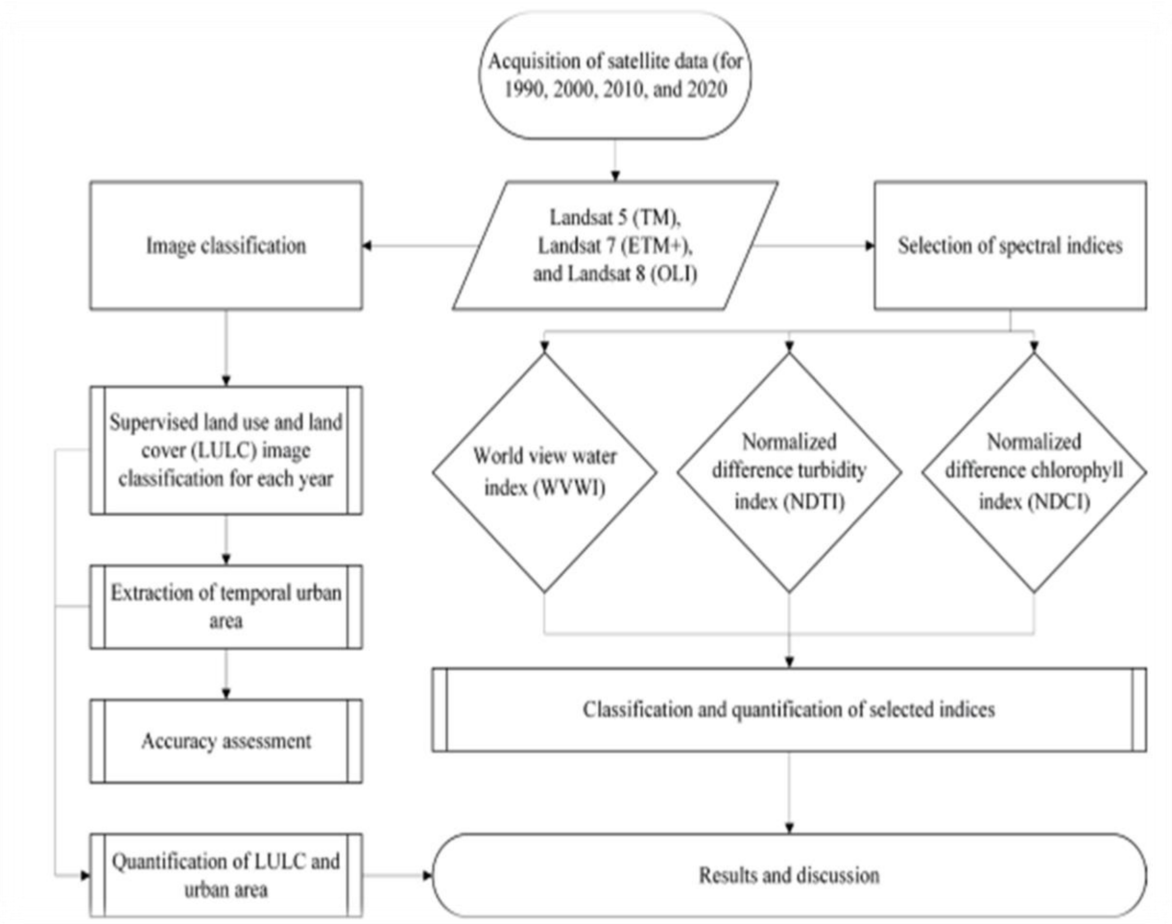


METHODOLOGY

- Secondary datasets from survey department Tarbela Dam Project
- Landsat 5, 7 and 8 imagery from1990 to 2020: USGS
- Geometric and radiometric correction
- Noise removal and cloud cover which was less than 10%.

Methodological Flowchart

Water Quality Assessment



LANDSAT DATA CHARACTERISTICS

Table 1. Characteristics of Landsat data used in the study

Satellite	Sensor	Level	Path	Row	Acquisition Date
Landsat 5	TM	L1	150	36	1990/04/24
Landsat 5	TM	L1	150	36	2000/05/21
Landsat 7	ETM+	L1	150	36	2010/06/02
Landsat 8	OLI	L1	150	36	2020/06/29

PIVOT POINT ADVANCEMENT

Data

- Pivot point elevation
- Pivot point distance from MED

Processing

- Arc GIS attribute table

Results

- Proportional symbols: advancement of pivot point
- Delta advancement forecast

DATA PROCESSING

Index	Equation
World View Water Index	$WVWI = \frac{CB - NIR2}{CB + NIR2}$
NORMALIZED DIFFERENCE TURBIDITY INDEX (NDTI)	$NDTI = \frac{Red - Green}{Red + Green}$
NORMALIZED DIFFERENCE CHLOROPHYLL INDEX (NDCI)	$NDCI = \frac{Blue}{Red}$

Land use land cover classification (LULC)

- Supervised classification with
- maximum likelihood algorithm

LULC ACCURACY ASSESSMENT

Table 2. Accuracy assessment (%)

Year	1990		2000		2010		2020	
Accuracy	User (%)	Producer (%)	User (%)	Producer (%)	User (%)	Producer (%)	User (%)	Producer (%)
Landcover								
Water	87.5	100	100	100	91.67	68.75	100	83
Vegetation	100	83.33	92.31	85.71	82.35	82.35	90	90
Snow	100	100	100	100	81.81	100	75	100
Boulder/Rock	66.67	100	83.33	90.91	88.89	100	91.66	84.61
Bare Land	100	85.71	80	80	90.9	100	80	88.89
Overall Accuracy (%)	91.43		90.91		86.67		88.00	
Kappa Coefficient	0.89		0.89		0.83		0.85	

RESULTS

LULC 1990-2020

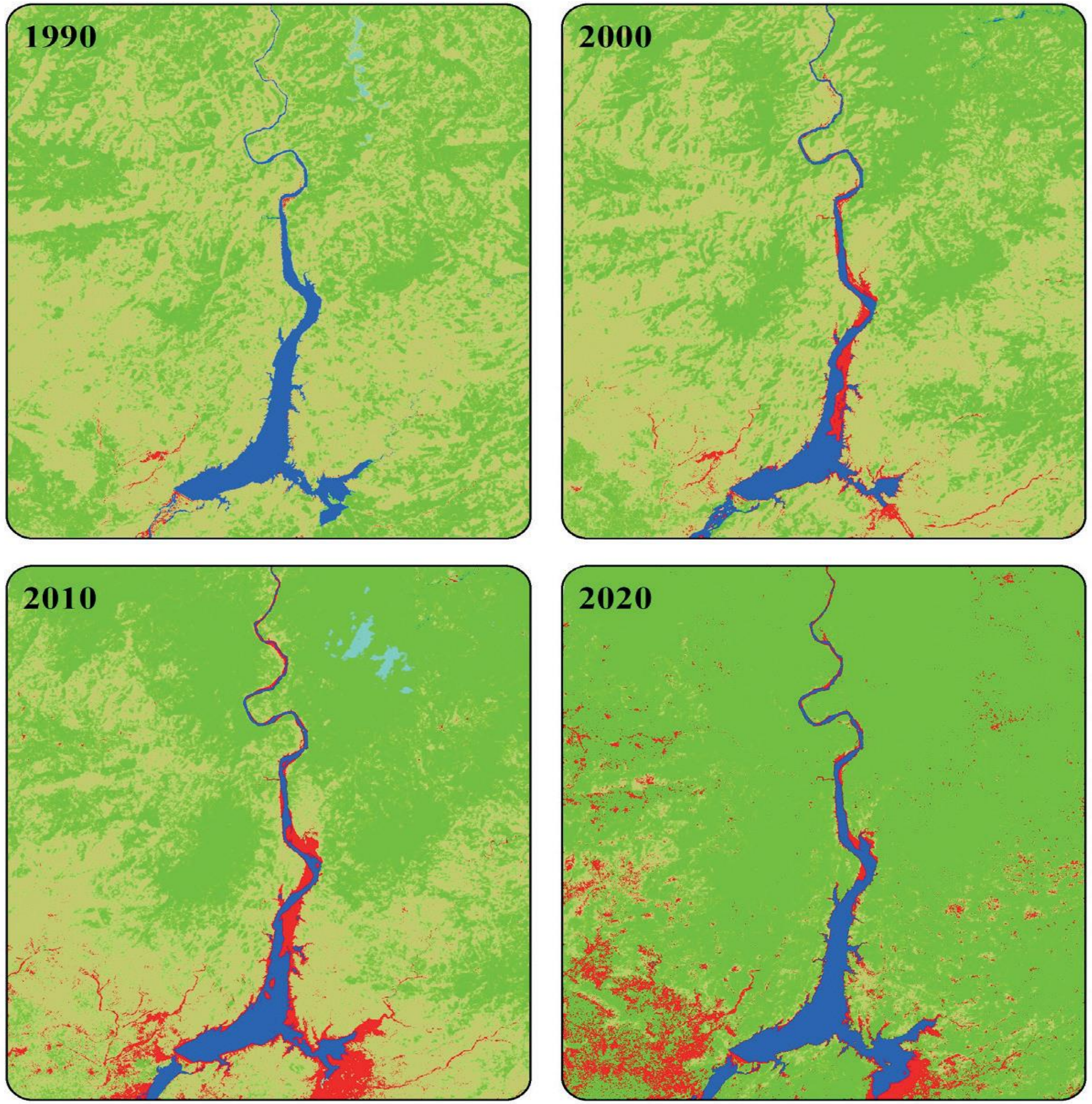
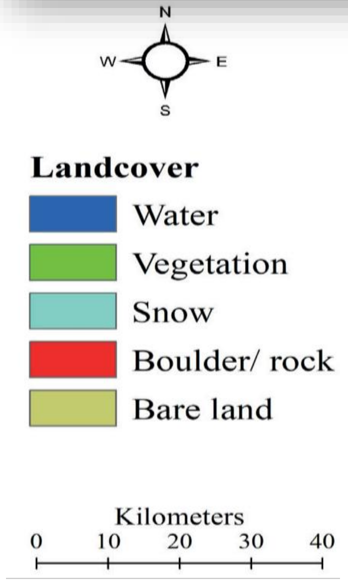


Table 3. Land Use and Land Cover (LULC) characteristics of the study area

Classes	1990 area (sq.km)	2000 area (sq.km)	2010 area (sq.km)	2020 area (sq.km)
Water	167	166	151	196
Bare Land	3733	3424	2680	549
Boulders/Rock	20	90	321	630
Snow	47	0	44	0
Vegetation	2100.94	2388	2872	4694



(NDCI)

NORMALIZED DIFFERENCE CHLOROPHYLL INDEX

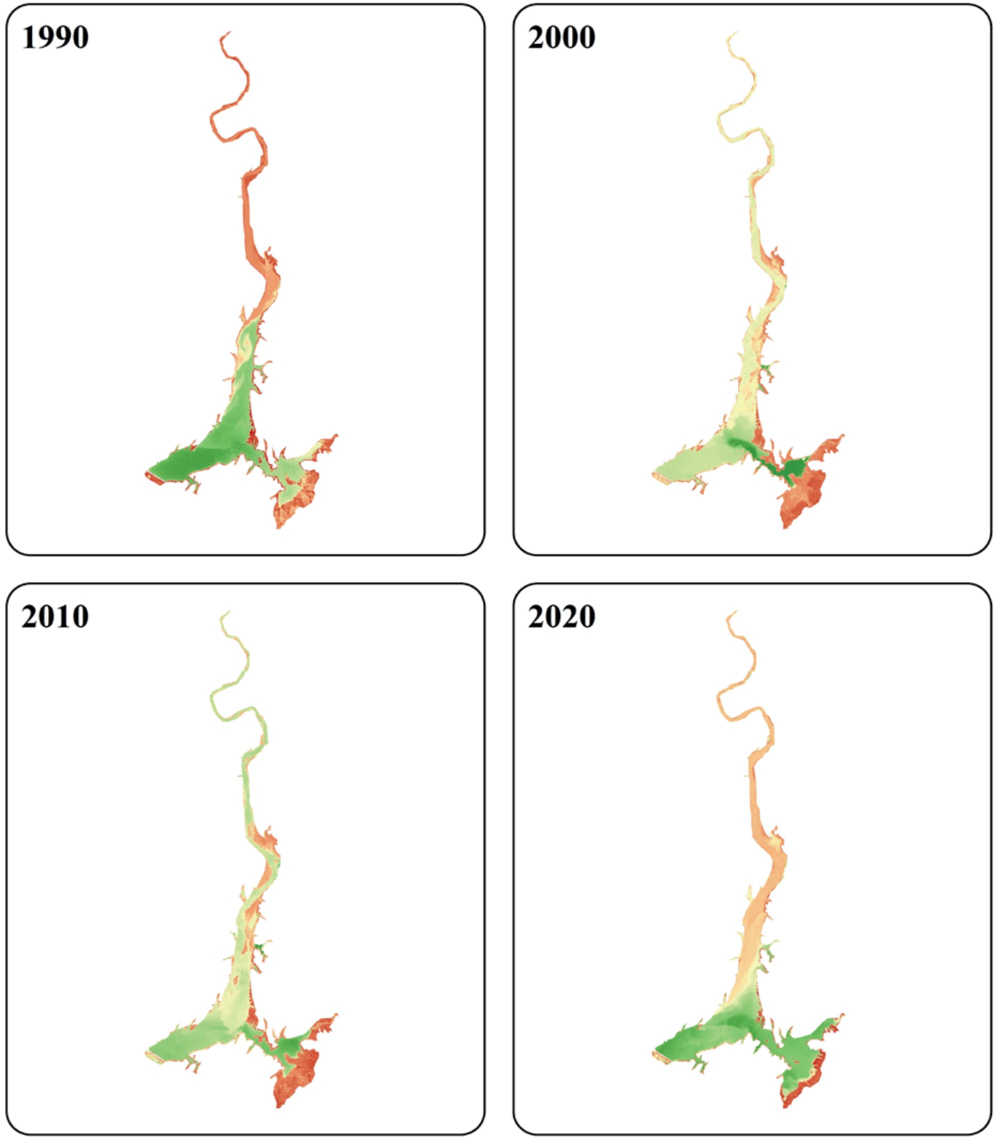
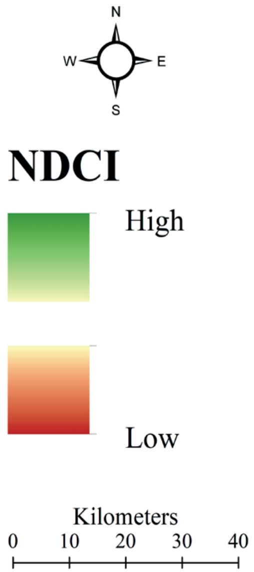


Table 4. Normalized Difference Chlorophyll Index (NDCI) characteristics of the study area

Classes	1990	2000	2010	2020
High	4.80	3.04	2.49	1.35
Medium	2.99	2.04	1.86	1.05
Low	1.19	1.05	1.24	0.75
Mean	3.04	1.76	1.79	1.12



(NDTI)

NORMALIZED DIFFERENCE TURBIDITY INDEX

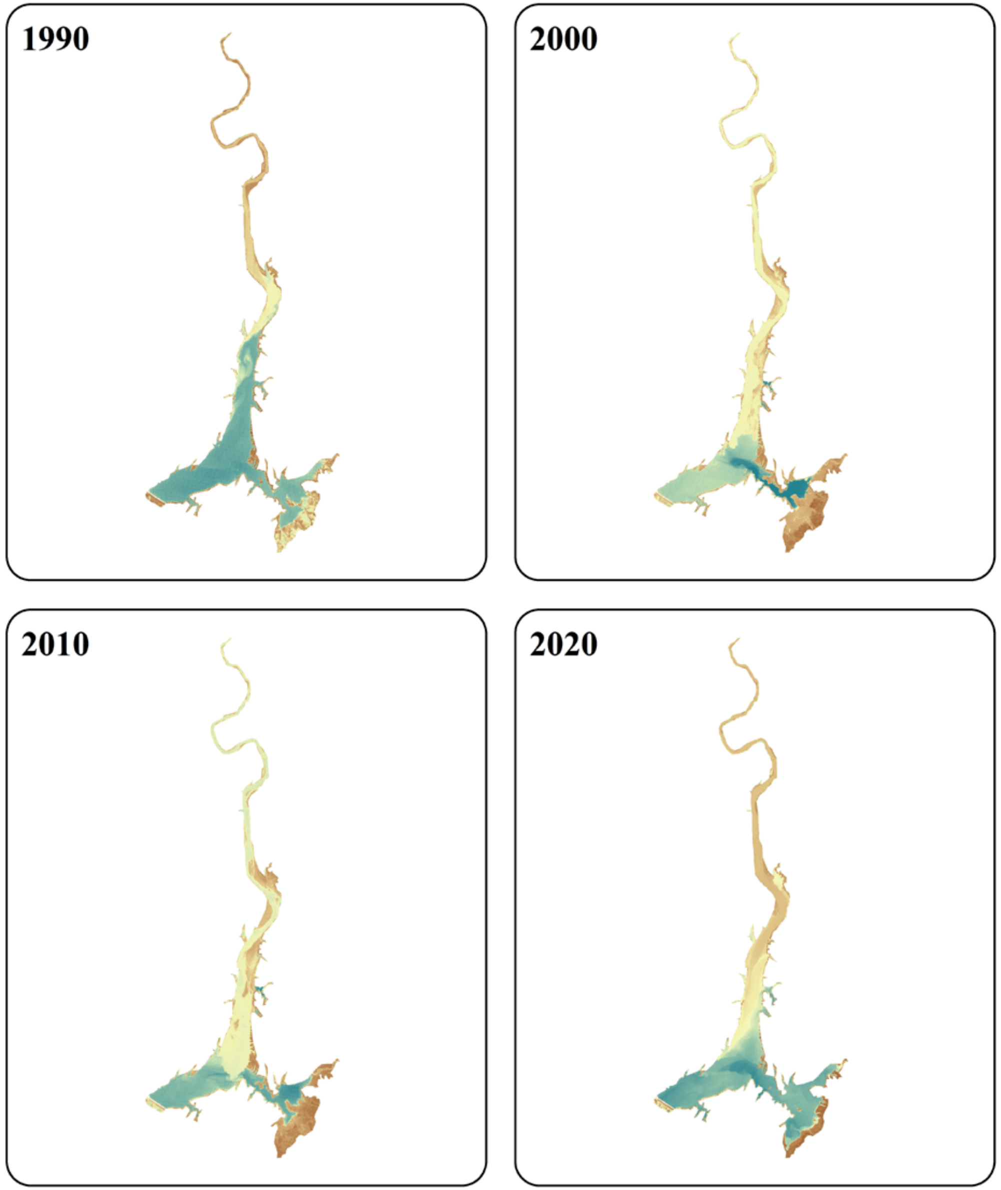
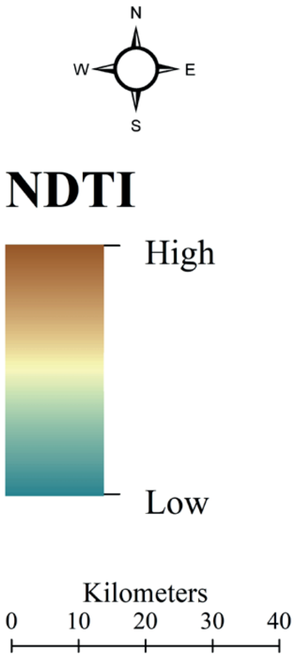


Table 5. Normalized Difference Turbidity Index (NDTI) characteristics of the study area

Classes	1990	2000	2010	2020
High	0.15	0.21	0.17	0.09
Medium	-0.07	0.01	0.04	-0.02
Low	-0.30	-0.18	-0.08	-0.14
Mean	-0.13	0.05	0.05	-0.05



(WVWI)

WORLD VIEW WATER INDEX

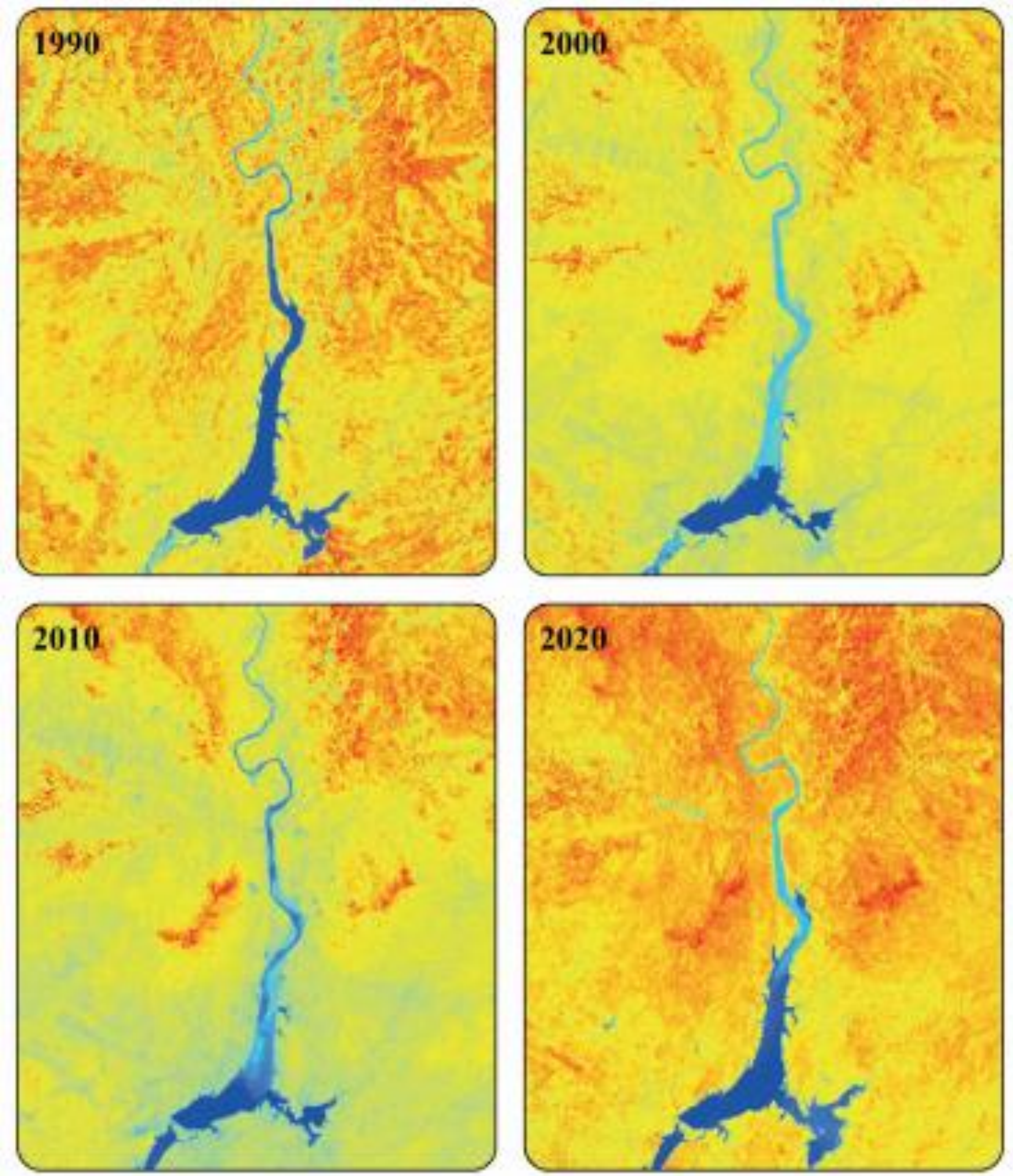
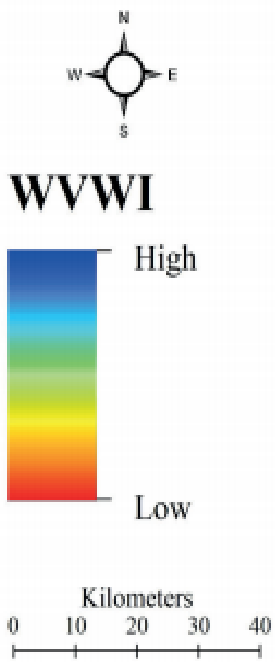
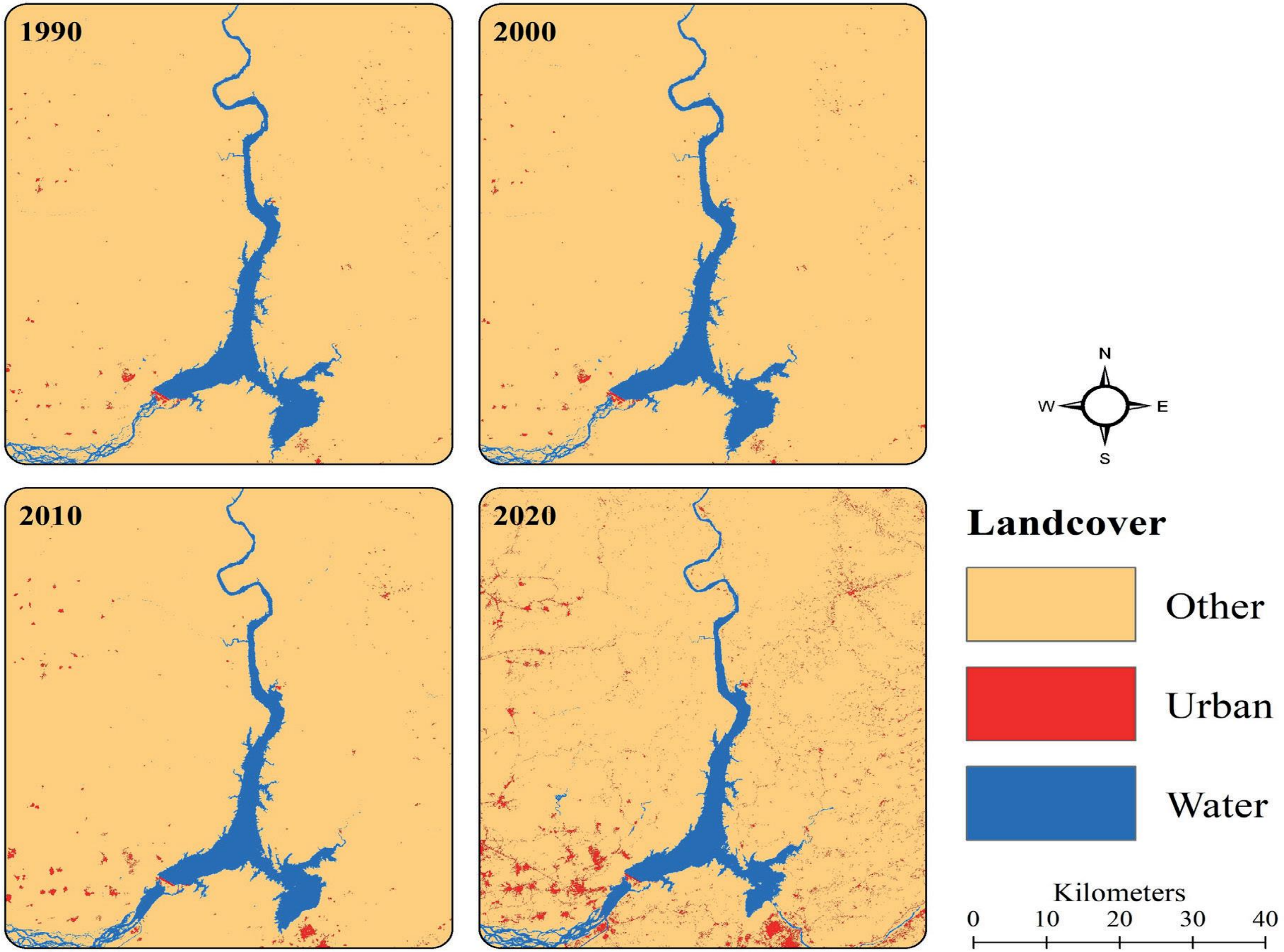


Table 6. World View Water Index (WVWI) characteristics of the study area

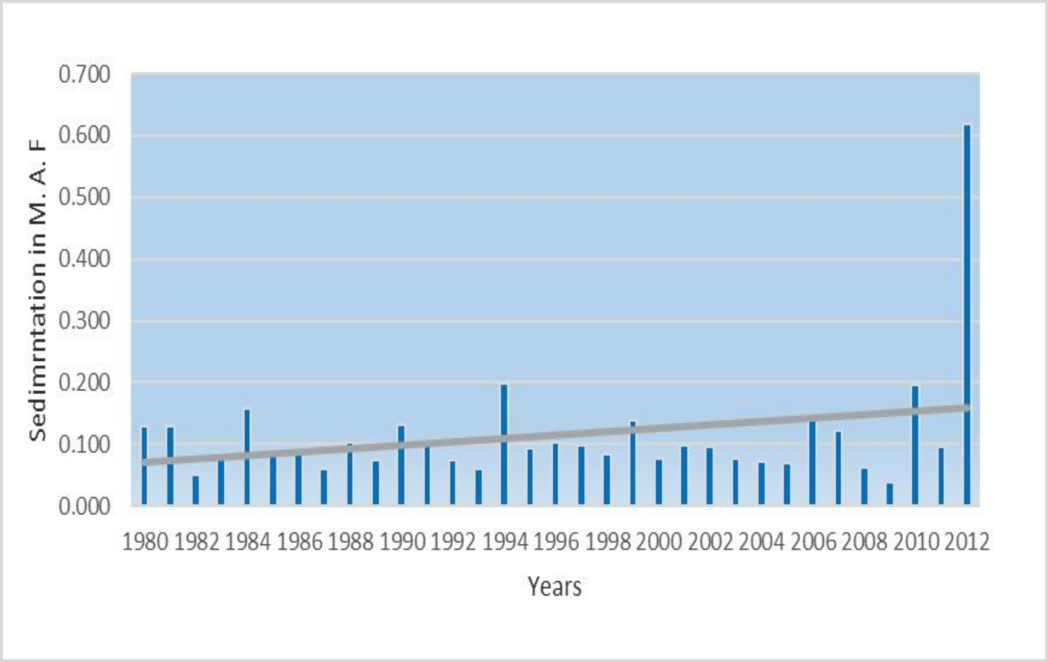
Classes	1990	2000	2010	2020
High	0.78	0.80	0.63	0.34
Medium	0.17	0.07	0.11	-0.21
Low	-0.11	-0.23	-0.13	-0.46
Mean	0.13	0.28	0.21	0.20



LAND COVER


1990
2000
2010
2020
N
W
E
S
Landcover
Other
Urban
Water
Kilometers
0
10
20
30
40

Tarbela Main Reservoir Sedimentation in MAF, 1980-2012, Hydrographic Survey



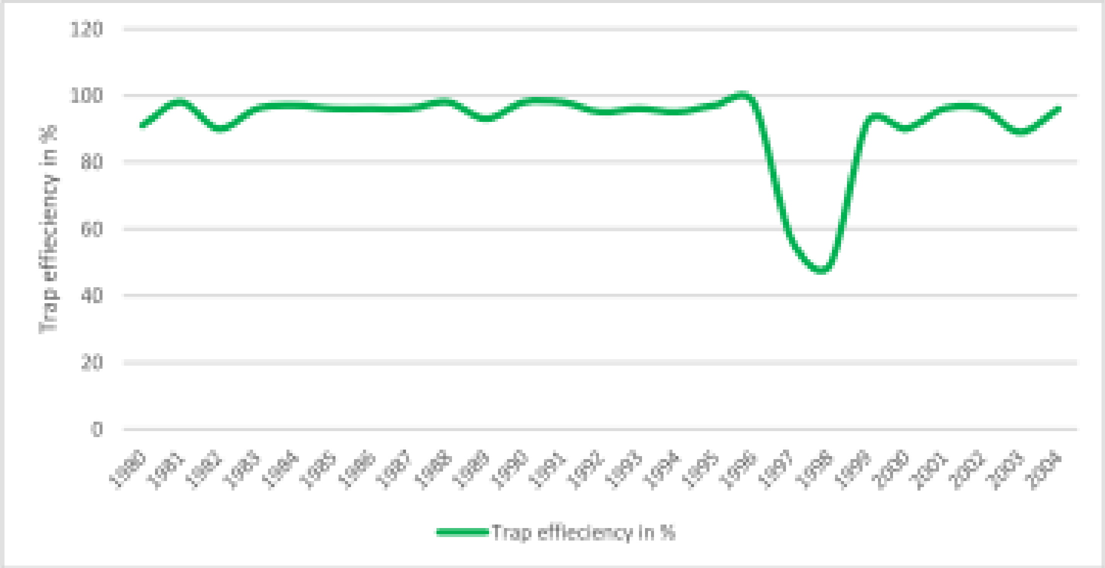


Fig. 3. Tarbela Reservoir Trap Efficiency, 1980-2004.

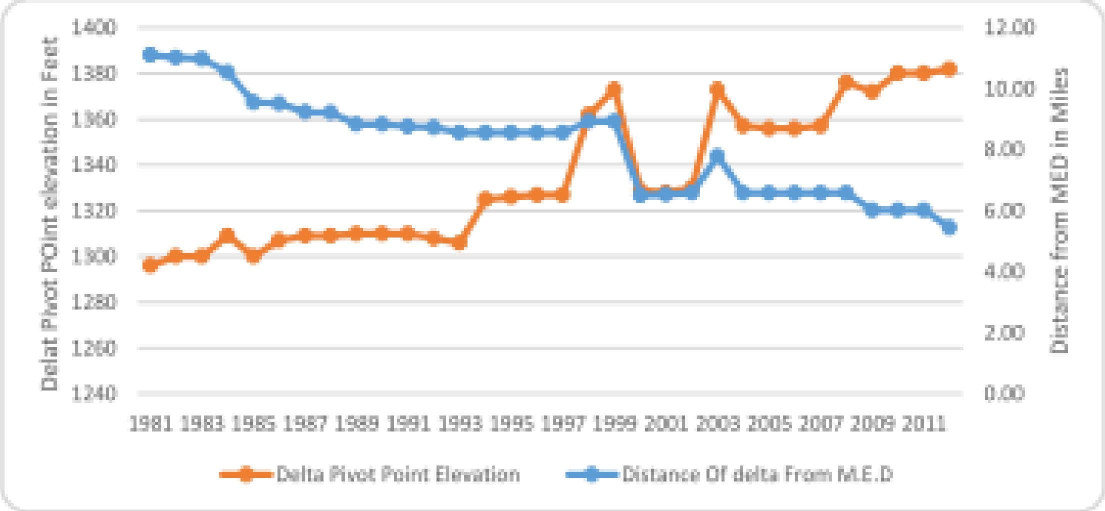
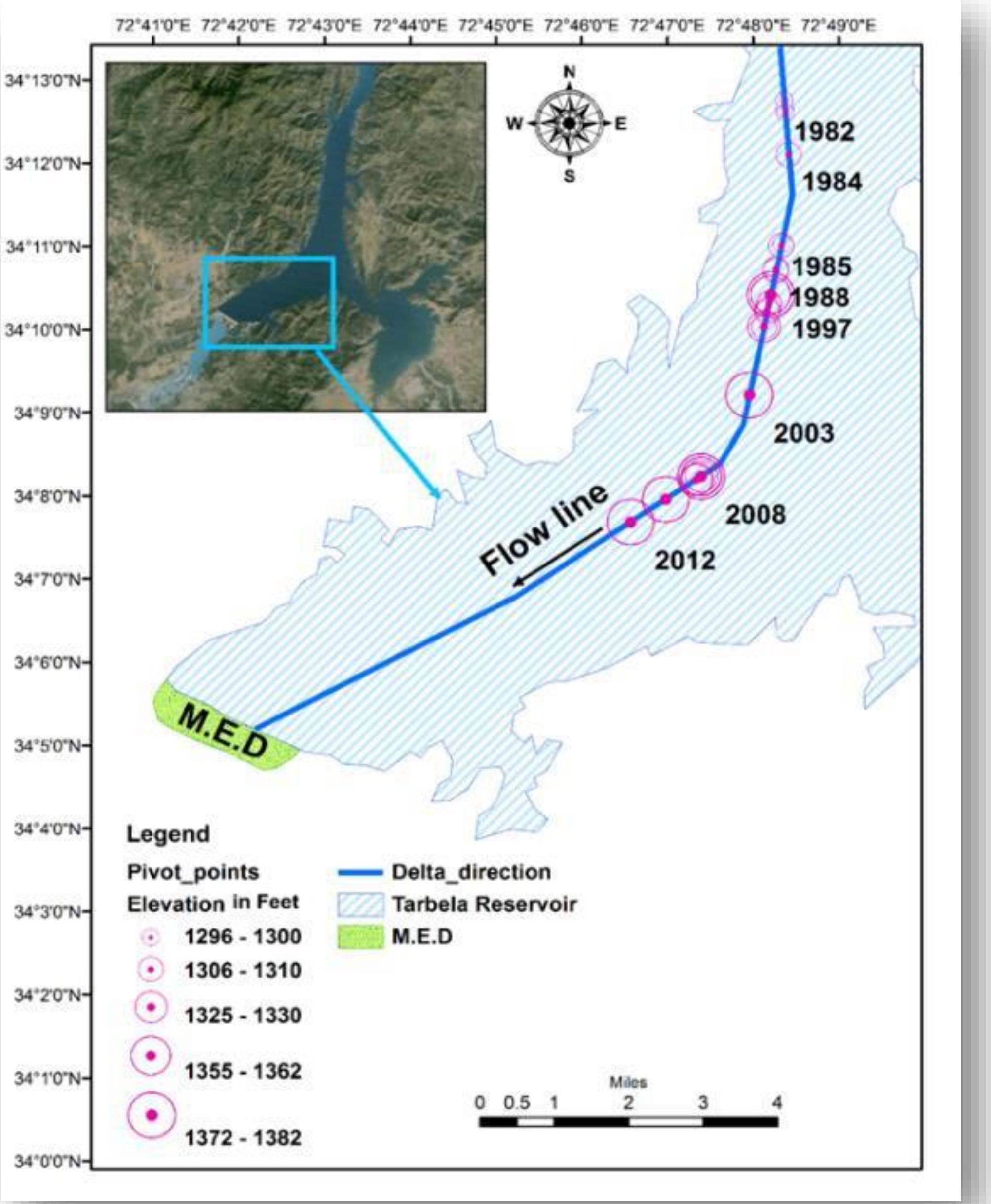
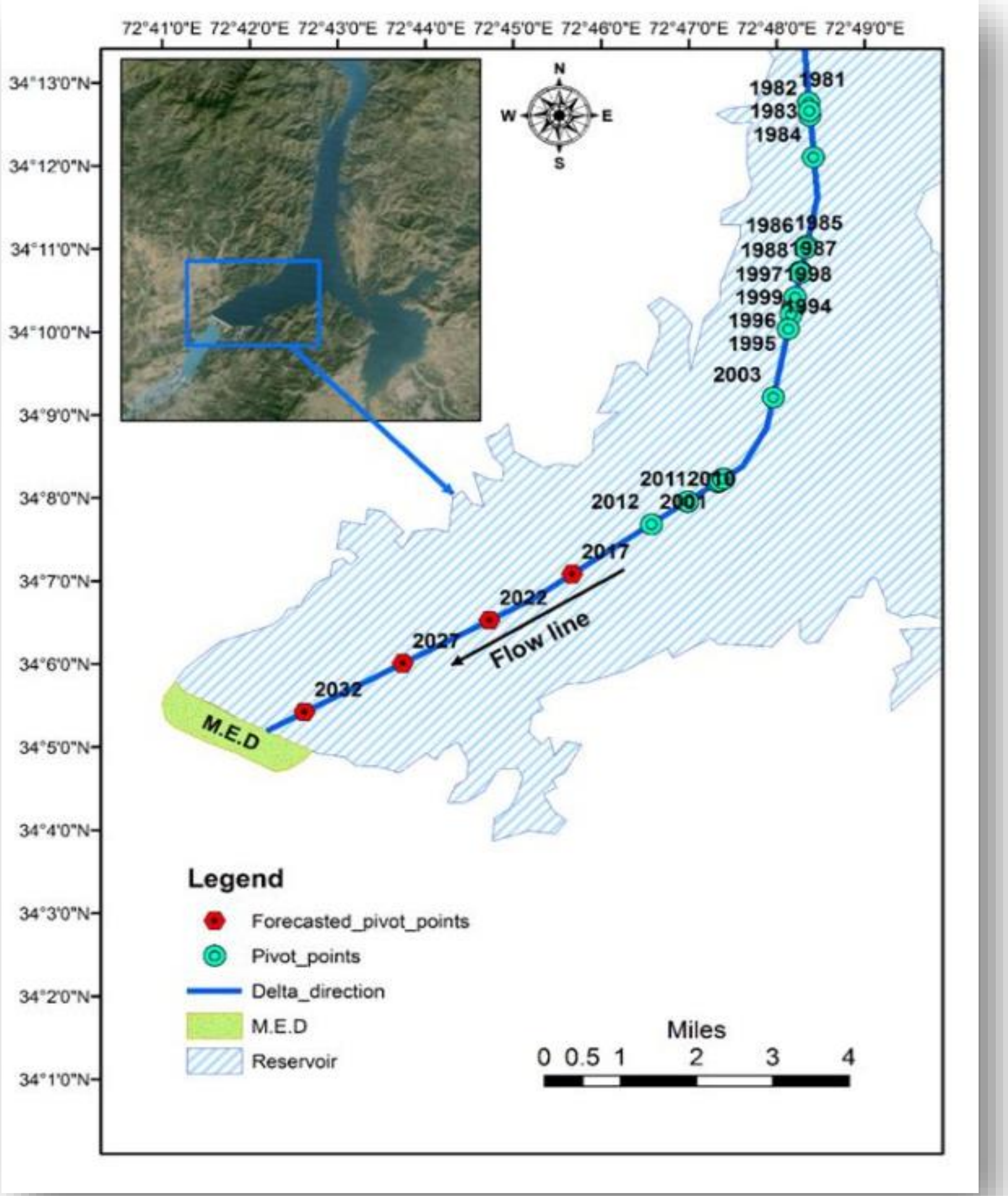


Fig. 4. Tarbela Reservoir Pivot Point Advancement, 1981-2012.

Delta Pivot Point Advancement towards M.E.D, 1981-2012.



Forecasted Delta Pivot Point Advancement till 2032



Main Findings

Significant increase in built-up area, of about 630 km^2 , in the western and eastern parts of the reservoir

Turbidity level, was high in 2000 but revealed a substantial decline with 4% decrease observed in the decade 2010-2020.

Expanse in the spatial coverage of chlorophyll index and water index, indicating increase in residence time of the water

Water quality continued to deteriorate with time, however, 2020 was a year of environmental healing

CONT. MAIN FINDINGS

The mean sedimentation coming in the reservoir from 1980 to 2012 was 0.100 MAF

The pivot point of the delta of Tarbela reservoir was at a distance of 11.11 miles away from MED in 1981

5.45 miles away from MED in 2012.

Its elevation has also varied a lot over the years, being 1296 ft. high in 1981 and 1382 ft. in 2012.

The average advancement of the pivot point for the 32 years was calculated to be 8.16 miles.

CONCLUSION

Further research with reservoir sample collections is recommended

The study's general findings compare water quality over decadal periods using satellite data.

Future research should focus on conducting month-wise comparisons for 2019 and 2020, analyzing variations in water quality.

Policymakers should consider formulating measures for sediment flushing and turbidity reduction on larger time scales.

Planning for sustainable urban dynamics near the Tarbela reservoir and upstream urban centers

RECOMMENDATIONS

Wallingford's (2011) study that concluded that at the current rate of sedimentation the Tarbela reservoir's dead and live storage capacity will largely be filled up by 2030.

Catastrophic impacts on the irrigation and energy sector of the country.

Practical mapping method to continuously monitor the advancement of the underwater pivot point of delta in the reservoirs

Immediate policy formulation for sediment management

Either active or passive methods e.g. dredging, hydro suction and flushing

A WAY FORWARD…

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

CAMPUS FRANCE

HIGHER EDUCATION COMMISSION

PHC- PERIDOT RESEARCH MOBILITY PROGRAM

PERIDOT is the Hubert Curien partnership set up between France and Pakistan. In France it is developed by the Ministries of Europe and Foreign Affairs (MEAE) and Higher Education, Research and Innovation (MESRI) and in Pakistan by the Higher Education Commission (HEC).

Thank You

DEPARTMENT OF GEOGRAPHY

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References

1: https://www.un.org
2: IPCC 6th report
3: WHO report
4:IRENA report
5: UN report
6: IEA report
7: EIA report
8: NREL report
9: Irena.org
10: www.un.org
11: South Asia | Geography, Countries, Map, & History | Britannica
12: https://study.com/learn/lesson/south-asia-geography-culture.html
13: Renewable Energy is the Future for Pakistan's Power System: A New World Bank Study
14: Pakistan | Climate Promise
15: Expanding Renewable Energy in Pakistan's Electricity Mix
16: Pakistan - Hydropower
17: Pakistan will add up to 10 GW of new hydropower capacity by 2030
18: Hydropower Potential in Pakistan – ResearchGate
19: Tarbela Dam - WAPDA
20: Tarbela Dam - ICOLD
21: Indus Basin Project - World Bank
22: Mangla Dam - WAPDA
23: Mangla Dam – ICOLD
24: https://www.britannica.com/topic/Mangla-Dam
25: https://www.wapda.gov.pk/project-details/63c56bde1a72c39284a3298b
26: https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-4/
27: Sea-level rise and sediment budget controlling the evolution of a transgressive barrier in south Brazil
28: Climate change impacts on sediment yield in the Mekong River basin: A case study of the Nam Ou basin, Lao PDR
29: Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin, Ethiopia
30: Water availability and response of Tarbela Reservoir under the changing climate in the Upper Indus Basin, Pakistan
31: Sedimentation in Tarbela Reservoir: A Case Study : [Analysis of Operational Changes of Tarbela Reservoir to Improve the Water Supply, Hydropower Generation, and Flood Control Objectives]
32: Tarar, R. N. (2006). Performance of tarbela dam project. Paper presented at the In Proceedings of Pakistan Engineering Congress, 69th Annual Session Proceedings Report; Punjab,Pakistan.
33: Mazhar, N., Mirza, A. I., Abbas, S., Akram, M. A. N., Ali, M., & Javid, K. (2021). Effects of climatic factors on the sedimentation trends of Tarbela Reservoir, Pakistan. SN Applied Sciences3, 1-9.
34: Roca, M. (2012). Tarbela Dam in Pakistan. Case study of reservoir sedimentation. Silvio, G., & Hotchkiss, R. (1995). Two Years Activity of ICCORES (International Coordinating Committee on Reservoir Sedimentation). Paper presented at the Sixth International Symposium on River Sedimentation.
35: Nayab, A., & Faisal, M. (2018). Water Management in Tarbela Dam By using Bayesian Stochastic Dynamic Programming in Extreme Inflow Season. Journal of Civil Environmental Engineering8(02).
36: Kontakiotis, G., Karakitsios, V., Cornée, J.-J., Moissette, P., Zarkogiannis, S. D., Pasadakis, N., . . . Antonarakou, A. (2020). Preliminary results based on geochemical sedimentary constraints on the hydrocarbon potential and depositional environment of a Messinian subsalt mixed siliciclastic-carbonate succession onshore Crete (Plouti section, eastern Mediterranean). Mediterranean Geoscience Reviews2, 247-265

37: Durrani, A. A., Khan, I. A., & Ahmad, M. I. (2021). Analysis of Electric Power Generation Growth in Pakistan: Falling into the Vicious Cycle of Coal. Eng, 2(3), 296-311.
38. Majeed, Z., UL–HASAN, Z., & Piracha, A. (2008). Developing hydropower schemes on existing irrigation network: A case study of upper Chenab Canal System. In the International River basin Management Congress book (No. 70, p. 884).