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XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1-5 December 2025

Kingdom of Morocco



Ministry of
Equipment and Water

Enhancing Water Security: Methodological Framework for Upscaling Managed Aquifer Recharge in Arid Regions

Muhammad Arshad et al. 2025
International Water Management Institute
Presentation date



Food and Agriculture
Organization of the
United Nations





Study Background

- In response to Groundwater Depletion and Water Scarcity Issues, the Government of Balochistan, with the support of the European Union (EU), Food and Agriculture Organization (FAO) and IWMI, is implementing the Revival of Balochistan Water Resources Programme (RBWRP).
- To address groundwater depletion through a series of initiatives focused on sustainable water management and aquifer recharge



What Is Managed Aquifer Recharge

MAR the Intentional infiltration and storage of water into aquifers for subsequent recovery or environmental benefit (Dillon et al., 2009).

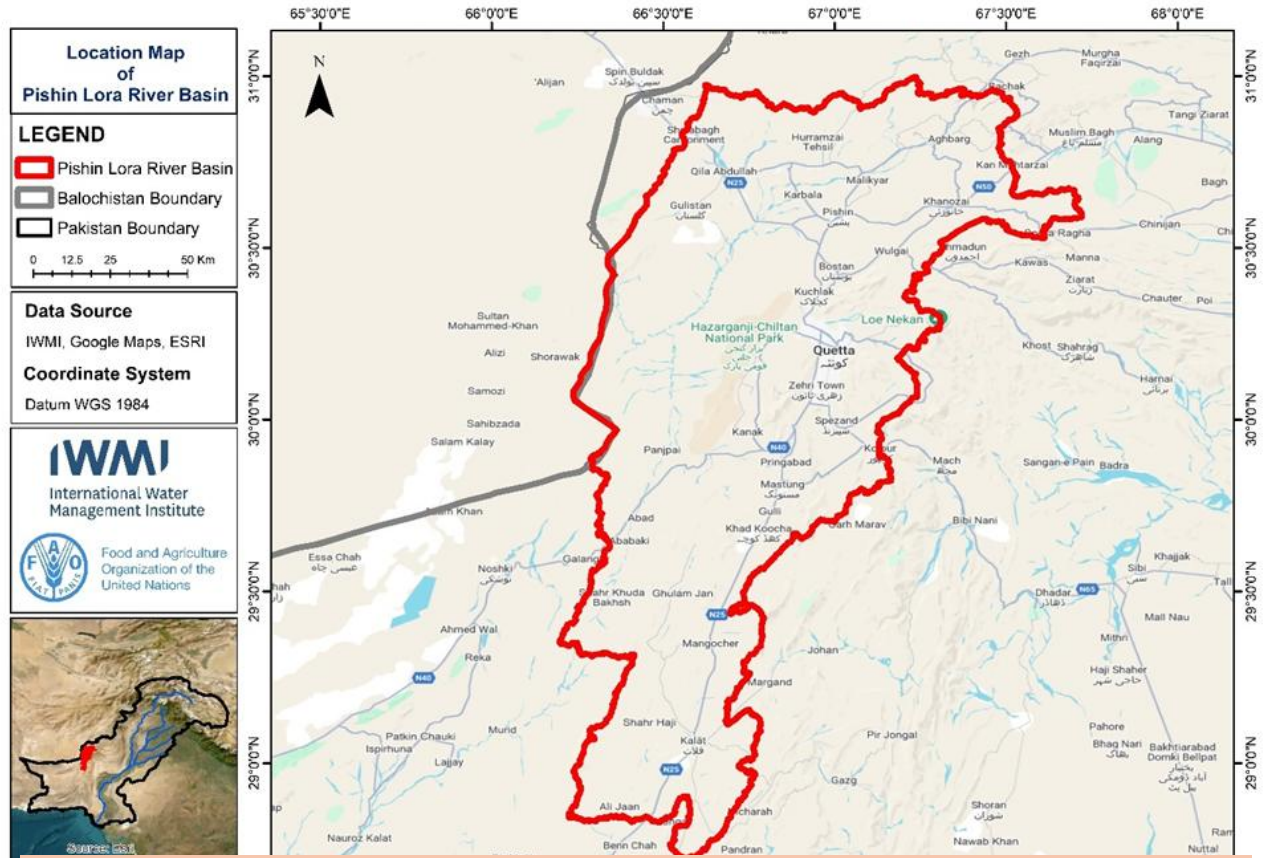
A variety of methods exists to execute MAR depending upon its suitability and usefulness to a set of conditions



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Basin Characteristics- Pishin Lora And Nari River Basin



Hydrology: Covers ~16, 796 km² with 11 sub-basins; drained by the ephemeral **Pishin River** (~400 km)

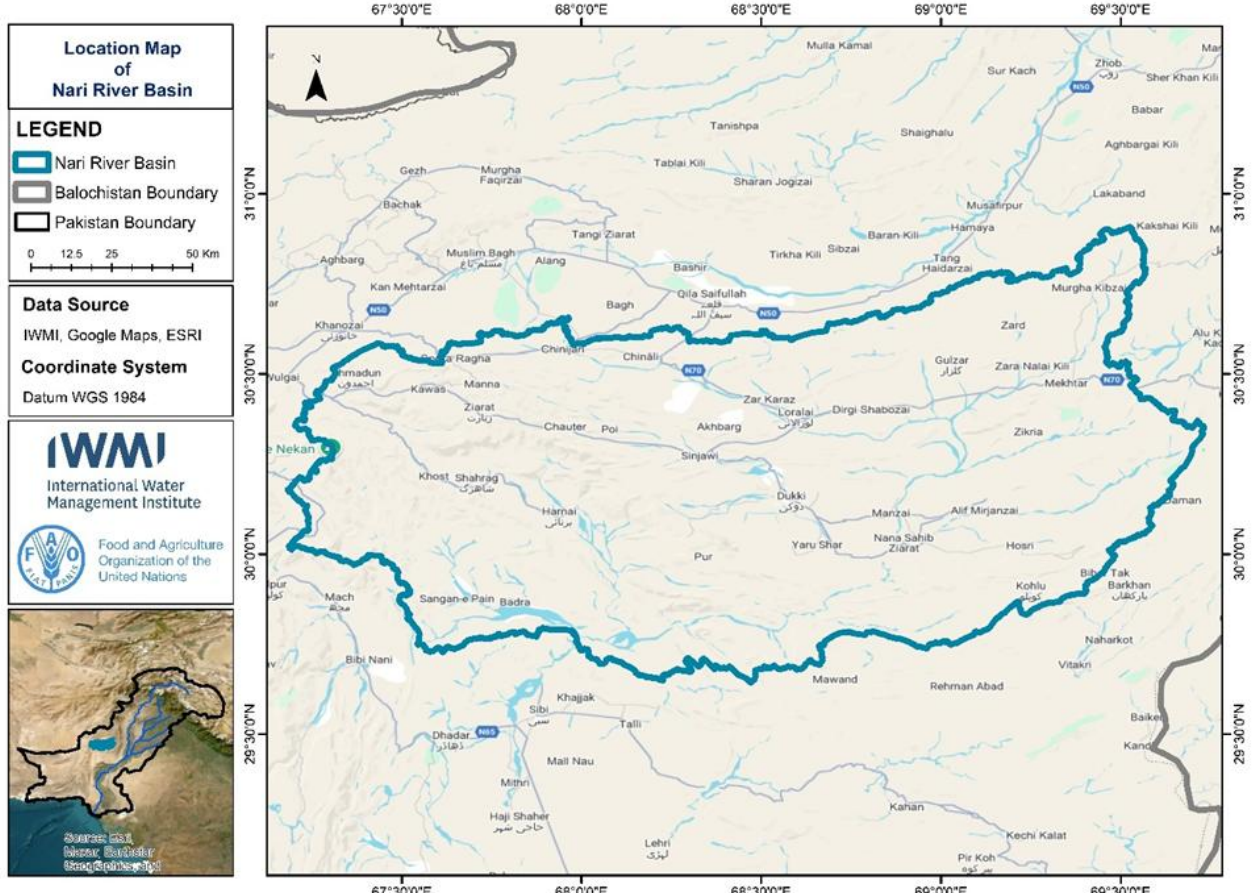
Climate: Arid to semi-arid with ~250 mm average annual rainfall (50–400 mm range); temperatures span –3.4°C to 36.2°C, while evaporation exceeds 2,000 mm annually.

Hydrogeology: Hosts two aquifer systems—high-yield alluvial aquifers (silty sand, gravel, boulders) supplying ~90% of abstraction, and underutilized fractured bedrock aquifers—with piedmont zones serving as key recharge areas.

Hydrology: Spanning ~21,367km², the Nari River (>400 km) sustains perennial flows in certain reaches.

Climate: Arid to semi-arid, with mean annual precipitation of 200–390 mm; northwestern highlands receive winter snowfall, while southern lowlands depend on sporadic monsoons; evaporation exceeds 2,000 mm annually.

Hydrogeology: Comprised of unconsolidated alluvial plains along the river, transitioning into fractured and weathered bedrock aquifers in uplands.





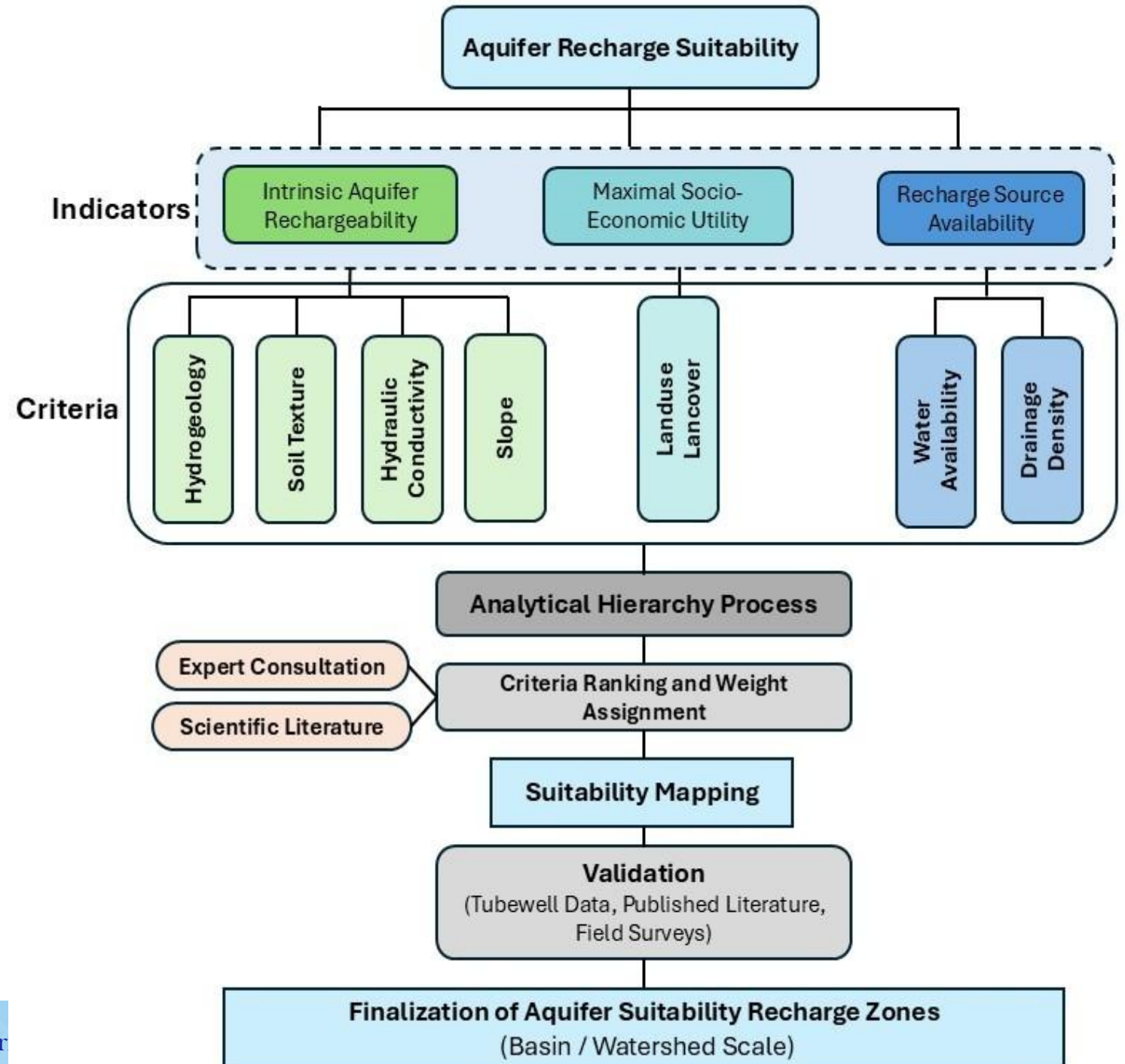
Selection of Datasets

	Dataset Name	Scale/ Resolution	Units	Source
1	Hydrogeology	1:253,440	-----	Geological Survey of Pakistan (Used geological sheets)
2	Water Availability	30 m	meters	IWMI – Google Earth Engine (Estimated by IWMI using various parameters)
3	Soil saturated hydraulic conductivity (Ksat)	250 m	cm/d (centimeters per day)	HiHydroSoil v2.0 (https://www.futurewater.eu/projects/hihydrosoil/)
4	Landuse / Landcover	10 m	-----	Sentinel-2 Imagery – processed by IWMI (https://dataspace.copernicus.eu/analyse/apis/sentinel-hub)
5	Slope	30 m	meters	SRTM DEM (https://earthexplorer.usgs.gov/)
6	Drainage Density	30 m	km/km ²	SRTM DEM (https://earthexplorer.usgs.gov/)
7	Soil Texture	1 km	-----	FAO HWSD v2.0 (https://gaez.fao.org/pages/hwsd)

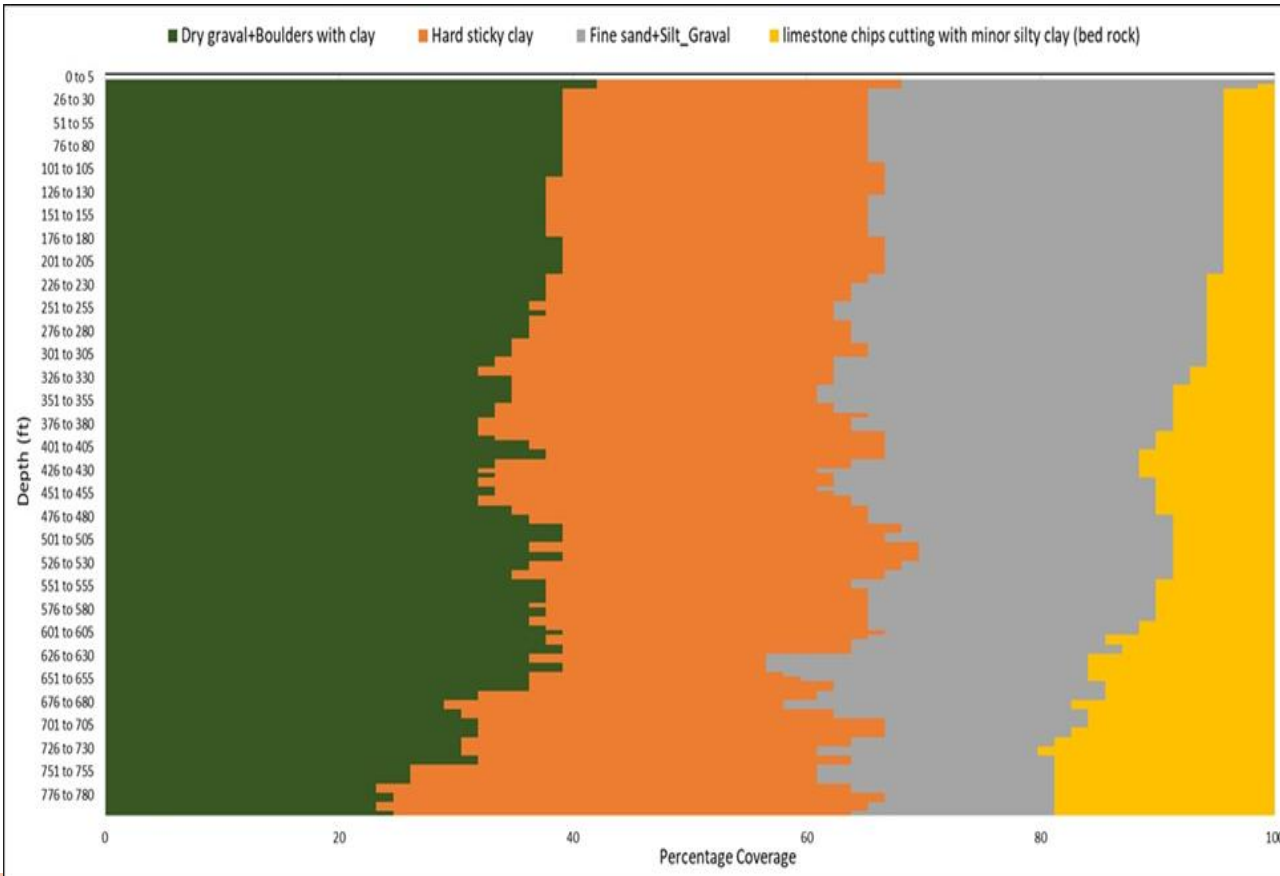


Methodology

Aquifer Recharge Suitability Mapping



Selection of Hydrogeological Dataset



Lithological analysis of 69 boreholes in the Quetta Valley, shows that the upper layers are dominantly composed of gravel and boulders mixed with clay, forming a dry surface layer covering approximately 40% of the area, which decreases with depth to about 22% at 780 ft (238 m). Hard sticky clay (25%) constitutes the second major class, followed by fine sand, silt, and gravel deposits (30%), while bedrock accounts for about 5% of the shallowest layers.

For accuracy assurance, the 69 borehole logs from the Quetta Valley were systematically compared with the Geological Survey of Pakistan (GSP) geological sheets.

The presence of tubewells from which bore-logs were derived, and the close alignment between **borehole lithologies** and **GSP** map-based geological classes, confirm the reliability of the borehole data for hydrogeological parameterization.

LEGEND

- Borehole Locations
- Stream Network
- ▭ Pishin Lora River Basin
- ▭ Balochistan Boundary
- ▭ Pakistan Boundary

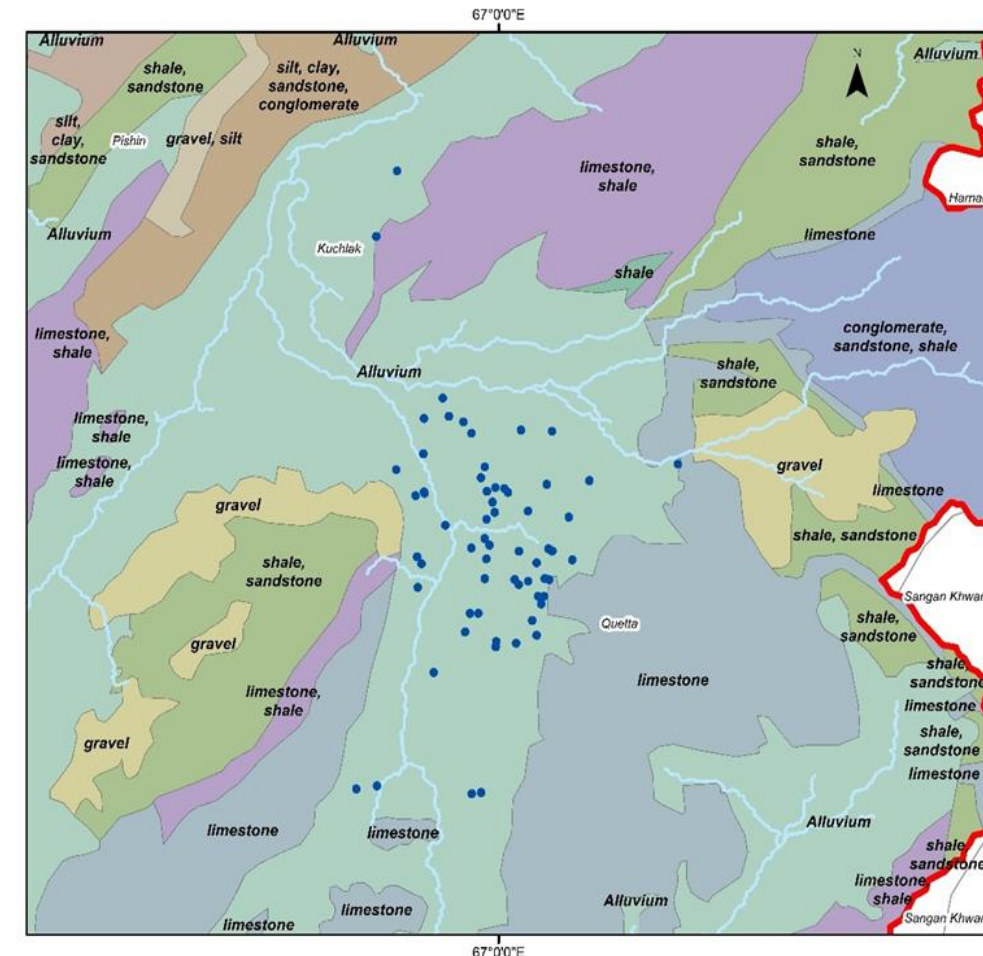
0 2.25 4.5 9 Km

Data Source
 BID, IWMI, USGS, ESRI

Coordinate System
 Datum WGS 1984

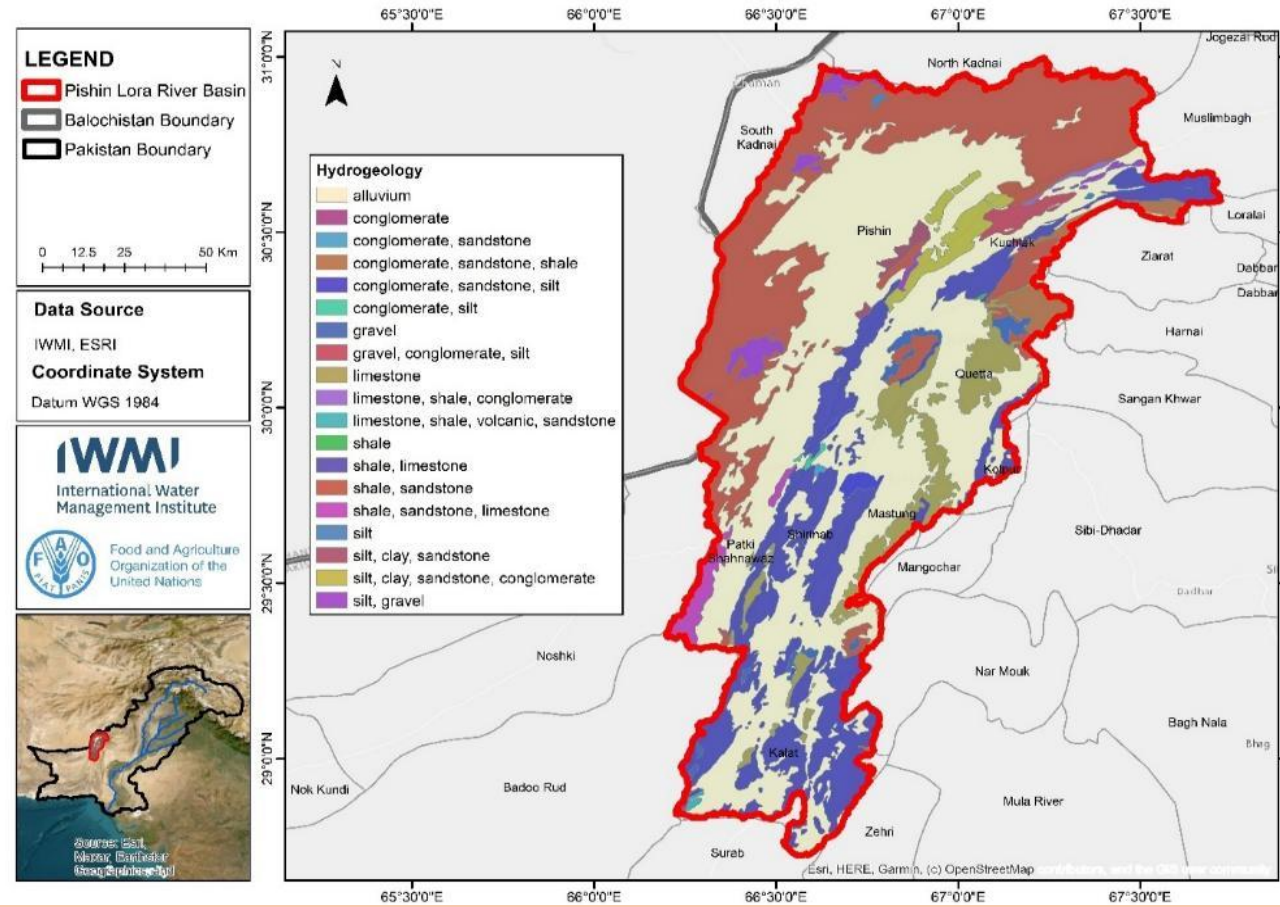
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FAO
 Food and Agriculture Organization of the United Nations



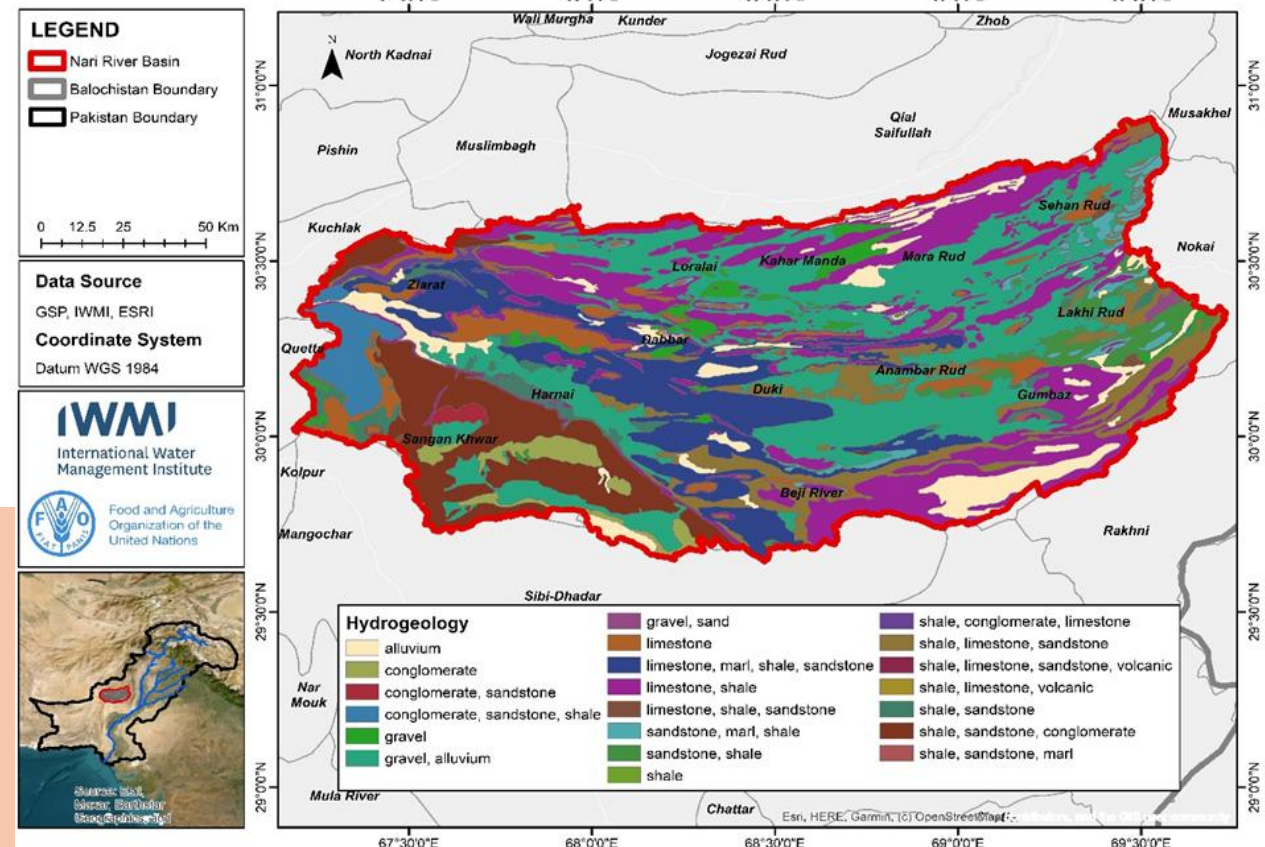
Hydrogeology

Nari River Basin (NRB) is primarily characterized by gravel and alluvium (31%), limestone with shale (21%), and limestone/sandstone with shale (12%). The remaining area consists of several other lithological classes, each contributing less than 10% of the total basin coverage, making the NRB a more complex setting in terms of hydrogeology.



The Pishin Lora Basin (PLB) is predominantly composed of alluvium (>43%), followed by sandstone with shale (24%) and limestone with shale (17%).

Most valley areas are covered with alluvium, enhancing their suitability for aquifer recharge.

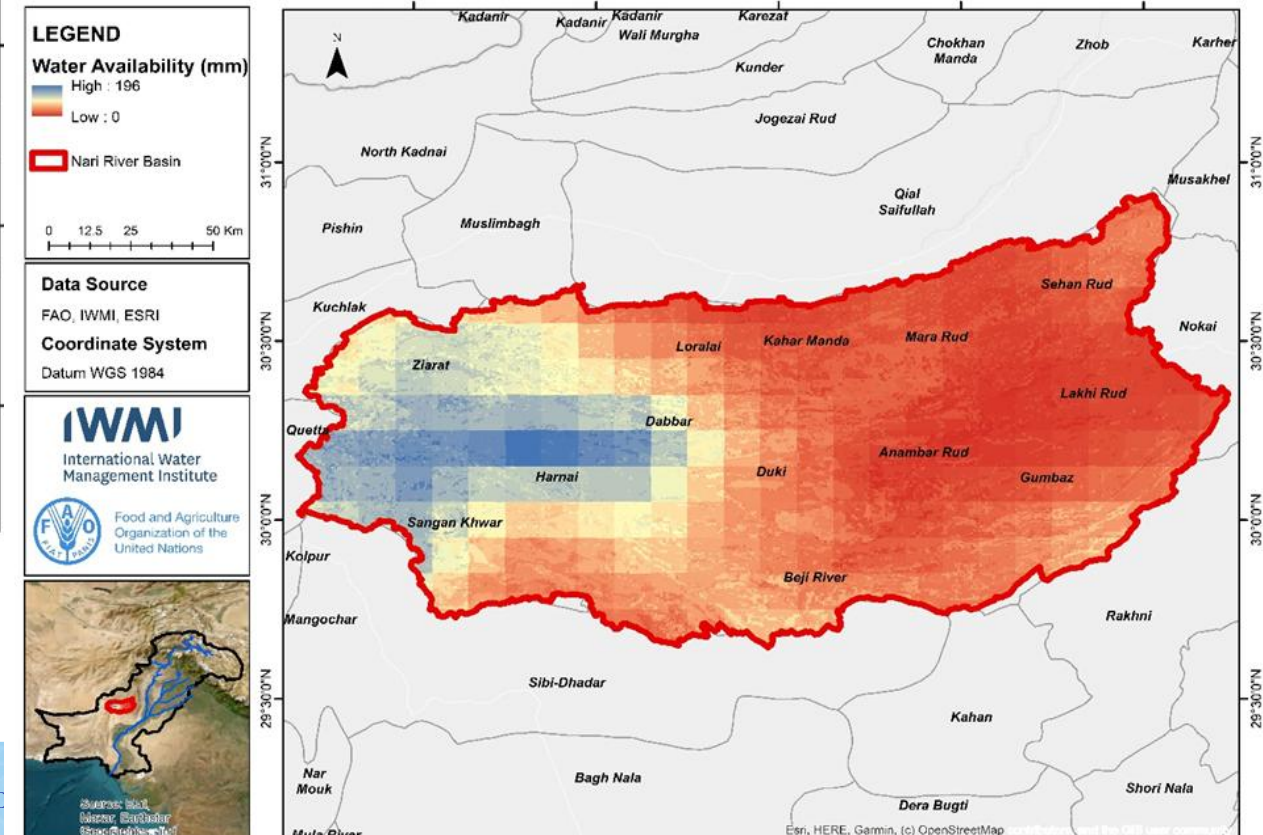
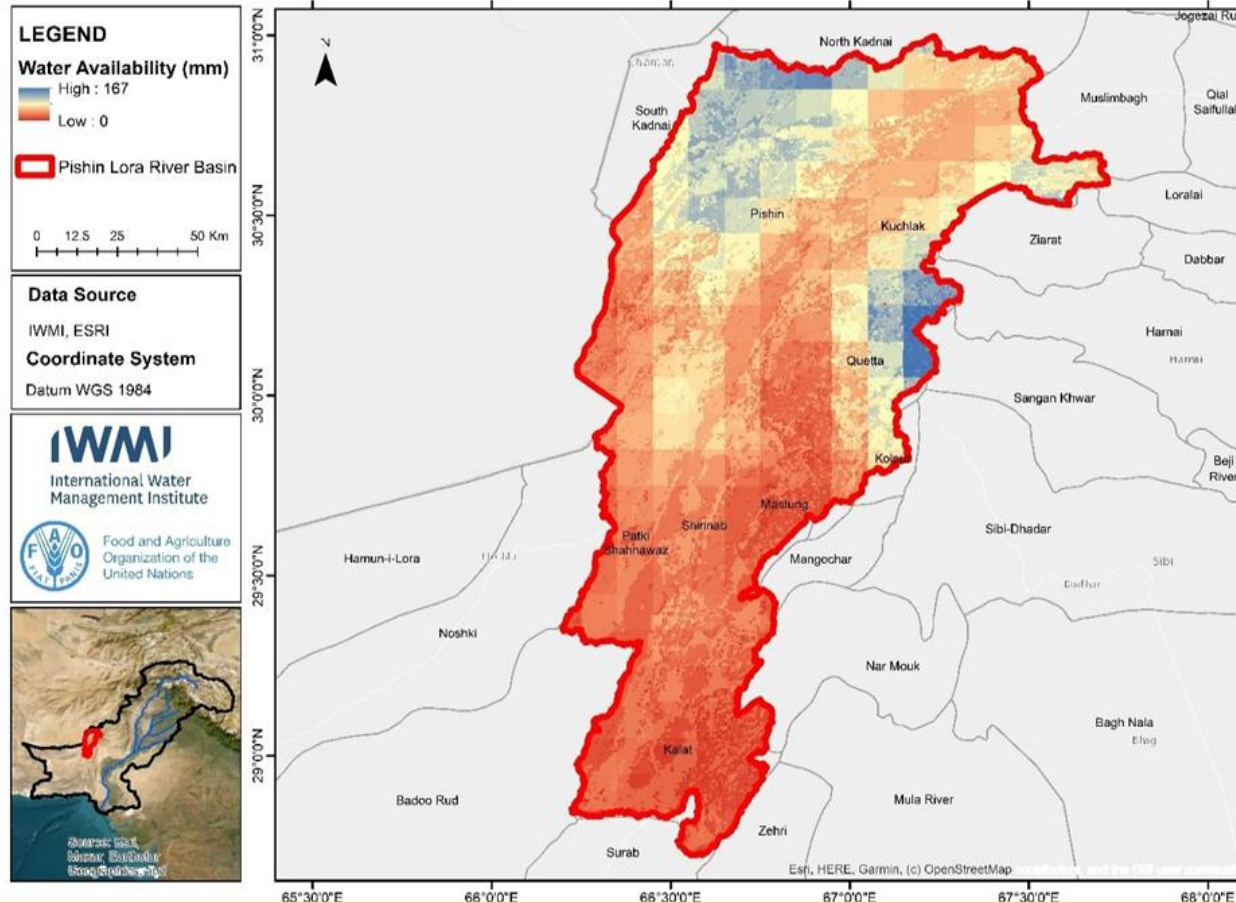


Water Availability



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The Nari River Basin records maximum water availability of up to 196 mm
The dominant water availability range is 40–118 mm covering 7,772.11 km² (50.8%) of the Nari River Basin.

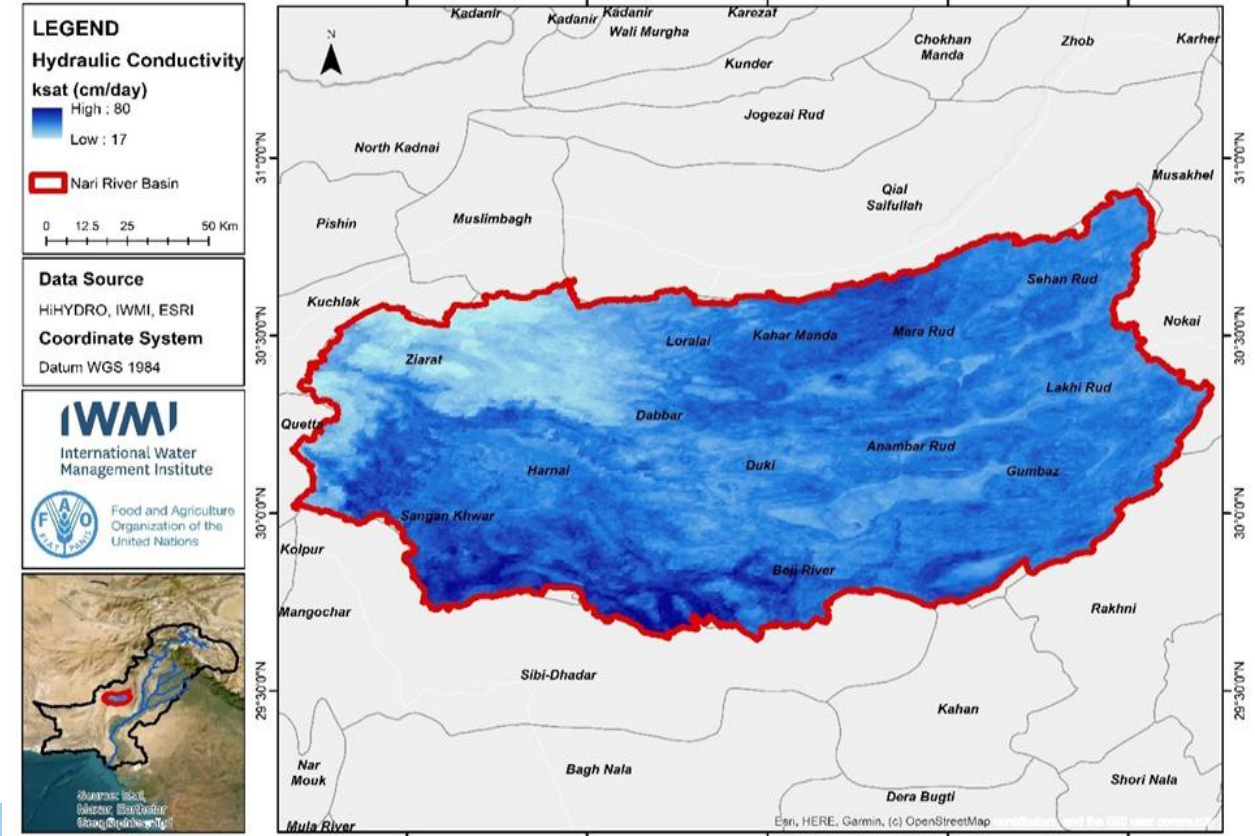
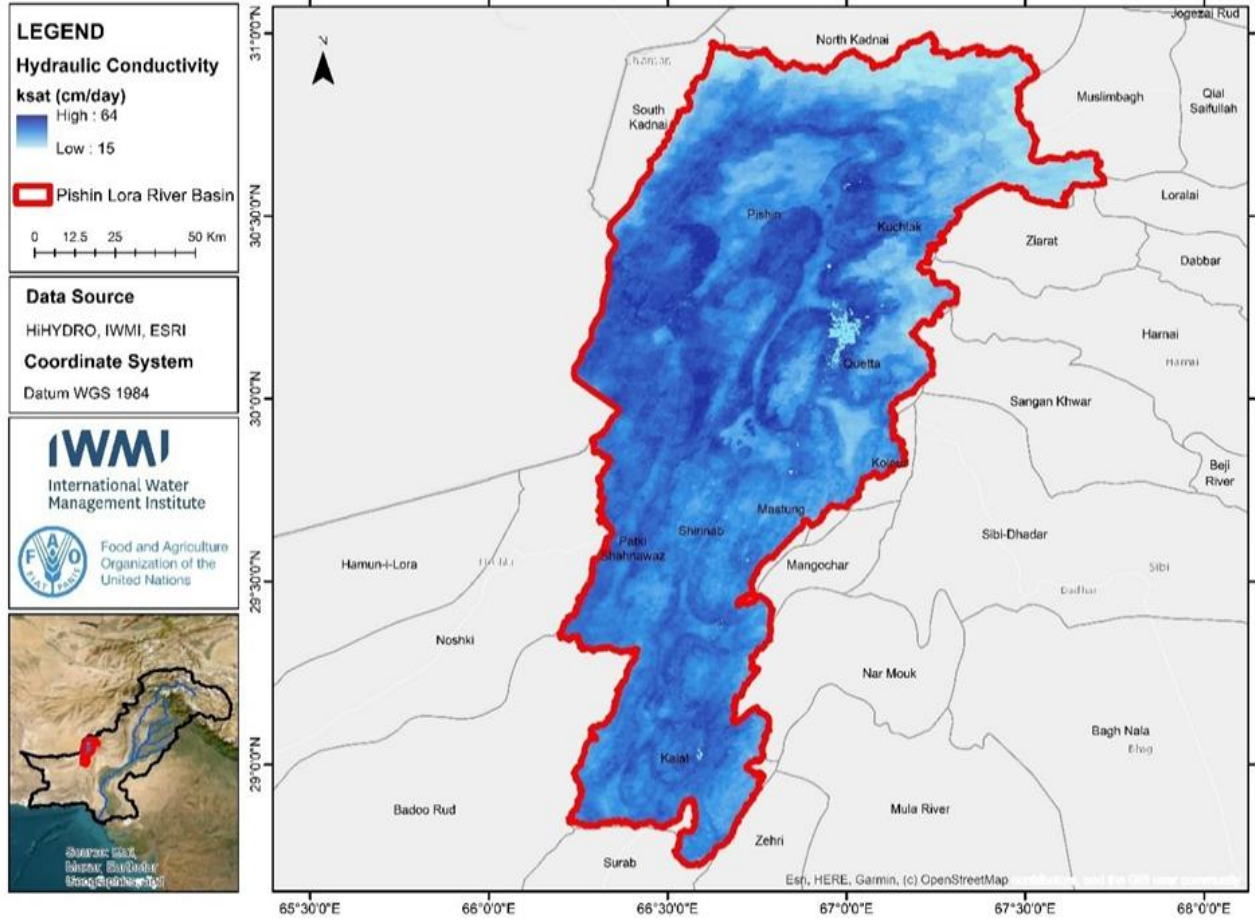


In the Pishin Lora Basin, maximum water availability reaches up to 166.7 mm.
Nearly half of the basin area (49%) is concentrated in the 34–67 mm and 39% of the basin area falls in the 67–100 mm range.

Soil Hydraulic Conductivity



In the Nari River Basin, k_{sat} values range from 17 cm/day to 80 cm/day. Nearly 41% of the basin area lies above the 43 cm/day k_{sat} value.

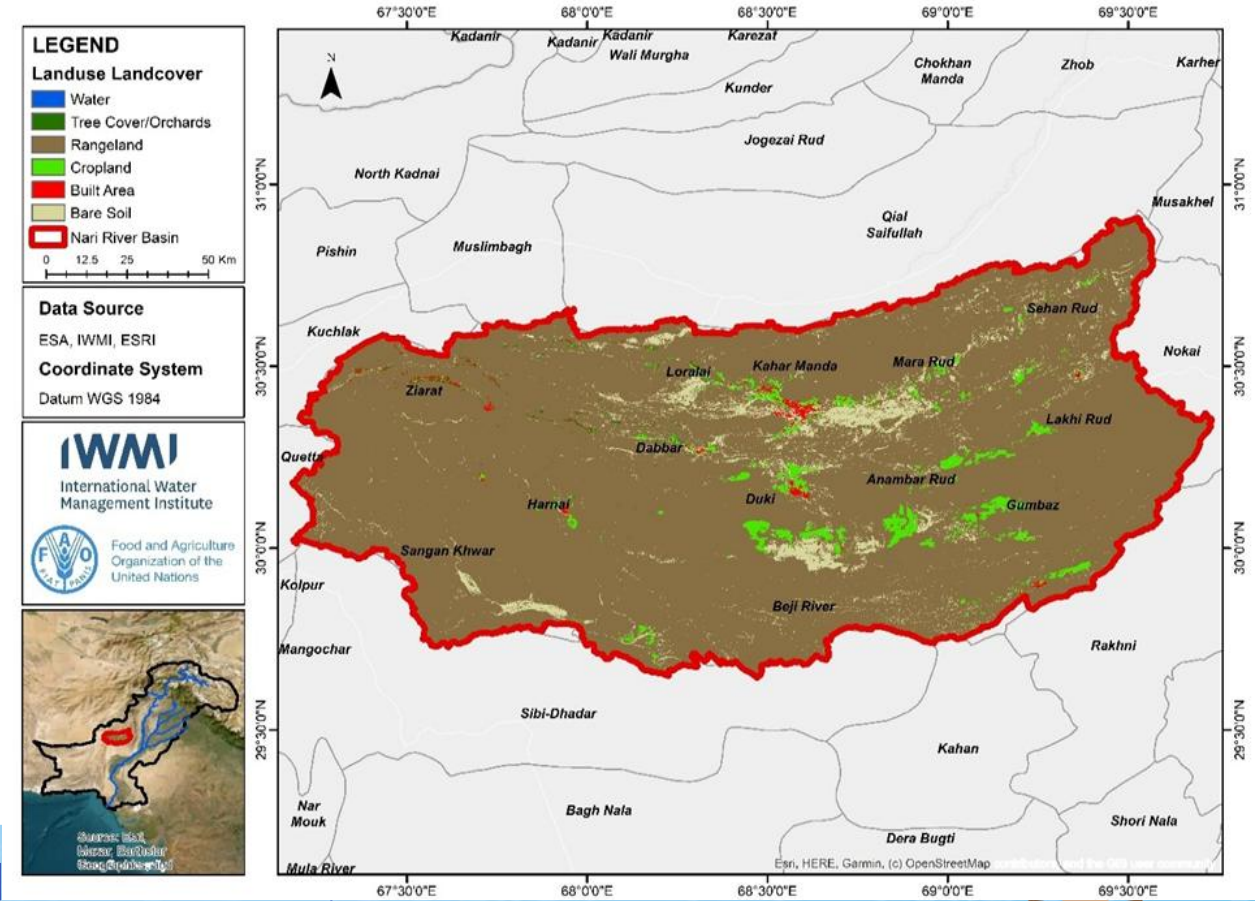
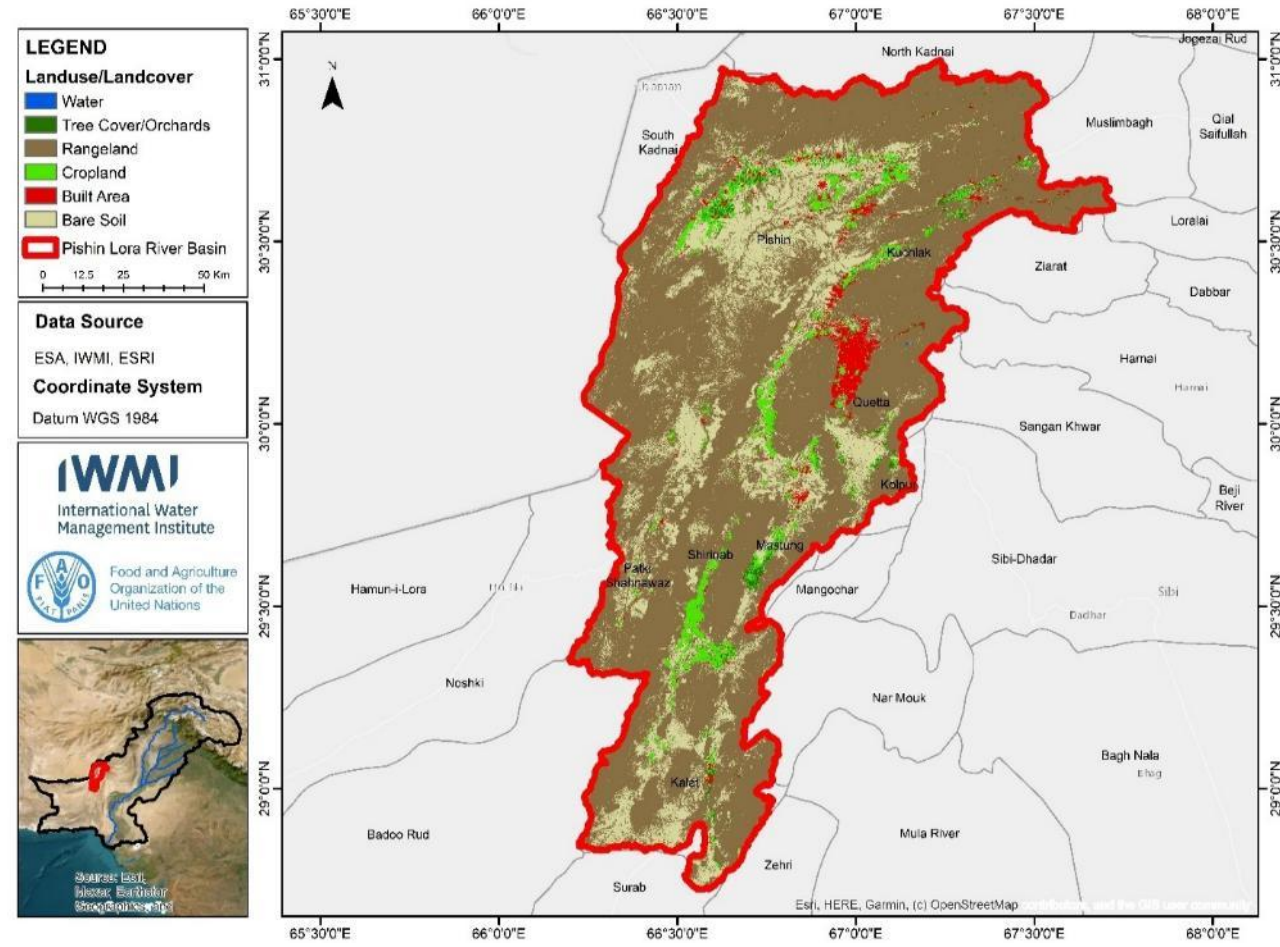


The Pishin Lora River Basin exhibits a range of 15 cm/day to 64 cm/day. Approximately 29% of the basin area lies above 43 cm/day k_{sat} value.

Land use Landcover



92% of the Nari River Basin Nari River Basin constitutes of Rangelands. Cropland/Orchards and built-up areas account for only 2.7% and 0.4% of the basin area, respectively.

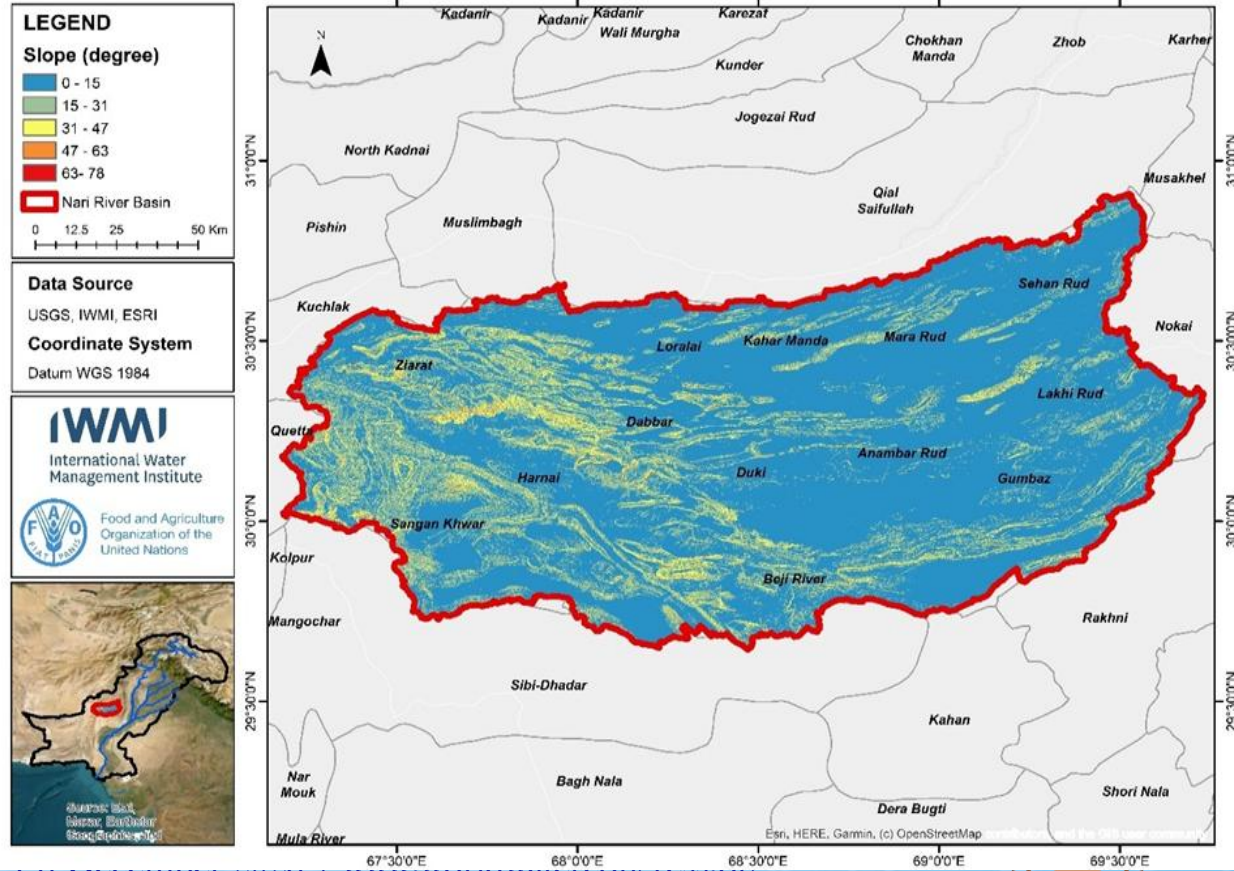
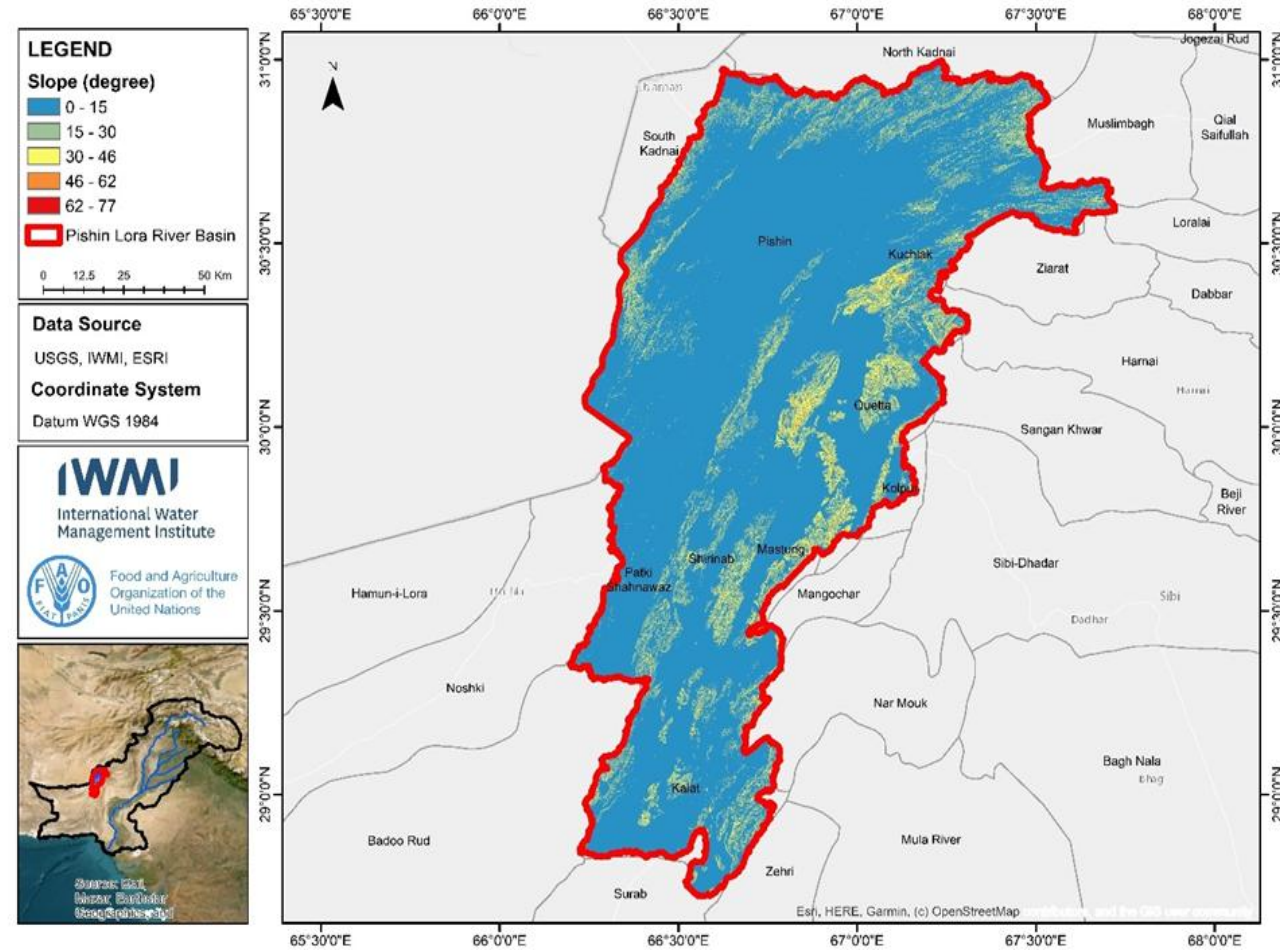


Rangeland is the dominant class, covering 73% of the Pishin Lora River Basin. Cropland and orchards account for 4.9%, while built-up area covers 2.0% of the river basin.

Slope



In Nari River Basin, approximately 50% of the landscape features slopes below 8°. Conversely, steep slopes greater than 45° are limited, occupying less than 6% of the basin area.

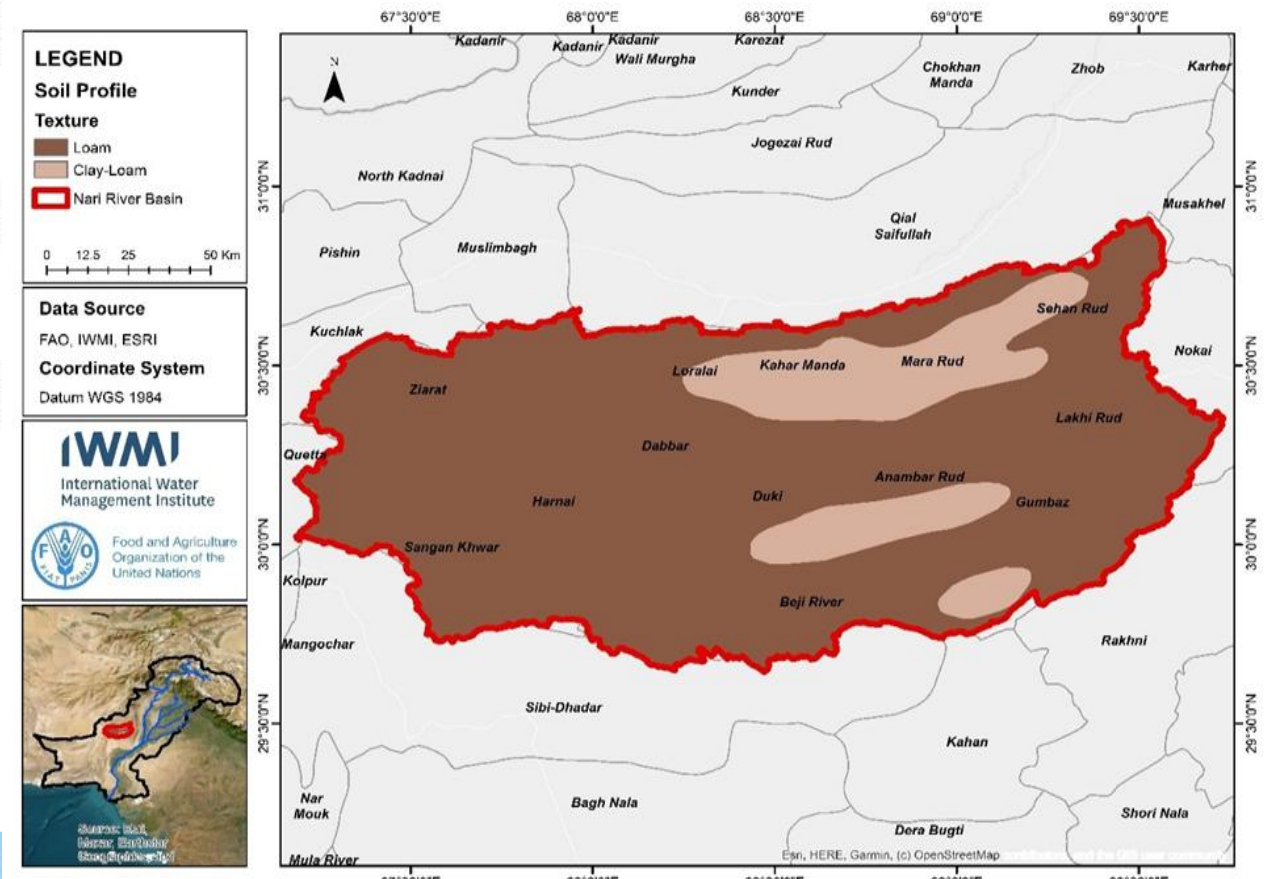
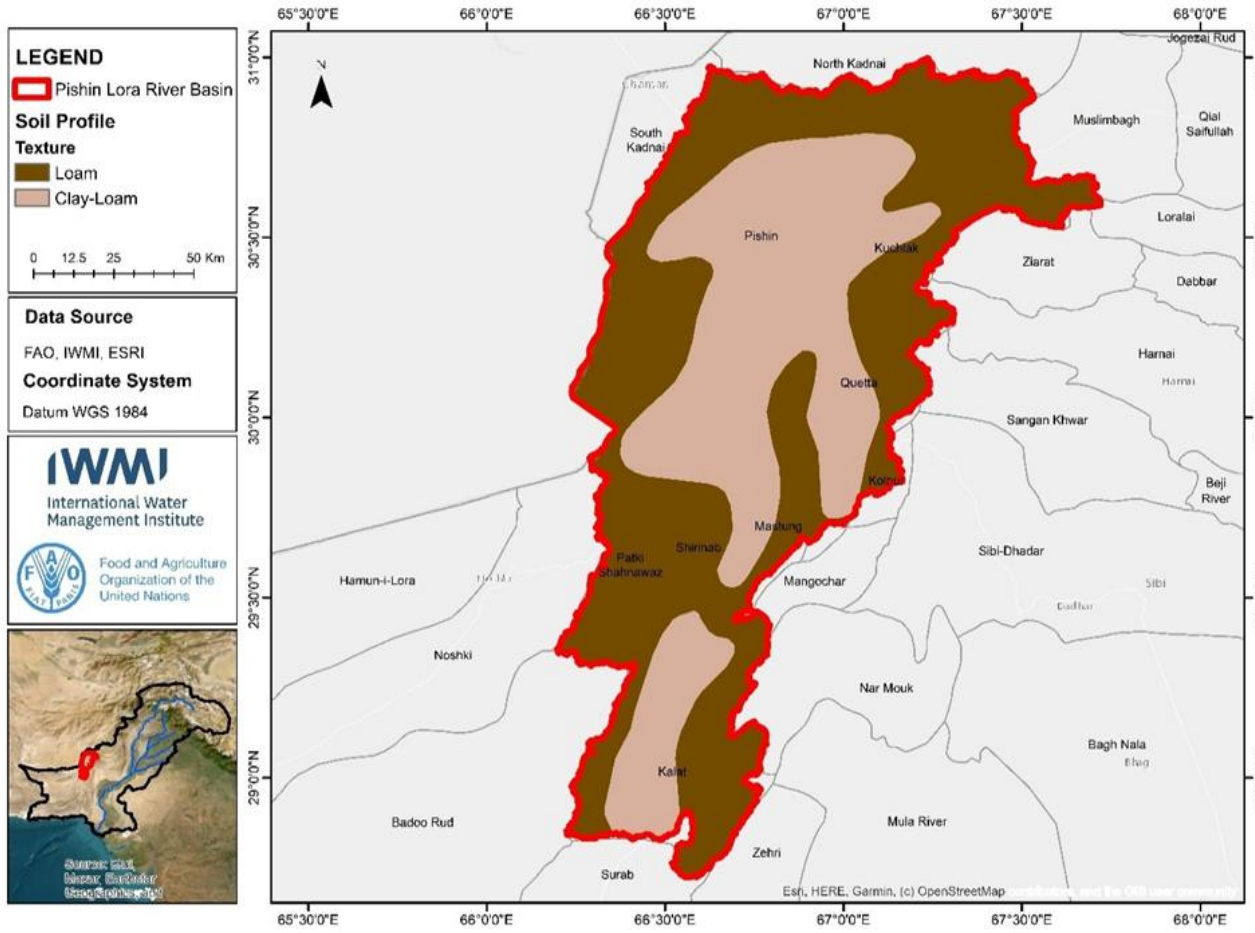


Pishin Lora River Basin exhibits considerable terrain variability, with slopes ranging from 0° (flat plains) to 77° (steep escarpments). A dominant portion of the basin (64%) consists of gentle terrain, including slopes of 0–5° (flat to very gentle) and 5–15° (moderately gentle).

Soil Texture



In the Nari River Basin, loam is also the principal soil class, occupying 84.8% of the area, with limited clay loam pockets found in the central-northern zones and southern reaches of the basin.



Loamy soils dominate the Pishin Lora River Basin, covering 9,861.18 km (58.7% of the basin area), occurring primarily along the basin boundaries. Clay loam soils, accounting for 6,935.56 km², are concentrated in the central regions.

AHP GIS-BASED Multicriteria Analysis



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I. AHP FOR DETERMINATION OF CRITERIA WEIGHTS

II. CRITERION RANKING

III. WEIGHTED OVERLAY ANALYSIS

Aquifer Recharge Suitability Score (z) = w_{lulc} *LULC + w_{slope} *Slope + w_{st} *Soil Texture + w_{wa} *Water Availability + w_{hg} *Hydrogeology + w_{dd} *Drainage Density + w_{hc} *Soil Hydraulic Conductivity

IV. SUITABILITY CLASSIFICATION

V. SUITABILITY MAPS GENERATION





AHP-based Criteria Weights

Criteria	Weight (%)
Hydrogeology	25
Water Availability	20
Soil Hydraulic Conductivity	17
LULC	15
Slope	10
Drainage Density	8
Soil Texture	5



RESULTS

NARI RIVER BASIN

Suitability Value	Suitability Class	NRB	
		Area (km ²)	Percentage
1	Very Low	57.51	0.27
2	Low	4323.07	20.23
3	Medium	9510.35	44.50
4	High	6952.79	32.54
5	Very High	524.02	2.45
Total Area		21367.75	100

In NRB, around 77.04% of the area falls under the medium-to-high suitability categories. These zones are largely associated with comparatively flat terrain, permeable lithologies, favorable land use/land cover types (cropland, orchards, and rangelands), and high infiltration capacity.

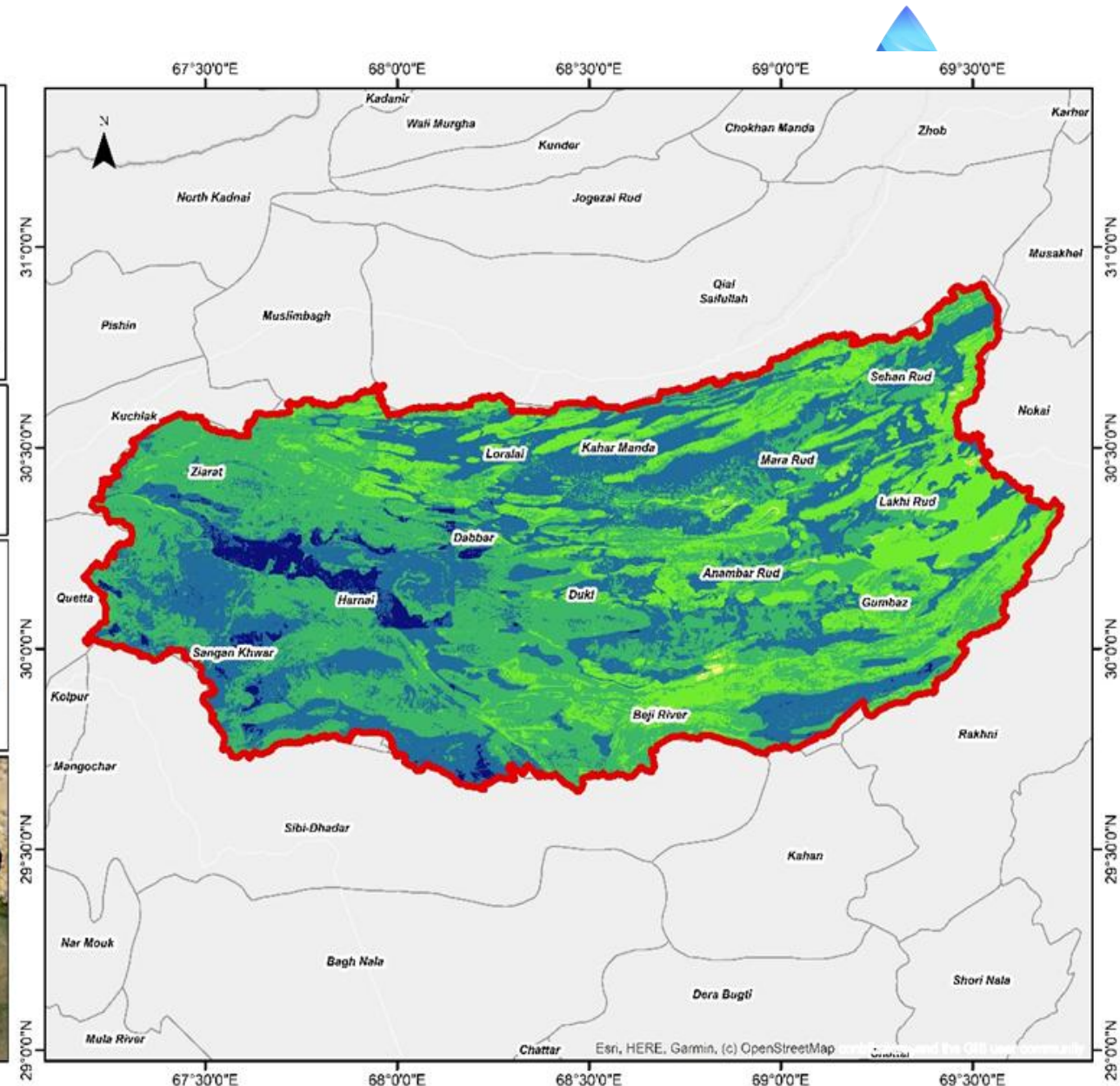


Data Source

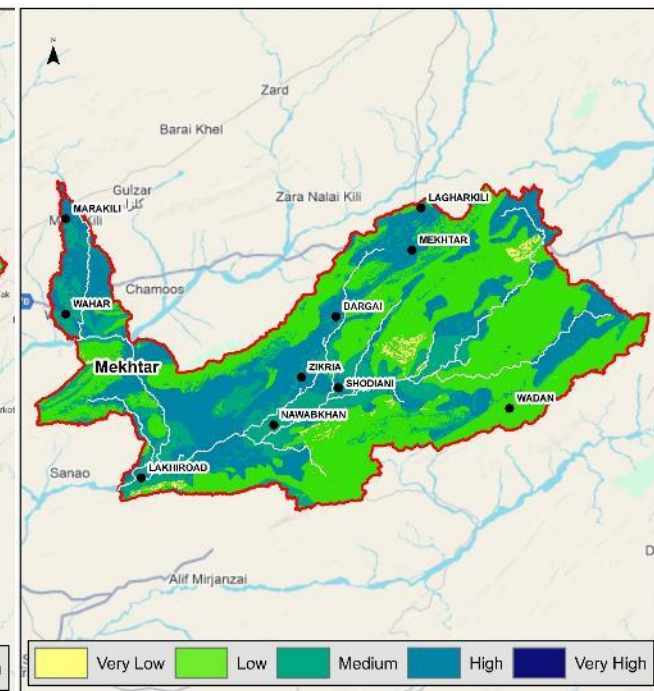
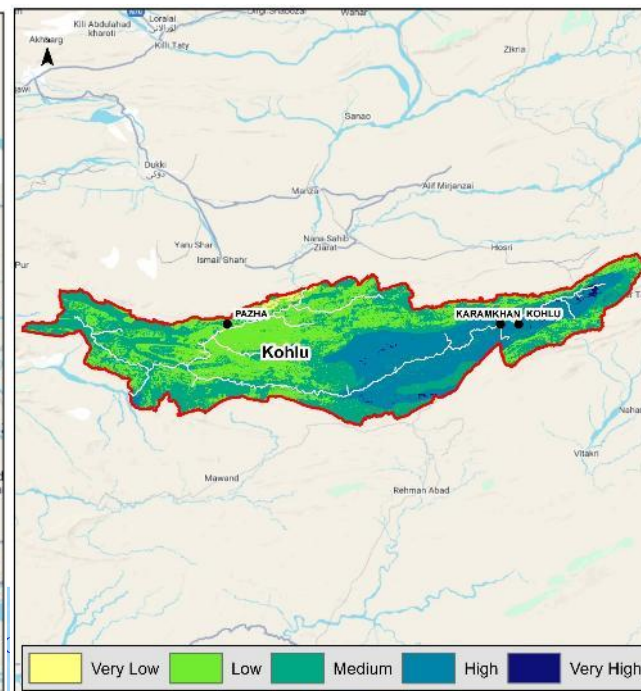
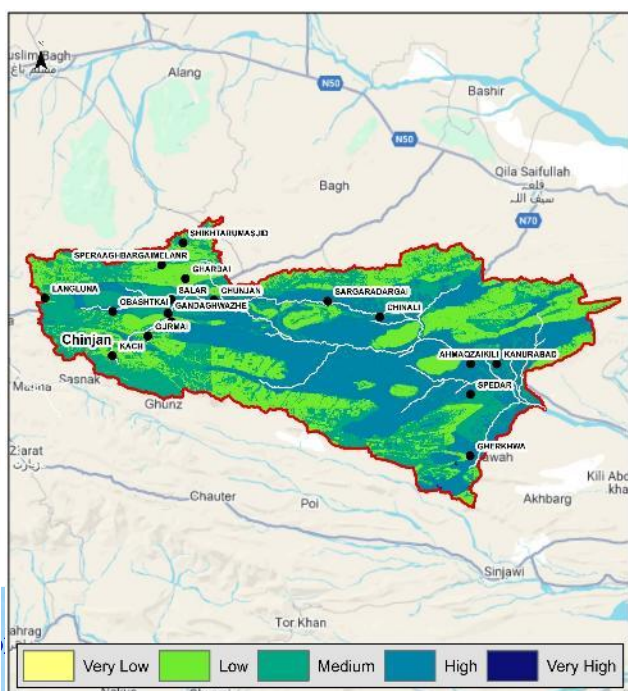
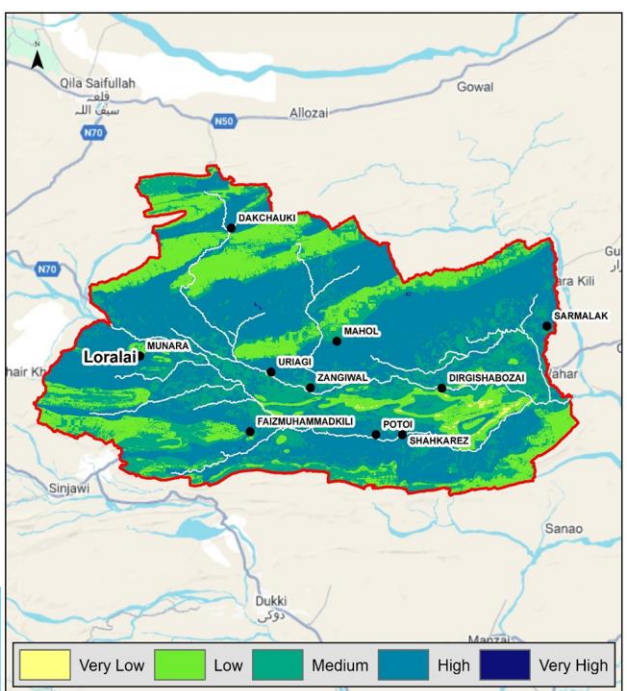
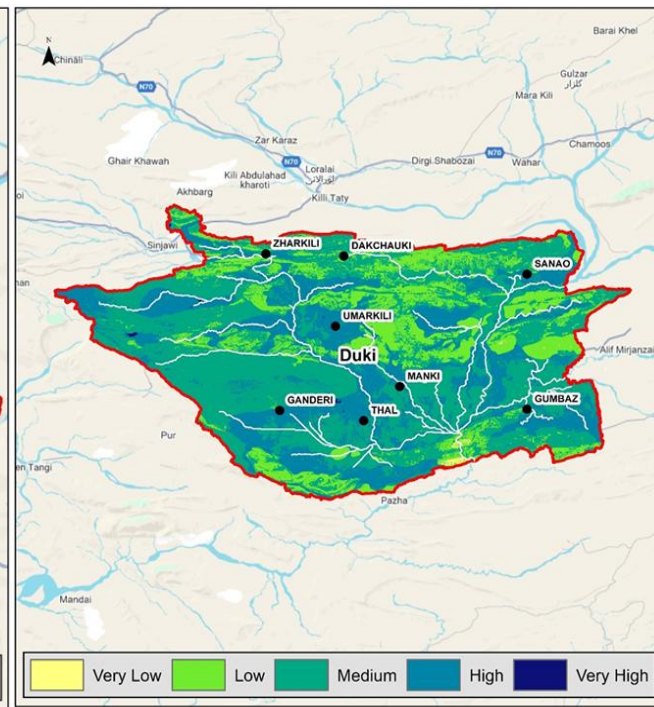
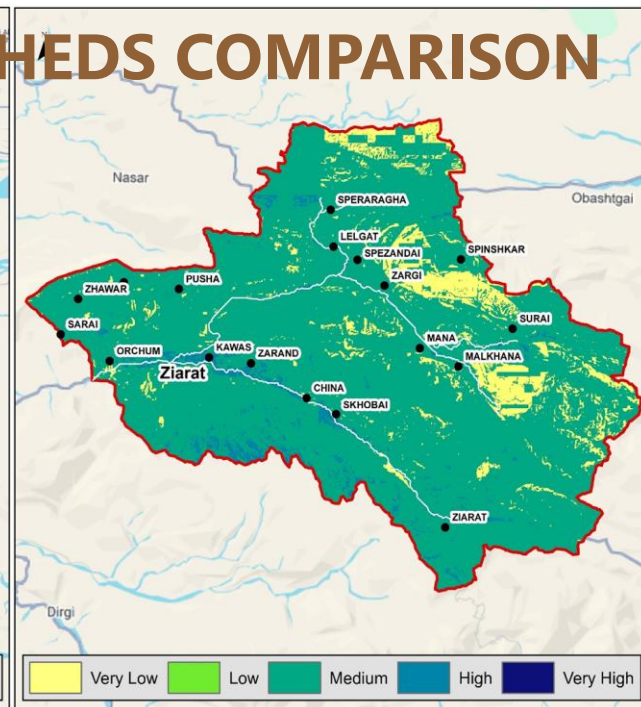
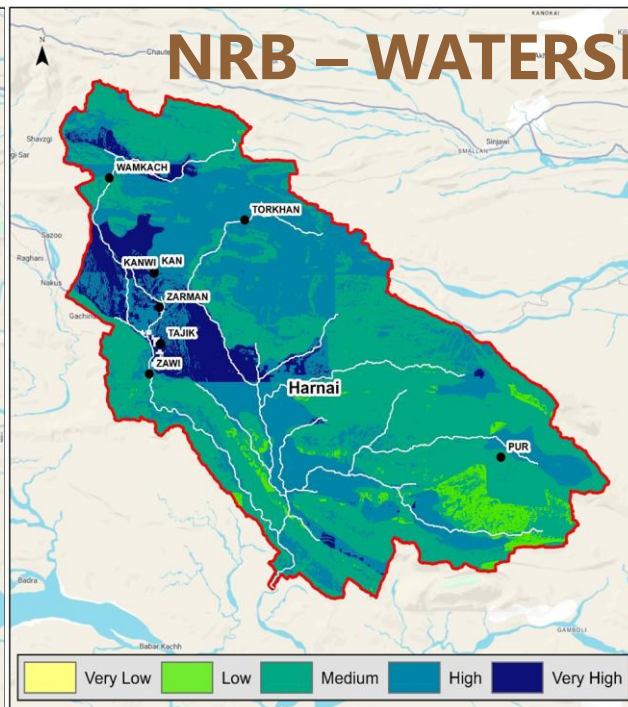
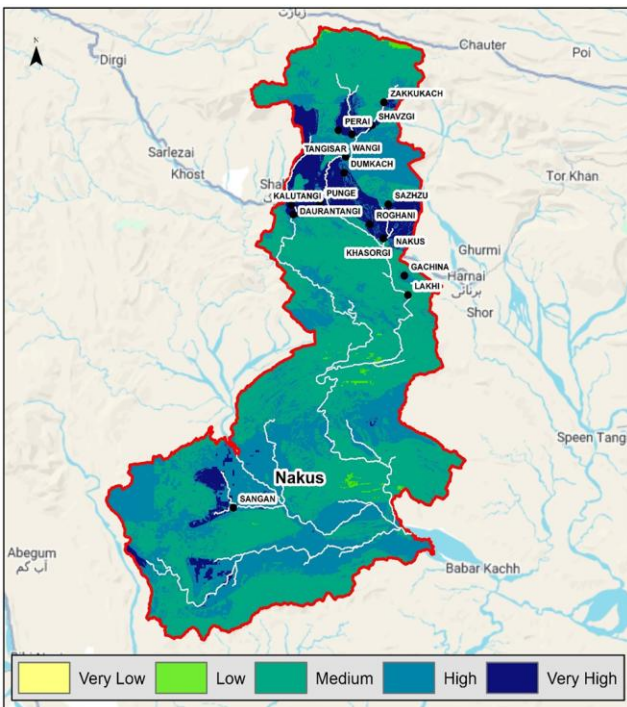
IWMI, ESRI

Coordinate System

Datum WGS 1984



NRB – WATERSHEDS COMPARISON



RESULTS - NRB

1. NAKUS WATERSHED
2. HARNAI WATERSHED
3. ZIARAT WATERSHED
4. DUKI WATERSHED

At the watershed scale, Nakus (99.51%), Harnai (96.54%), Ziarat (90.95%), and Duki (81.22%) stand out as the top-ranked watersheds, offering the highest potential for implementing recharge interventions

CHINJAN MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	0.28	0.02
2	Low	365.73	29.70
3	Medium	413.99	33.62
4	High	450.76	36.61
5	Very High	0.47	0.04
Total Area		1231.22	100.00
DUKI MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	6.54	0.24
2	Low	503.14	18.54
3	Medium	1431.04	52.72
4	High	770.74	28.39
5	Very High	2.90	0.11
Total Area		2714.36	100.00
HARNAI MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	0.00	0.00
2	Low	54.65	3.47
3	Medium	820.00	52.01
4	High	572.41	36.31
5	Very High	129.60	8.22
Total Area		1576.65	100.00
KOHLU MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	10.96	0.72
2	Low	519.00	33.87
3	Medium	642.31	41.91
4	High	353.47	23.07
5	Very High	6.68	0.44
Total Area		1532.42	100.00

LORALAI MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	5.87	0.34
2	Low	355.59	20.79
3	Medium	486.90	28.46
4	High	861.88	50.38
5	Very High	0.50	0.03
Total Area		1710.74	100.00
MEKHTAR MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	17.57	1.27
2	Low	648.66	46.75
3	Medium	318.56	22.96
4	High	402.74	29.03
5	Very High	0.00	0.00
Total Area		1387.53	100.00
NAKUS MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	0	0
2	Low	6.82	0.47
3	Medium	819.86	56.76
4	High	500.14	34.62
5	Very High	117.50	8.13
Total Area		1444.34	100
ZIARAT MAR SUITABILITY			
Suitability Value	Suitability Class	Area (km ²)	Percentage
1	Very Low	0.00	0.00
2	Low	44.94	9.05
3	Medium	433.93	87.38
4	High	17.75	3.57
5	Very High	0.00	0.00
Total Area		496.62	100.00



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VALIDATION



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Compare with
Hydrogeological
Maps



Overlay with
Tubewell Data



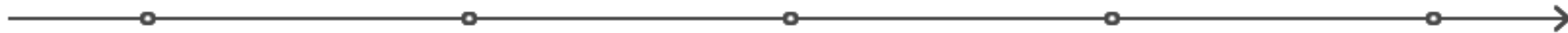
Validate with
Literature



Conduct
Expert
Consultation



Perform
Ground
Validation



MCDA- VALIDATION

WITH GROUND VALIDATION SURVEYS

**Sampling Grid for
Aquifer Recharge Validation
Activity in
Nari River Basin**

LEGEND

- Validation Cells
- Sampling Grid
- Nari River Basin

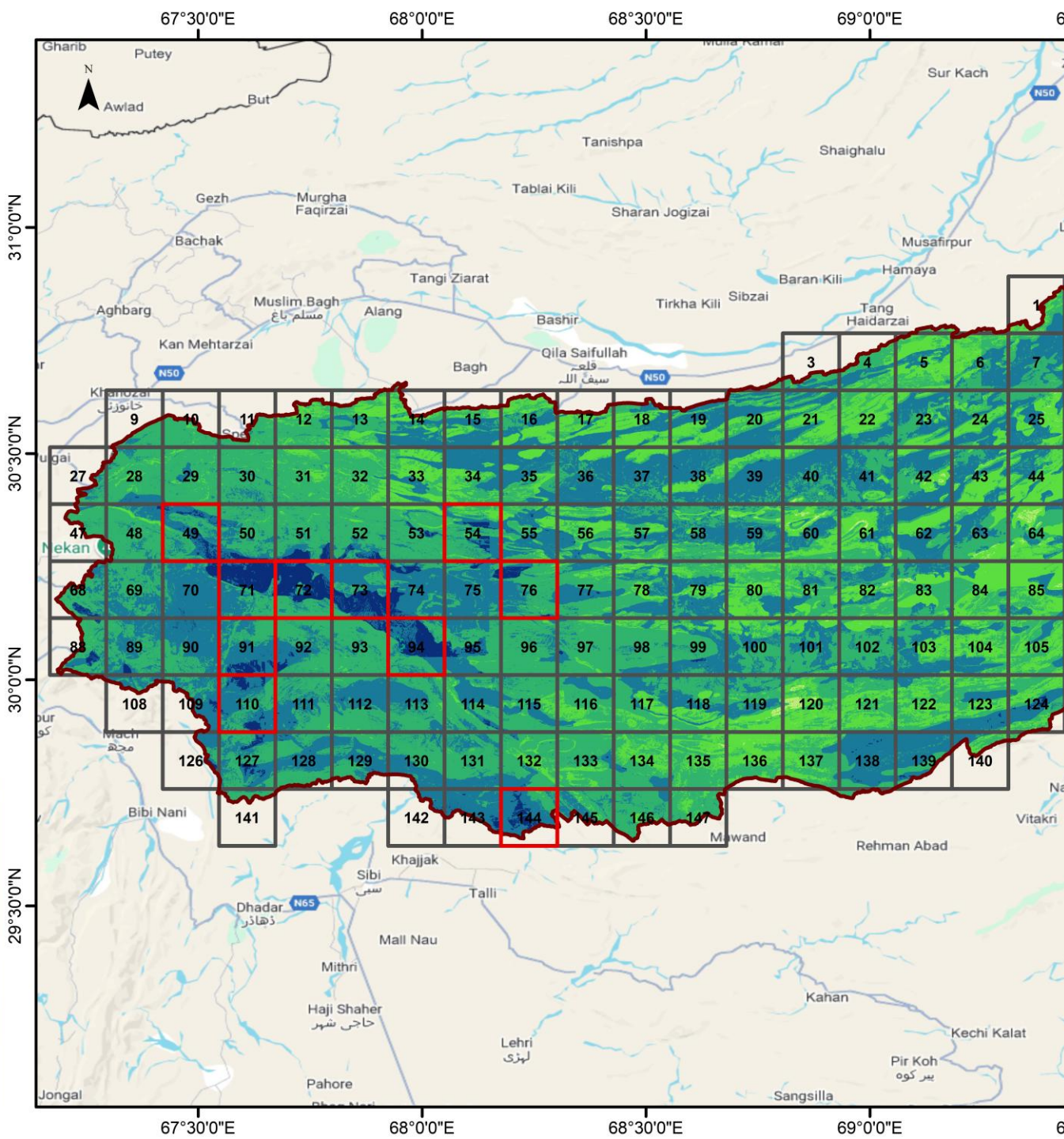
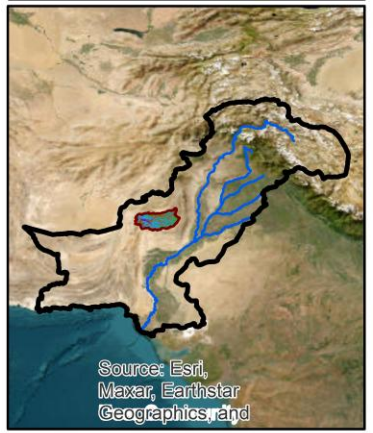
GRID DETAILS

Cell Size 14km*14km
 Total Cells 147
 Selected Validation Cells 10

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Key Findings



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RECHARGE POTENTIAL IN PISHIN LORA RIVER BASIN

- In PLB, most of the area falls under the Low (36.45%) and Medium (32.66%) suitability classes, collectively accounting for nearly 70% of the basin.
- Extensive areas remain less favorable for aquifer recharge due to factors such as steep slopes, limited permeability, or reduced water availability.
- The Central and Northern (lowlands, which are comparatively flat areas, valleys and irrigated parts of the PLB show higher recharge suitability, due to favorable hydrogeological conditions such as permeable soils or alluvial deposits. (e.g. Killa Abdullah, Pishin, Panjpai, Kuchlak, Quetta, Patki Shahnawaz, Mastung).

RECHARGE POTENTIAL IN NARI RIVER BASIN

- Nearly half of the basin (44.50%) is categorized under Medium suitability, followed by High suitability (32.54%). These two classes together cover over around 77.04% of the NRB, pointing to a broad scope for MAR interventions.
- Low suitability areas (20.23%) are less dominant compared to PLB.
- The Northern and Western portion of the basin (e.g. Ziarat, Harnai, Khost, Loralai, Sanjawi, Dabbar) of the basin appears to be more suitable for MAR.

Recommendations

- **Prioritization of MAR:** Interventions should focus on the most favorable watersheds within the Pishin Lora Basin (PLB) and Nari River Basin (NRB).
- **Site-specific design:** Selection of structures (e.g., gabions, check dams, infiltration ponds, recharge wells, spreading basins) must align with local hydrogeological, topographic, and land use conditions.
- **Groundwater monitoring:** Strengthening and digitizing monitoring networks is essential for tracking groundwater levels, quality, and abstraction patterns to assess MAR impacts.
- **Integration with IWRM:** MAR should be embedded within broader watershed conservation, rangeland management, and flood control strategies to ensure sustainability and multi-sectoral benefits.
- **Institutional coordination/Capacity Building:** Strong collaboration among provincial departments, local authorities, and communities is required for policy alignment, regulatory enforcement, and resource mobilization.
- **Community participation:** Engaging local stakeholders throughout planning, implementation, and monitoring fosters ownership, social acceptance, and equitable groundwater access.

Community Participation

Engage stakeholders for ownership and acceptance



Institutional Coordination

Collaboration among departments and communities



Integration with IWRM

Embed MAR in broader conservation strategies



Groundwater Monitoring

Track groundwater levels and quality



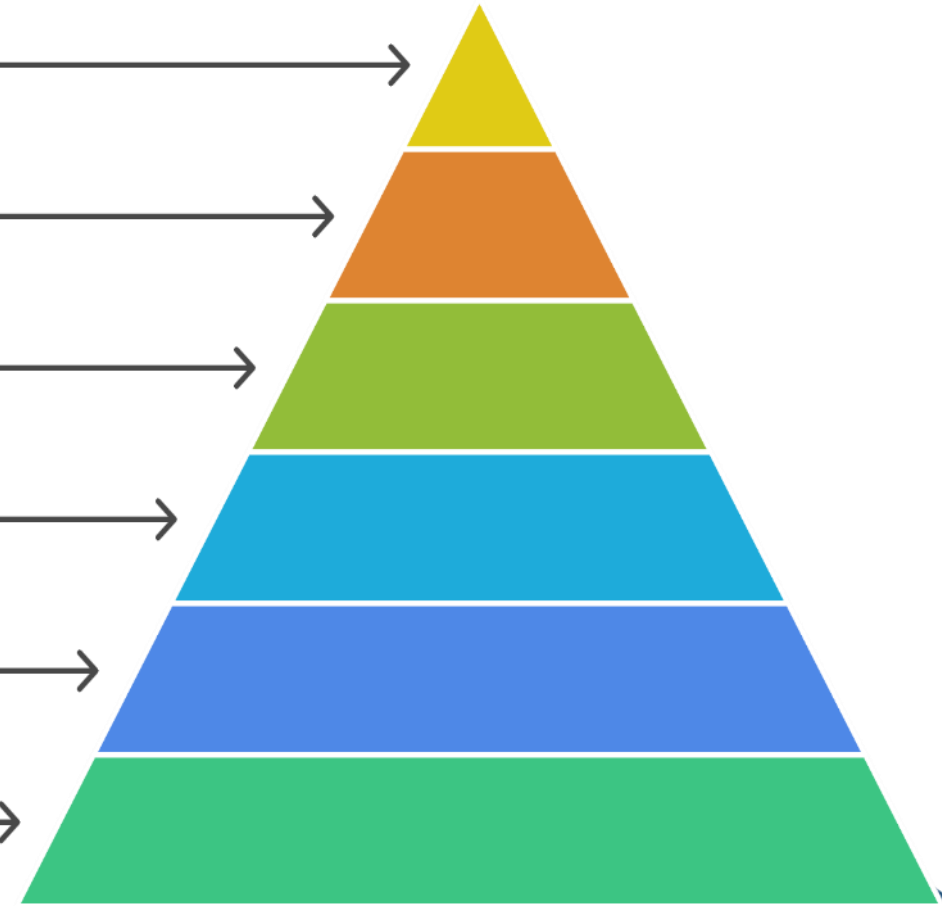
Site-Specific Design

Structures align with local conditions



Prioritization

Focus on favorable watersheds in PLB and NRB



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Thank you!

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