Trans-boundary hydro-ecological and spatio-temporal characterization of large water reservoirs

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Background
Background

- Can we understand water storage dynamic via Space Technology usage?
- How DEMs can be used for physical characterization of reservoirs?
- How can we estimate the water surfaces and associated volumes through RS/GIS approach?
- Is there any change in spatio-temporal water storage dynamics in selected reservoirs?
- Ground data can represent specific point but will Space Technology improve our understanding for larger areas?
Background

Sources
Google Maps
## Background

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Element</th>
<th>Tarbela Dam</th>
<th>Pong Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Country</td>
<td>Khyber Pakhtunkhwa, Pakistan</td>
<td>Himachal Pradesh, India</td>
</tr>
<tr>
<td>2</td>
<td>Construction Year</td>
<td>1968 – 1976</td>
<td>1975</td>
</tr>
<tr>
<td>3</td>
<td>Type of Dam</td>
<td>Earth and rock filled Dam</td>
<td>Earth core gravel shell</td>
</tr>
<tr>
<td>4</td>
<td>Catchment Area</td>
<td>169600 km²</td>
<td>12560 km²</td>
</tr>
<tr>
<td>5</td>
<td>Reservoir Area</td>
<td>259 km²</td>
<td>260 km²</td>
</tr>
<tr>
<td>6</td>
<td>Max reservoir depth</td>
<td>137.00 m</td>
<td>97.84 m</td>
</tr>
<tr>
<td>7</td>
<td>Gross storage capacity</td>
<td>11.60/7.99 MAF</td>
<td>6.95 MAF</td>
</tr>
<tr>
<td>8</td>
<td>Live storage capacity</td>
<td>9.30/6.85 MAF</td>
<td>5.91 MAF</td>
</tr>
<tr>
<td>9</td>
<td>Max reservoir level</td>
<td>472.44 m</td>
<td>433.12 m</td>
</tr>
<tr>
<td>10</td>
<td>Normal reservoir level</td>
<td></td>
<td>423.67 m</td>
</tr>
<tr>
<td>11</td>
<td>Dead storage level</td>
<td>420.01 m</td>
<td>384.05 m</td>
</tr>
<tr>
<td>12</td>
<td>Project Usage</td>
<td>Hydroelectric, Irrigation and Flood Control</td>
<td>Hydroelectric, Flood Control and Irrigation</td>
</tr>
</tbody>
</table>

**Sources**
- WAPDA, Pakistan
- Central Water Commission, India
Data and Method
Data and Method
Data and Method

Landsat constellation time series data

• Earlier Satellite image used for Extent Mapping only
• 1998-1999 (6 Satellite images)
• 2016-2017 (6 Satellite images)
• Bands of Green, Red, NIR and Two SWIR
• Monsoon (Pre Kharif), Post Monsoon (Post Kharif) and Post Western Disturbances (Post Rabi)
Digital Elevation Models (DEM)

- **Shuttle Radar Topography Mission (SRTM, 2003)** – 90m
- **Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER, 2009)** – 30m
- **Advanced Land Observing Satellite "DAICHI" (ALOS) PRISM** (Panchromatic Remote-sensing Instrument for Stereo Mapping), 2014 – 30m
In situ Water levels and Volumes

• Tarbela Dam Water levels (meters amsl)

• Pong Dam Water Levels (meters amsl) and Volume (Million Acre Feet)
Data and Method

GDEMs Comparison based on Topographic Analysis
- SRTM
- ASTER
- ALOS

SWAT Model based Watershed analysis
- DEMs Processing for input
- SWAT mode installation
- SWAT configuration
- Watershed Delineation

Water Surface and Volume Estimation
- Landsat Satellite Data Downloading and Processing
- Water Index and Thresholding
- Dams Water Level based Volumetric Analysis
- Grid based volumetric Analysis

Spatio-Temporal Analysis
- 1998-1999
- 2016-2017
- Seasonal
Topographic Analysis
## Topographic Analysis

<table>
<thead>
<tr>
<th>Difference in Elevations</th>
<th>Tarbela</th>
<th>Pong</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-1.48</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>-6.27</td>
<td>-3.36</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>2.67</td>
<td>5.85</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>2.36</td>
<td>2.96</td>
</tr>
</tbody>
</table>

### Tarbela

<table>
<thead>
<tr>
<th>Difference in Elevations</th>
<th>ASTER vs ALOS</th>
<th>SRTM vs ASTER</th>
<th>SRTM vs ALOS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-1.48</td>
<td>0.29</td>
<td>1.48</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>-6.27</td>
<td>-4.69</td>
<td>-2.14</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>2.67</td>
<td>17.40</td>
<td>17.27</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>2.36</td>
<td>6.06</td>
<td>5.35</td>
</tr>
</tbody>
</table>

### Pong

<table>
<thead>
<tr>
<th>Difference in Elevations</th>
<th>ASTER vs ALOS</th>
<th>SRTM vs ASTER</th>
<th>SRTM vs ALOS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-1.319</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>-1.620</td>
<td>-0.21</td>
<td>-1.10</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>4.69</td>
<td>95.29</td>
<td>95.30</td>
</tr>
<tr>
<td><strong>S.D.</strong></td>
<td>3.36</td>
<td>3.40</td>
<td>3.43</td>
</tr>
</tbody>
</table>
Topographic Analysis

Watershed Delineation

DEM Setup
- Open DEM Raster
  - C:\Training_exmpl\Watershed\Grid\SourceDem
- DEM projection setup

Stream Definition
- DEM-based
- Pre-defined streams and watersheds
- Pre-defined
  - Watershed dataset
  - Stream dataset:
  - Stream network

Outlet and Inlet Definition
- Subbasin outlet
- Inlet of draining watershed
- Point source input
- Point source input

Watershed Outlets(s) Selection and Definition
- Whole watershed outlet(s)
- Cancel selection
- Delineate watershed

Calculation of Subbasin Parameters
- Reduced report output
- Skip stream geometry check
- Skip longest flow path calculation

Number of Outlets: 21
Number of Subbasins: 21

Dam, India
Tarbela Dam, Pakistan

0 30 60 15
Kilometers
0 30 60 15
Kilometers
### Watershed Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Tarbela</th>
<th></th>
<th></th>
<th>Pong</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ASTER</td>
<td>ALOS</td>
<td>SRTM</td>
<td>ASTER</td>
<td>ALOS</td>
</tr>
<tr>
<td>Total Basin Area</td>
<td>Sq Km</td>
<td>16268.90</td>
<td>16250.80</td>
<td>16172.00</td>
<td>12711.90</td>
<td>12604.50</td>
</tr>
<tr>
<td>Sub-basins</td>
<td>Numbers</td>
<td>9.00</td>
<td>9.00</td>
<td>9.00</td>
<td>15.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Minimum Sub-Basin Area</td>
<td>Sq Km</td>
<td>200.00</td>
<td>198.00</td>
<td>200.00</td>
<td>0.34</td>
<td>0.32</td>
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<tr>
<td>Maximum Sub-Basin Area</td>
<td>Sq Km</td>
<td>4281.90</td>
<td>4275.00</td>
<td>4196.00</td>
<td>4142.00</td>
<td>2378.60</td>
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### Sub Basin Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Units</th>
<th>Tarbela</th>
<th></th>
<th></th>
<th>Pong</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SRTM</td>
<td>ASTER</td>
<td>ALOS</td>
<td>SRTM</td>
<td>ASTER</td>
</tr>
<tr>
<td>Slope</td>
<td>Percent</td>
<td>56.07</td>
<td>62.96</td>
<td>69.04</td>
<td>43.91</td>
<td>51.41</td>
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<tr>
<td>Length</td>
<td>Km</td>
<td>39.87</td>
<td>44.38</td>
<td>45.36</td>
<td>28.39</td>
<td>37.40</td>
</tr>
<tr>
<td>Depth</td>
<td>meters</td>
<td>2.42</td>
<td>2.43</td>
<td>2.42</td>
<td>1.57</td>
<td>1.87</td>
</tr>
<tr>
<td>Avg Elevation</td>
<td>meters</td>
<td>2566.00</td>
<td>2573.00</td>
<td>2576.00</td>
<td>1756.93</td>
<td>2122.84</td>
</tr>
<tr>
<td>Avg Elevation Minimum</td>
<td>meters</td>
<td>361.00</td>
<td>425.00</td>
<td>349.00</td>
<td>393.00</td>
<td>333.00</td>
</tr>
<tr>
<td>Avg Elevation Maximum</td>
<td>meters</td>
<td>5769.00</td>
<td>5915.00</td>
<td>5918.00</td>
<td>6214.00</td>
<td>6582.00</td>
</tr>
</tbody>
</table>
Water Surface Extraction
Water Surface Extraction

![Water Surface Extraction Diagram]

- Tarbela Dam
- Kilometers

Kilometers
Water Volume Analytics
Reservoirs Water volume analytics

Tarbela Dam

- ALOS
  - Linear (ALOS)
  - $y = 0.1267x - 53.7$
  - $R^2 = 0.98$

- ASTER
  - Linear (ASTER)
  - $y = 0.1149x - 48.6$
  - $R^2 = 0.96$

- SRTM
  - Linear (SRTM)
  - $y = 0.0774x - 33.3$
  - $R^2 = 0.75$
Reservoirs Water volume analytics

\[ y = 0.1735x - 68.117 \]
\[ R^2 = 0.9981 \]

\[ y = 0.1444x - 56.825 \]
\[ R^2 = 0.991 \]

\[ y = 0.0856x - 33.992 \]
\[ R^2 = 0.8746 \]
Reservoirs Water volume analytics

Pong Dam

\[ y = 0.8814x + 0.9412 \]
\[ R^2 = 0.9895 \]

\[ y = 0.5372x + 0.6261 \]
\[ R^2 = 0.9864 \]

\[ y = 0.5046x + 0.3733 \]
\[ R^2 = 0.993 \]
Reservoirs Water volume analytics

Water Storage Profile along Latitude

Tarbela Dam

Pong Dam
Reservoirs Water volume analytics

Water Storage Profile along Longitude

Tarbela Dam

Pong Dam
Spatio-Temporal Analysis
Spatio-Temporal Reservoirs Characteristics

Red Shortwave Infra-Red Water Index

Post Monsoon (Post Kharif)
Spatio-Temporal Reservoirs Characteristics

Red Shortwave Infra-Red Water Index

Post Western Disturbances (Post Rabi)
Spatio-Temporal Reservoirs Characteristics

Red Shortwave Infra-Red Water Index

Monsoon (Pre Kharif)
### Spatio-Temporal Reservoirs Characteristics

#### Reservoir Dynamics by Water Surface Area

<table>
<thead>
<tr>
<th>Year</th>
<th>Monsoon (%)</th>
<th>Post Monsoon (%)</th>
<th>Post Western Disturbances (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tarbela</td>
<td>Pong</td>
<td>Tarbela</td>
</tr>
<tr>
<td>1998</td>
<td>88.9</td>
<td>70.4</td>
<td>92.2</td>
</tr>
<tr>
<td>1999</td>
<td>98.2</td>
<td>37.6</td>
<td>71.0</td>
</tr>
<tr>
<td>Average</td>
<td>93.6</td>
<td>54.0</td>
<td>81.6</td>
</tr>
<tr>
<td>2016</td>
<td>90.2</td>
<td>92.8</td>
<td>86.7</td>
</tr>
<tr>
<td>2017</td>
<td>87.9</td>
<td>39.7</td>
<td>81.3</td>
</tr>
<tr>
<td>Average</td>
<td>89.1</td>
<td>66.3</td>
<td>84.0</td>
</tr>
<tr>
<td>Change</td>
<td>-4.5</td>
<td>12.3</td>
<td>2.4</td>
</tr>
</tbody>
</table>

#### Reservoir Dynamics by Water Volume

<table>
<thead>
<tr>
<th>Year</th>
<th>Monsoon (%)</th>
<th>Post Monsoon (%)</th>
<th>Post Western Disturbances (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tarbela</td>
<td>Pong</td>
<td>Tarbela</td>
</tr>
<tr>
<td>1998</td>
<td>71.7</td>
<td>60.7</td>
<td>76.8</td>
</tr>
<tr>
<td>1999</td>
<td>93.0</td>
<td>31.3</td>
<td>49.0</td>
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<tr>
<td>Average</td>
<td>82.4</td>
<td>46.0</td>
<td>62.9</td>
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<tr>
<td>2016</td>
<td>69.5</td>
<td>92.8</td>
<td>65.2</td>
</tr>
<tr>
<td>2017</td>
<td>68.7</td>
<td>32.9</td>
<td>56.6</td>
</tr>
<tr>
<td>Average</td>
<td>69.1</td>
<td>62.9</td>
<td>60.9</td>
</tr>
<tr>
<td>Change</td>
<td>-13.3</td>
<td>16.9</td>
<td>-2.0</td>
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</table>
Conclusion
Conclusion

Key findings are:

• DEMs data from different sources have inherit differences and errors which must be considered for site specific hydro-ecological analysis.

• SWAT model based watershed delineation from DEMs revealed that there are no large differences between two basins but internal sub-basin characteristics varies.

• Landsat Water Indices quite helpful in automatic water surface extraction.

• ALOS and SRTM are better for volumetric estimation based on dam water level for Tarbela Dam while Aster and ALOS are better for Pong Dam.

• Grid based volumetric estimation using DEMs revealed that ALOS overestimated while Aster and SRTM underestimated for Pong. No data are available to evaluate predicted volume in case of Tarbela dam.
Conclusion

• Maximum volume latitudinal/longitudinal DEMs based analysis revealed distinctive water storage profiles for both reservoirs.

• Spatio-temporal evaluation is based on three seasons i.e., Monsoon, Post Monsoon and Post Western Disturbances and change is documented for water surface area and volume for both reservoirs.

  i. Tarbela reach its maximum level during Monsoon season while Pong dam reach during Post Monsoon

  ii. Tarbela command area is facing shortage of irrigation water for Rabi and Kharif cropping season while Pong although not currently directly linked with canal irrigation system is only facing shortage during Rabi season.

• The study demonstrated an effective use of Space Technology through research study on trans-boundary hydro-ecological and spatio-temporal characterization of large water reservoirs