An appraisal of the Indus river basin: a case study under GEF portfolio

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Academics:  
- PhD in Water and Climate
- PGS in GIS and RS
- EMBA Project Management
- BSc Civil Engineering
Current Research:

- UNIVERSITY OF TWENTE.
- International Institute for Applied Systems Analysis (IIASA)
- Newcastle University
- NASA
- MONTANA STATE UNIVERSITY
- Universiteit Utrecht
- Be Boulder
- University of Colorado Boulder
- Oak Ridge National Laboratory
Global challenges

- Population growth
- Global warming and climate change

Increased population will need more: i) water supply, ii) food production, iii) energy production/supply, iv) flood and drought mitigation, v) urbanization, and v) industrial development

Global challenges

- Population growth
- Global warming and climate change
  - Global mean surface temperature increased by 0.74 +/- 0.18 °C during 1906-2005, while
  - Projected expected increase is 1.4 to 5.8 °C during 1990 to 2100 (IPCC 2007, 2013)
    - Global warming is causing glacier retreat,
    - Severity in floods and droughts,
    - Increasing water scarcity,
    - Increasing slope instability and landslides,
    - Increasing Glacier Lake Outburst Floods (GLOFs)
    - Reservoir sedimentation,
    - Forest fires, and
    - Increasing water losses/evapotranspiration
    - Adverse impact on Eco-system

Source: (Inman 2010)
1. **No Poverty**
2. **Zero Hunger**
3. **Good Health and Well-being**
4. **Quality Education**
5. **Gender Equality**
6. **Clean Water and Sanitation**
7. **Affordable and Clean Energy**
8. **Decent Work and Economic Growth**
9. **Industry, Innovation and Infrastructure**
10. **Reduced Inequalities**
11. **Sustainable Cities and Communities**
12. **Responsible Consumption and Production**
13. **Climate Action**
14. **Life Below Water**
15. **Life on Land**
16. **Peace, Justice and Strong Institutions**
17. **Partnerships for the Goals**

**Sustainable Development Goals**

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**University of Cambridge**

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**International Institute for Applied Systems Analysis**
Potential mitigation measures

- Decline in Green House Gas (GHG) emissions,
- Construction of new irrigation, hydro-power groundwater recharge dams,
- Renewable energy exploitation (hydropower, Bio fuel, solar and wind energy)
- Adaptation of improved irrigation practices,
- Adaptation of sustainable agricultural practices,
- Precise and accurate policy making against floods and droughts,
- Afforestation, and
- Preparation of climate change adaptation strategies and policies
Case study areas

The Indus Basin
The Indus Basin

The Indus Basin originates from the Hindukush-Karakoram-Himalaya and Tibetan Plateau (HKH-TP) region, and runs from the north to south.
The Indus Basin
The Indus Basin

- The Indus Basin Irrigation System (IBIS) is one of the largest in the world
- Fulfills ~ 90% of the irrigation needs
- Cater for > 33% of energy needs (mostly in Pakistan)
- More than 56-70% of Pakistan and India’s population is dependent on agriculture
- Agriculture contribute ~24% in annual GDP of Pakistan
- 90% Agriculture is dependent on irrigation
Population distribution
Water: Population growth and food demand

<table>
<thead>
<tr>
<th>S.No</th>
<th>Description</th>
<th>Year</th>
<th>Units</th>
<th>Afghanistan</th>
<th>China</th>
<th>India</th>
<th>Disputed Area</th>
<th>Pakistan</th>
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<td></td>
<td></td>
<td></td>
<td>%</td>
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<td>9.4</td>
<td>22.8</td>
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<td>2010</td>
<td>Million</td>
<td>11.69</td>
<td>0.02</td>
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<td>2050</td>
<td>Million</td>
<td>24.7</td>
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<td>15.1</td>
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<td>2100</td>
<td>Million</td>
<td>34.8</td>
<td>0.12</td>
<td>30.7</td>
<td>17.1</td>
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<tr>
<td>3</td>
<td>Population Density</td>
<td>2010</td>
<td>people/km²</td>
<td>162.8</td>
<td>0.3</td>
<td>284.2</td>
<td>66</td>
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<td>2050</td>
<td>people/km²</td>
<td>343.9</td>
<td>1.5</td>
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<td>541.8</td>
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<td>people/km²</td>
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<td>389.5</td>
<td>90.3</td>
<td>597.6</td>
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Note: Areas are as per delineation procedure explained in Khan et al. (2014). Population data is as per Jones and O'Neil (2013) SSP2 scenario. Population increase till 2050s based on SSP1-SSP5 is ranging between 255.3 million people to 366.6 million people.
Water: Population growth and food demand

Source: Yu et al. (2013)

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
<th>2000</th>
<th>2013</th>
<th>2025</th>
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<tbody>
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<td>Population</td>
<td>million</td>
<td>148</td>
<td>207</td>
<td>267*</td>
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<tr>
<td>Water requirement</td>
<td></td>
<td></td>
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<tr>
<td>Irrigation</td>
<td>1000m³</td>
<td>176.5</td>
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<td>Non-irrigation</td>
<td>1000m³</td>
<td>7.3</td>
<td>10.7</td>
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<td>Total requirement</td>
<td>1000m³</td>
<td>183.8</td>
<td>265.3</td>
<td>342.2*</td>
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<tr>
<td>Water availability**</td>
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<tr>
<td>Total surface and ground water</td>
<td>1000m³</td>
<td>134.1</td>
<td>132.3</td>
<td>156.2</td>
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<tr>
<td>Shortfall</td>
<td>1000m³</td>
<td>49.7</td>
<td>133</td>
<td>186</td>
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</table>

* Projected estimates, ** Available at watercourse head

Source: Afzal (1996)
Water: water scarcity
Water: water stress in 2040

Water Stress by Country: 2040

NOTE: Projections are based on a business-as-usual scenario using SSP2 and RCP8.5.

For more: ow.ly/RiWop

WORLD RESOURCES INSTITUTE
Energy Demand: Current and Future

Current shortfall in Pakistan is > 4000 MW (Javaid et al., 2011)

Source: Hussain et al. (2011)
Sources of Energy Production

Sources of energy production in Pakistan (Awan and Khan, 2014)
Sources of Energy Production

Installed electrical capacity in Afghanistan (Oct. 2009)

- Big hydropower: 245 MW (31%)
- Small hydropower: 61.4 MW (8%)
- Solar energy: 0.1 MW (0%)
- Wind energy: 0.1 MW (0%)
- Thermal power: 94 MW (12%)
- Diesel generators: 132.2 MW (17%)
- Imports: 251.4 MW (32%)

Estimated cost per kilowatt hour:

- Hydroelectric power: Rs1.25
- Coal-fired power: Rs2.5
- Furnace oil-based electricity: Rs6
- Wind power: Rs4
- Solar electricity: Rs22
Hydro-power potential in the Indus Basin

- The potential hydropower in the Indus Basin (within Pakistan) is 60,158 MW
- The potential hydropower in the Indus Basin (within India) is about 111,210 MW
- The potential hydropower in the Indus Basin (within Afghanistan) is about 2,200 MW
Hydro-power potential in the Indus Basin

There are 6 Dams under-construction, while 51 planned in the Indus Basin, within Pakistan (~42,500MW)

<table>
<thead>
<tr>
<th>S.No</th>
<th>Country</th>
<th>No of Dams</th>
<th>Hydro-power potential (MW)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Afghanistan</td>
<td>13</td>
<td>~2200</td>
<td>FAO Aquastat (2011)</td>
</tr>
<tr>
<td>2</td>
<td>Pakistan</td>
<td>57</td>
<td>~42500</td>
<td>PPIB (2011)</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>355*</td>
<td>~111380</td>
<td>IR (2008)</td>
</tr>
</tbody>
</table>

* Overall dams in the Himalayas (Dams in the Indus Basin boundary to be identified). Under-construction/planned dam sites in the Basin (within Pakistan and Afghanistan) are shown in Figure. Total available natural potential is greater than above mentioned hydro-power potential, however above mentioned is either under-construction or planned potential.
Hydro-power potential in the Indus Basin

- Currently 10-15% population has access to electricity
- Afghanistan has planned 13 Dams in the Indus Basin (~2,200 MW)
- May reduce water supply in Pakistan by 16-17%
- There is no water-treaty between Pak-Afghan
- Lead and UN are working on water-treaty since long
Hydro-power potential in the Indus Basin

- India planned 355 Dams in the Himalayas with a total potential capacity of ~111,380 MW

Note: Sites within the Indus Basin to be confirmed
Problem: Sedimentation

- Tarbela Dam lost ~31% of storage capacity during 1978-2015,
- Mangla Dam lost ~ 18% (1967-2009),
- Chashma barrage lost 51% during 1971-2009

Sedimentation will rise with increase in snow and glacier melt
## Problem: GLOFS Threat

<table>
<thead>
<tr>
<th>Watershed</th>
<th>No of glacial lakes</th>
<th>Area (km²)</th>
<th>Specific Area (km²)</th>
<th>No of Potentially dangerous lakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gilgit</td>
<td>614</td>
<td>39.17</td>
<td>0.064</td>
<td>8</td>
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<td>Hunza</td>
<td>110</td>
<td>3.21</td>
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<td>Shigar</td>
<td>54</td>
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<td>0.02</td>
<td>0</td>
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<td>Shyok</td>
<td>66</td>
<td>2.68</td>
<td>0.041</td>
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<td>Kharomong</td>
<td>812</td>
<td>37.65</td>
<td>0.046</td>
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<tr>
<td>Astore</td>
<td>126</td>
<td>5.52</td>
<td>0.044</td>
<td>9</td>
</tr>
<tr>
<td>UIB at Tarbela</td>
<td>1782</td>
<td>89.32</td>
<td>0.05</td>
<td>44</td>
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</table>

Source: Campbell (2005). Specific Area is total Area divided by number of lakes.
**Problem:** Biodiversity and Eco-system

<table>
<thead>
<tr>
<th>Ecosystems</th>
<th>Threats</th>
<th>Afghanistan</th>
<th>Bangladesh</th>
<th>Bhutan</th>
<th>India</th>
<th>Maldives</th>
<th>Nepal</th>
<th>Pakistan</th>
<th>Sri Lanka</th>
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</thead>
<tbody>
<tr>
<td>Coastal (mangroves, mudflats, estuaries)</td>
<td>Inundation, salination, storms, species loss</td>
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<td></td>
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<tr>
<td>Coral reefs</td>
<td>Bleaching, acidification, loss of ecological and protective services, reduction in species diversity</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Inland wetlands</td>
<td>Desiccation, drainage and diversion, degradation and service loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forests</td>
<td>Loss of forest cover and species, altered composition and structure, enhanced evapotranspiration</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Mountain (subtropical, temperate)</td>
<td>Altitudinal shifts in vegetation disrupting species types</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mountain (subalpine, alpine)</td>
<td>Loss of vegetation cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Glaciers</td>
<td>Loss of coverage</td>
<td></td>
<td></td>
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<tr>
<td>Desert</td>
<td>Expansion</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Rangelands &amp; Grasslands</td>
<td>Regime shift, degradation due to overgrazing and increased incidence of fire</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Freshwater (rivers, lakes)</td>
<td>Desiccation, increased salinity at coast, degradation due to increased demand</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Species diversity (floral &amp; faunal)</td>
<td>Loss of diversity and habitat, changes in species composition and food web</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

*Key:* Locations particularly vulnerable to impacts of climate change.

(source: Foley/World Bank, 2009)
Issues/Problems

- Asian temperature rise is greater than world’s average temperature rise (IPCC 2007, 2013)

- According to CMIP 5, under the RCP 4.5, the expected temperature rise is about 2°C (relative to 1961-1990) in the whole HKH during 2021-2050,

- The HKH-TP region has a glacier area of about 33,000 Km² (ICIMOD, 2009) and contains about 12,000 Km³ of freshwater (IPCC, 2007b)

- Glaciers in the western Himalayas, Hindukush, and eastern Karakoram are losing mass at a high rate (Kaab et al., 2012, 2015, Gardelle et al., 2012, 2013)

- Glaciers in the western Karakoram are advancing and bear slightly negative mass balance during the last decade (Kaab et al., 2012, 2015; Gardelle et al., 2012, 2013)

- Monsoon precipitation became more intense and frequent in the last four decades, and is responsible for floods in the region (Wang et al., 2011)
Shrinking glaciers
Issues/Problems

- Snow- and glacier-melt contributes more than 80% in stream flows in various sub-basins of the Indus Basin.
- Any change in temperature or snow-fall or snow-/glacier-melt will cause significant ramification on downstream water resources.
- Land sliding and floods may affect existing and ongoing projects, such as Pak-China economic corridor.
- Historic civilization in the northern Indus basin under threat due to floods, and proposed reservoirs.
- There are more than 1800 glacial lakes, of which >50 are potentially dangerous (Campbell, 2005).

However

Available studies cannot be used for precise and accurate policy making and sustainable water-energy-food supply and production, due to:
Uncertainty in existing studies

- a) SIHP (WAPDA) | Area = ~ 833,000 sq.km
- b) HydroSHEDS | Area = ~ 867,157 sq.km
- c) Immerzeel et al. (2010) | Area = ~ 1,005,786 sq.km
- d) ICIMOD | Area = ~ 1,116,086 sq.km
- e) FAO (2012) | Area = ~ 1,120,000 sq.km
- f) GRDC 2007 | Area = ~ 1,141,521 sq.km
- g) IWMI | Area = ~ 1,207,100 sq.km
- h) Hasson et al. (2013, 2014, 2015) | Area = ~ 1,230,000 sq.km
## Uncertainty in existing studies

<table>
<thead>
<tr>
<th>S.No</th>
<th>Area (km²)</th>
<th>Type of Study/Studies</th>
<th>Reference</th>
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<tbody>
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<td>Sediment budget and transport³, Food and Agriculture⁵</td>
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<td>Water Resource Management⁶</td>
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<td>4</td>
<td>970,000</td>
<td>Geology, Hydro-climatology⁷, Hydro-climatology⁸</td>
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<td>Hydrological Modelling⁹,¹⁰</td>
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<td>Hydro-climatology¹⁴-¹⁶</td>
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<td>10</td>
<td>1,137,819</td>
<td>Current and Future Water Resource Management¹⁷</td>
<td>17</td>
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<td>11</td>
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<td>Glaciers and Water Resources under Changing Climate¹⁸</td>
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Constraints: FAO water scarcity results are questionable?
Constraints: ISI-MIP results are questionable?
Uncertainty in existing studies
Constraints: variability in flow components

<table>
<thead>
<tr>
<th>Basin</th>
<th>Station name</th>
<th>Data Period</th>
<th>Glacier melt</th>
<th>Snow melt</th>
<th>Rain Runoff and Base flow</th>
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<td>1966-2010</td>
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<td>80.6</td>
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<td>1998-2007</td>
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<td>Doyian</td>
<td>1974-2000</td>
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<td>1974-2010</td>
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UIB stands for Upper Indus Basin. References are: 1 is Naz (2011), 2 is Yu et al. (2013), 3 is Lutz et al. (2014a), 4 is Shrestha et al. (2015), 5 is Lutz et al. (2014b), 6 is Bocchialia et al. (2011), 7 is Immerzeel et al. (2009). River flow components’ separation in various studies is different in all studies, therefore in some rows few components are combined, and are in percent of the total annual flows. Flow component contributions for Lutz et al. (2014a) are based on their published paper and additional results acquired from the author.
Uncertainty in existing data

Source: Palazzi et al. (2013)
Needs and Objectives

Therefore, there is intense need to study hydro-climatology of the Indus Basin, and to precisely and accurately plan energy-water-land use to cater for future demands under changing climate

Potential Objectives

➢ To rectify basin boundaries,

➢ To identify best available input datasets for hydrological modelling in the Indus basin,

➢ To provide best estimates for various flow components in various sub-basins,

➢ To project future changes in water resources, and its implications on energy and agriculture,

➢ To identify most vulnerable districts (for floods) in Pakistan, and to provide precise flood mitigation/resilience plans,
Needs and Objectives

- To identify GLOFs vulnerable projects, civilization and population,
- To predict socio-economic growth and to evaluate and predict expected changes in living standards, urbanization, food intake habits, industrialization and environmental impact
- To provide climate change adaptation plan, and best agricultural practices under various scenarios
The Nexus Challenge

Underlying socioeconomic trends → Increasing resource demands → Solutions for human welfare → Avoiding Environmental Degradation

Population growth
Rising middle class
Urbanization

Water → Clean Water
Energy → Reliable Energy
Land → Food, Feed, and Fiber

Aquatic Ecosystems
Climate Change
Terrestrial Ecosystems
Nexus Decision Framework

- Stakeholder-informed
- Place-specific solutions
- Investment and policy strategies

- Modular design
- Full sectorial representation
- Consistent platform
- Integration-ready
- Scalable and transferable
- Robust decision-making
- Elucidate uncertainty
- Sustainable scenarios

Regional priorities and response options
- Facilitate data collection
- Translation of insights to action
- Increase visibility and utility of tools

- IIASA YSSP and Post-doc
- Regional research groups
- Stakeholder meetings
- Local solution portfolios

Global Hotspot Assessment

Stakeholder engagement

Water

Regional Case Studies
## Indus (Asia)

- **Area:** 833,000 km²
- **Countries:** Pakistan, India, China, Afghanistan
- **Population:** 187.5 Mio. people
- **Projection 2050 (SSP1-5):** 307-342 Mio. people

### Main land cover: [%]
- Cropland: 30%
- Irrigated cropland: 24%
- Forest: 0.4%

### GDP per cap. [US$]:
- 700 (Afghanistan) - 7600 (China)

### Main challenges:
- **Climate Change**
- Glacier melting
- Flood & drought risk
- **Water security**
- Water scarcity
- Agricultural pollution
- **Energy security**
- Potential of hydropower
- Energy access
- **Food security**
- Irrigation
- Groundwater exploitation
- **Socioeconomic**
- Population growth
- Urbanization
- Economic growth
- **Ecosystems**
- Loss of biodiversity

## Zambezi (Africa)

- **Area:** 1,332,000 km²
- **Countries:** Zambia, Angola, Zimbabwe, Mozambique, Malawi, Tanzania, Botswana, Namibia
- **Population:** 38 Mio. people
- **Projection 2050 (SSP1-5):** 70-95 Mio. people

### Main land cover: [%]
- Cropland: 20%
- Irrigated cropland: 0.1%
- Forest: 4%

### GDP per cap. [US$]:
- 300 (Burundi) - 5400 (Angola)

### Main challenges:
- **Climate Change**
- Flood & drought risk
- **Water security**
- Water infrastructure
- Water scarcity
- Urban, industrial pollution
- **Energy security**
- Potential of hydropower
- Energy access
- **Food security**
- Potential of irrigation
- Soil degradation
- **Socioeconomic**
- Population growth
- Urbanization
- Economic growth
- **Ecosystems**
- Loss of biodiversity
Any?
Back Up Slides
Data availability:

- WAPDA and CWC
- PMD and IMD
- AEDB
- PCRET
- Soil Survey of Pakistan and India
- FAO, GLC Landcover
- Pakistan Forest Institute
- Bureau of statistics in Pakistan and India
Main Stakeholders:

Ministries and Government

- Ministry of water and power
- Ministry of Climate Change
- Ministry of Agriculture and Food
- Ministry of Culture and Heritage
- Ministry of Planning and Development
- Ministry of Science and Technology

Donors/Sponsoring Agencies

- World Bank
- ADB
- UN: UNDP, UNEP, FAO
- USAID
- IIASA
- ICIMOD
- IWMI
- JICA
Solar potential in Pakistan