Sedimentation and mitigation measures in Sudan

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Nile River Basin
## Water Resources in Sudan

<table>
<thead>
<tr>
<th>Water Resources</th>
<th>Quantity (bcm)</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudan present share from the Nile Waters Agreement</td>
<td>20.5</td>
<td>Seasonal pattern coupled with limited storage vessels. Expected to be shared with riparian.</td>
</tr>
<tr>
<td>Wadis Waters</td>
<td>5 to 7</td>
<td>Highly variable, short duration flows which are difficult to monitor or harvest. Some are shared with neighbors.</td>
</tr>
<tr>
<td>Renewable Groundwaters</td>
<td>4.0</td>
<td>Deep water entailing high cost of pumping. Remote areas of weak infrastructure.</td>
</tr>
<tr>
<td>Present Total</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>Expected from reclamation of swamps</td>
<td>6.0</td>
<td>Capital investment need with considerable social and environmental cost.</td>
</tr>
<tr>
<td>Total</td>
<td>35.5 to 37</td>
<td></td>
</tr>
</tbody>
</table>
Sudan water Demand

The water demand projection as given by the MIWR within the Long Term Agricultural Strategy (2002-2027)

Water demands (BCM)

<table>
<thead>
<tr>
<th>Year</th>
<th>Agriculture</th>
<th>Water Supply</th>
<th>Animals &amp; Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>27.1</td>
<td>1.1</td>
<td>3.9</td>
<td>32.1</td>
</tr>
<tr>
<td>2020</td>
<td>32.6</td>
<td>1.9</td>
<td>5.1</td>
<td>39.6</td>
</tr>
<tr>
<td>2025</td>
<td>40.3</td>
<td>2.5</td>
<td>5.3</td>
<td>48.1</td>
</tr>
<tr>
<td>2027</td>
<td>42.5</td>
<td>2.8</td>
<td>7.3</td>
<td>52.6</td>
</tr>
</tbody>
</table>

water demand will exceed the available water resources
Stresses on Water Resources

• Population growth *(More Certain!)*
• Climate Impact *(Uncertain!)*

Challenges

• Reliable Water Supply
  more storage is needed
  Preserve Reservoir Storage
• Increases water use efficiency
• sustainable development of water resources
Sediment management is playing a key role in achieving ‘water security’
Total annual sediment load (million tons) for different rivers
Sedimentation of the Blue Nile river basin
In search of sustainable catchments and basin-wide solidarities in the Blue Nile river basin
The effect of the sedimentation downstream the Blue Nile Basin

Upstream

Erosion

Changed hydrology

Increase in sediment load

Increase the peak flows and more floods and less usable

Downstream

Increase in sedimentation

Increase in sediment entering irrigation canals

Inadequate funding of operation and maintenance

Inadequate irrigation

Low irrigation performance

Vicious cycle

Farmer dissatisfaction and low cost recovery

Low yield and low income

Inadequate agricultural and water use

Poverty
Characteristics of the Blue Nile sediment

• Fine sediment distribution (clay, silt and fine sand)

• Suspended Sediment yield estimates of the Blue Nile catchment area is 480 (t/km²/year)

• Total annual sediment inflow at El Deim about 140 Million tons

• The peak of sediment concentration 20,000-25,000 ppm during the flood season.
Dams within the Nile basin

- High Aswan
- Merowe
- Jebel Aulia
- Sennar
- Roseires
- Lake Tana
- Lake Nasser
- Khartoum
- Upper Atbara and Setit
- Tezeke
- Khashm El Girba
- GERD
Reduction in Storage Capacity in dam reservoirs due to Sedimentation

<table>
<thead>
<tr>
<th>Name of dam</th>
<th>Location</th>
<th>Year of commission</th>
<th>Design Capacity ($10^9$ m$^3$)</th>
<th>Present capacity ($10^9$ m$^3$)</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sennar</td>
<td>Blue Nile</td>
<td>1925</td>
<td>0.93</td>
<td>0.36</td>
<td>60</td>
</tr>
<tr>
<td>Jebel Awlia</td>
<td>White Nile</td>
<td>1937</td>
<td>3.0</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td>ElGirba</td>
<td>Atbara River</td>
<td>1964</td>
<td>1.3</td>
<td>0.6</td>
<td>54</td>
</tr>
<tr>
<td>Roseries</td>
<td>Blue Nile</td>
<td>1966</td>
<td>3.2 (before heightening)</td>
<td>1.9 (before heightening)</td>
<td>40</td>
</tr>
</tbody>
</table>
Sennar Dam

- located on the Blue Nile, about 300 km upstream of Khartoum
- The main purpose is to store water for irrigation schemes, with hydropower as a supplementary purpose.
- 80 low-level sluice gates sluiced the annual volume of sediment.
- 112 spillway gates to pass the peaks of extreme floods.
- Two turbines of 7.5 MW each installed in 1962 for hydropower generation.
Sennar Dam

Initial storage capacity = 980 Mm³
Current storage capacity = 360 M m³
Average operation curve for Sennar dam since 1962 to facilitate sluicing - except for the period 1981 to 1986
Sediment Management in Sennar Dam

Density Current Venting

Concept

Density Current (moving current)

Clear Water

Low Level Outlet
Effects of changing the operation policy of Sennar Dam (1981 and 1986)

- Loss of storage from 1925 to 1981 (56 years) about \(4.6 \text{ Mm}^3/\text{year}\) (0.5 % per year represent 28%).

- Loss of storage from 1981 to 1986 (5 years) about \(54 \text{ Mm}^3/\text{year}\) (5.8 % per year represent 29 %).

- The changed of operating policy between 1981 and 1986 increase the deposition tenfold.
Reduction of reservoir storage capacity over years.
Roseries Dam

The dam

D/S of the dam
Roseries Dam

Location: Roseires dam first stage, commissioned in 1966, is on the Blue Nile at Roseires town some 500 km south of Khartoum.

Purpose: Irrigation, hydropower

The Reservoir:

- Design capacity at R.L. 480 m a.m.s.l. 3200 Mm$^3$
- Surface area 290 km$^2$
- Design capacity R.L. 490 m a.m.s.l. 7200 Mm$^3$
  (after heightening)
- Minimum retention level 467 m a.m.s.l.
- Normal range of annual regulated water level 13 m
Hydrology:  
Blue Nile catchment area 254,230 km² 
Average peak flood discharge 6,300 m³/s 
Maximum recorded flood 10,800 m³/s 
Average low river flow 100 m³/s 
Total average annual flow at Roseires 50,000 Mm³

Design Capacity to mean annual inflow ratio = 0.06

Sediment Inflow: 
Reasonable measured data for sediment transport are available. The measurements are mainly for suspended sediment transport during the rainy season. Rating curve for suspended sediment transport was developed from these measurements which indicated a peak transport rate of about 3 million metric tons per day


Main Problems: Loss in capacity, interruption in hydropower generation
Roseries Dam

Initial storage capacity = 3200 Mm³
Current storage capacity = 1900 Mm³
Accumulated sediment deposits with time in Roseires reservoir

Accumulated Sediment Deposition (Mm$^3$)

$\Sigma$ sediment $\sim T^{1/2}$

bathymetry

satellite

Abbas Hidytalla (2005)
Reduction in storage capacity of Roseries Reservoir over years
The Roseires Reservoir capacity reduction with time

Roseires Reservoir capacity reduction with time in selected upper levels of the reservoir
(Source: Abd Alla and Elnoor, 2007).
Control measures
1. Sediment Sluicing

Operation Rules for Roseires Reservoir

Discharge (Mm$^3$/day)

Sediment Load (Mtons/day)

10 day - Period

- discharge
- operation curve
- sediment load
Operation of Roseries Dam

From Jun- mid Sept During Flood:
- It is the minimum level for operating the power station to increase the velocity of the river flow to reduce the effect of silt.
- the deep sluice gates are used to pass the flow (five sluiceways controlled by five radial gates their size are 10.5m height and 6 m wide.)
- the spillway gates are used to pass the excess flow (even radial gates their size are 13m height and 10m wide)

From mid Sept. to Nov
- When the silt content in the water is reduced, impounding commences, taking about 60 days to raise the level of the reservoir from 468 to R.L 490 m
The filling Programme

a) On 22 August if by that date the flow at Eddeim either has never risen above 450 Million m³ per day or, having previously risen above that rate, has by then fallen below it, Or

b) On the date later than 10th of September immediately following the day when the flow at Eldeim has fallen to 450 Million m³ per day, Or

c) On 26th of September at latest, even if the flow at Eddeim then is still greater than 450 Million m³ per day.
2. Sediment Dredging

• A dredging process is executed every year in front of the power intake by dredging the sediment and dumping it in front of the deep sluice gates between 100,000-200,000 m³.

• The sediment removal flushed during the flood season when all the dam gates are opened. The process is generally carried out before the flood season.

• The average annual reduction in power generation in Roseires during August is 3.27 MWh which costs about 0.35 million US$, (ENTRO, 2007)
Khashim ElGirba Dam

Initial storage capacity = 1300 Mm$^3$
Current storage capacity = 600 Mm$^3$
“Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilized and transported through bottom outlets.” (Page 47 of ICOLD Bulletin 115)
Flushed Operation in Kashm El Girba Reservoir, 13 – 19 Aug. 2013

Vol. of net total flushed sediment = 25 Mm³
Khashm El Girba Reservoir after Flushing
Variation of sediment flushed with water used (after Paul & Dhillon 1988)

\[ V_s = 0.1048V_w^{0.687} \]

- Santo Domingo
- Kundah Palam
- Pillar
- Safidrud
- Baira (prototype)
- Baira (model)
- Sukhna Lake (model)
- Kashm El Girba

\( V_s \) volume of sediment \( (10^6 \text{m}^3) \)
\( V_w \) volume of water \( (10^6 \text{m}^3) \)
Effects of sediment in Khashem Elgirba Dam

- The annual deposit sediment 20-50 Mm$^3$
- Reduction in irrigated area in Halfa Irrigation Scheme from 330,000 fed to 180,000 fed (50%) and hydropower generated due to loss of storage.
- The cost of hydroelectricity production forgone due to loss of storage is estimated as 0.1 million US$/year.
- An area of 5850 Feddans of irrigated land in Halfa is lost every year due to sedimentation in Khashm ElGirba (ENTRO, 2007).
Marowe Dam

• Start operation 2009
• capacity 12.5 Billion m³
• Installed capacity of hydropower plant 1,250 MW (10 units at 125 MW each).
Pressure Flushing

High Water Surface Elevation

Gate

Pressure Flow

Local Scour Hole Erosion (Limited Influence Zone)

Scour zone created by opening the bottom outlet while reservoir level remains high.
Retaining long term storage
Reservoir Sedimentation Management Options

Upstream Management
- Check Dams
- Re-Forestation
- Contour Farming

Sediment Routing
- Sluicing
- Density Current Venting
- Bypass

Sediment Removal
- Dredging
- Excavation
- Hydro-suction
- Pressure Flushing
- Drawdown Flushing
Sedimentation in irrigation canals
Gezira Irrigation Scheme

- Total area 880,000 ha.
- Total water delivered 6-7 BCM per year
- Total sediment load 10 Million ton
- The sediment concentration reached 15000 mg/l
Sedimentation problems in irrigation canals
Sediment load and water release at the off-take of Gezira Main Canal at Sennar between July and October for the last 16 years
Amount of sediment removal and cost of the removal
Inadequate irrigation

Inadequate funding of operation and maintenance

Farmer dissatisfaction and low cost recovery

Inadequate agricultural and water use extension

Low irrigation performance

Vicious cycle
Sediment management in irrigation canals

- To reduce the impacts of sediment deposition in irrigation canals by improving operation and maintenance procedures

- To develop a numerical model to simulate suspended sediment transport in irrigation canals

- To improve the reliability of irrigation water delivery in Gezira Scheme considering the sedimentation problem
Field measurement and data collection

Field measurement between July and October in 2011 and 2012.

Data collected:
- water level measurement
- flow velocity
- sediment data
- bathymetric survey
- cropped area, sowing dates
- maintenance activities
• 1080 water levels readings per year
• 1290 sediment samples were analysed
Scheme analysis

- Stability of the water level
- Effect of change in geometry and structures settings on the water level
- Calibration of measuring structures
- Mass balance studies
- Laboratory analyses

Process of deposition with time
Numerical Model development (FSEDT)

- Hydrodynamic computation
- Suspended sediment transport computation
- Morphological change computation
Water released and crop water requirement

Crop water requirement and release to Zananda Major Canal in 2011

Water released at offtake Zananda Major Canal
Options of operation for the major canals

Reduction in deposition for different scenarios compared to actual situation in 2011

<table>
<thead>
<tr>
<th>Operation scenarios</th>
<th>Reduction in deposition %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; reach</td>
</tr>
<tr>
<td>Based on crop water requirement</td>
<td>51</td>
</tr>
<tr>
<td>Future scenario, 50% reduction in concentration</td>
<td>74</td>
</tr>
</tbody>
</table>
Operation under future conditions

(a) Reduction by 50%  
(b) Actual situation

Accumulation of sediment at offtake of major canal based on reduction of concentration by 50% and in actual situation
Conclusions and the way forward

• Adjust supply to satisfy the crop water demand in irrigation canals with full capacity of the field outlet pipes is the way for better sediment and water management

• In Search of Sustainable Catchments and Basin-wide Solidarities; Integrated sediment and Water Management of the Blue Nile River Basin is highly needed

• Regional and international cooperation soil conservation of catchments, should be given the highest priority

• Sediment management is highly needed to increase the live time of dams and reduce the cost of dredging as well as construct of sediment control measures.

• Upgrading the monitoring system and the development of a new techniques is needed.
Thank you