Sedimentation and its effect on storage capacity in Naghlu reservoir

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Abstract. The Naghlu reservoir has been studied to determine the level of siltation and sedimentation characteristics in the reservoir bed. The study was fulfilled in two phases, i.e., field survey and laboratory work for determining the level of siltation and carrying out the grain size analyses of the collected sediment samples at 34 locations representing the whole reservoir area.

The Naghlu Dam is a gravity dam which has been built to generate electricity. The dam was built on the Kabul River. Two main tributaries of the Kabul River, i.e., the Kabul and the Panjshir, feed the reservoir. The catchment area of Kabul and Panjshir tributaries feeding the Naghlu reservoir is around 26,000 km^2. The reservoir's surface area is around 15.5 square kilometers, and the volume is 550 million m^3 at the normal operation level; the useful volume of the reservoir is around 380 million m^3. Dam provides 100 MW of electricity for the surrounding areas, including Kabul and Jalalabad.

1 Introduction

Naturally, most of the unconstrained rivers by dams are in an equilibrium state, i.e., the sediment inflow and outflow are balanced. This balance is disturbed when dams are constructed across the rivers causing increasing flow depth velocity (settling capacity) and decreasing flow velocity (transporting capacity), which leads to the deposition of transported sediment by rivers in the reservoirs [1-4].

Sedimentation is a complex process consisting of erosion, transportation, and deposition. The process starts from the watersheds and continues in the river bed and banks. Rivers have enough energy to cause headward, lateral, and vertical erosion of their banks and bed surfaces over the flow by hydraulic action and corrasion processes. The broken particles are pulverized during the water flow into very small particles. These particles are usually carried down to the downstream areas. The river sediments become smaller and more rounded towards the rivers downstream. Large-sized sediments such as boulders are transported by rolling and pushing processes (traction) as Rivers transport the large-sized eroded materials such as boulders by pushing and rolling processes (traction). The smaller grains are carried away by the saltation process [5 –9].

Turbulent currents carry small size materials like silt and clay in the form of suspended load for a long distance. When the river carrying energy decreases, the suspended materials start settling down along the river, forming different sediment formations. The construction of dams causes a decrease in the river's water flow velocities, resulting in the settling down of sediments across different parts of the river. The decrease of velocities is gradual along the river leading to the body of the reservoir, where the water velocity is almost zero. The coarser sediments like pebbles and gravel usually get settled at the upper parts of the reservoir territory, i.e., at the point where the water begins to reach the pond, whilst the finer materials, in the state of suspension, deposit near the dam body. Experience shows that around 90% of sediments deposit in reservoirs, and only around 10% or less are transported through sluicing and spillway to the downstream area [10 – 14].

2 Method

Field studies for analyzing siltation concentration in the Naghlu reservoir through bathymetric survey and laboratory analysis of the probes is the method for this work.

3 Results and Discussions

The reservoir takes water from two tributaries of the Kabul River, i.e., Kabul and Panjshir, which are fed by the watersheds of Chak wa Logar, Kabul, and Panjshir, covering about 26,000 square kilometers. The Naglu Dam was built in 1968 with the help of the former Soviet Union. The Naghlu Reservoir was surveyed in 2020 to figure out the dam's siltation scale.

Siltation has very negative effects on the functionality of dams and their stability. It reduces the useful life of the reservoir and brings many environmental changes in the area due to the increased concentration of suspended sediments, harmful chemicals, and other pollutants. Siltation may cause damage to the mechanical parts of the dam, like power-generating turbines. On average, siltation causes 0.5 to 1.0 % annual loss of the total storage capacity of reservoirs. To mitigate dam siltation problems, dam designers and planners should be very careful while planning dam projects. It is especially important in the era of climate change, which has changed precipitation and evaporation patterns and has been causing severe flooding and soil degradation.

Due to many factors, including long-time operation (over 55 years), lack of proper maintenance, absence of sediment clearing technologies, and the recent increase in sediment concentration caused by seasonal floorings, the Naghlu dam has been silted greatly [15-20].

For tackling the siltation problem of the Naghlu dam, being the first replicable research of its kind in the country, the researchers were encouraged to launch studies in and around the reservoir to figure out the causes and extent of siltation, as well as suggest mitigation strategies for long term operation of the reservoir. The protection, proper maintenance, and siltation mitigation in the Naghlu dam are very important for the country's economy, preservation of the environment, and ensuring proper operation of the downstream hydraulic structures like the Sarubi and Darunta dams. For this reason, this important study, which includes a bathymetric survey and sediment analysis in the reservoir, has been carried out, and the results are discussed in this paper.

3.1 Bathymetric Survey

A bathymetric survey, sometimes called a fathometric survey, is a type of hydroFig.ic survey that maps the depths and shapes of underwater terrain to illustrate the land below the water. It is the measurement of water depth—the height (vertical measurement) from the water bed to the water surface. There are different techniques and methods for performing such surveys, like using a sounding pole and lead line, wire drag, single-beam echo sounder, multibeam echo sounder, side scan sonar, etc.

In the Naghlu reservoir bathymetric survey, a motor boat and an echo sounder with a 200-kHz single beam type Sea Charter 480DF were used (Fig. 1). This equipment was linked to a Real-Time Kinematic Global Positioning System (RTK-GPS) for determining the absolute x, y, and z coordinates of the reservoir bottom during the survey process. The RTK-GPS provided the horizontal position of the boat, and the echo sounder provided the vertical depth of water. The echo sounder was calibrated before the bathymetric survey following Ferrari and Collins (2006) and Eagle Electronics (2003) methods. The error values of the water depth measurements were ±5 cm, depending on the reservoir water depth. The water temperature ranged between 19 °C and 21 °C during the survey period. According to Ferrari and Collins (2006), this small water temperature variation has negligible effects on the water depth measurements. To achieve a negligible effect on the water waves, the bathymetric survey was conducted in calm water periods when the wave heights were less than 10 cm.

Fig. 1. Fish Elite 480 and Sea Charter 480DF echo sounder and Van Veen Grab sampler

The reservoir was surveyed for around 10 days between 22 September to 2 October 2020. Thirty-four locations were selected for collecting samples from the deposited sediment at the bottom of the reservoir (Fig. 2). Due to ease of use in water environments, a Van Veen grab sampler was utilized to collect sediment samples (Fig. 2).

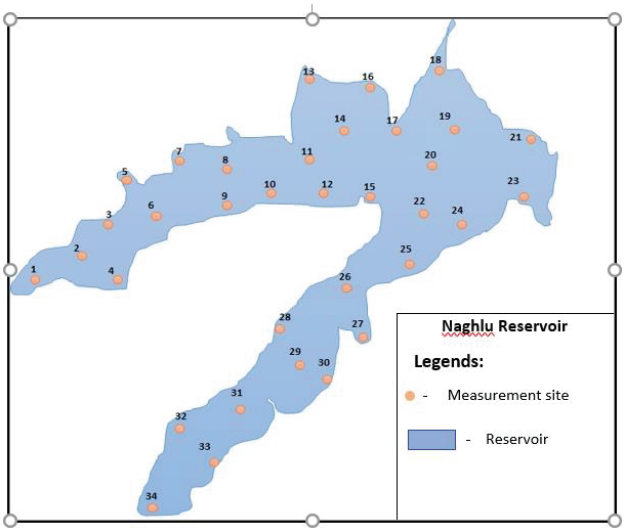

Fig. 2. Locations at bottom of Naghlu reservoir from where the samples were taken

3.2 Data Processing

The data files (in slg format) collected from the Naghlu reservoir's echo-sounding survey were processed and analyzed using software programs and ArcGIS. The data files include water depth and boat position data. Using the Sonar Viewer program, depths were transformed to the reservoir bed elevations according to the reservoir elevations on the survey date (Lowrance, 2012, cited in Issa, 2015). Fig. 3 represents the elevations of the reservoir bottom.

As per the bathymetric survey results, the reservoir has lost about 40% of its useful capacity, and around 220 million m^3 of sediments have been accumulated in the reservoir.

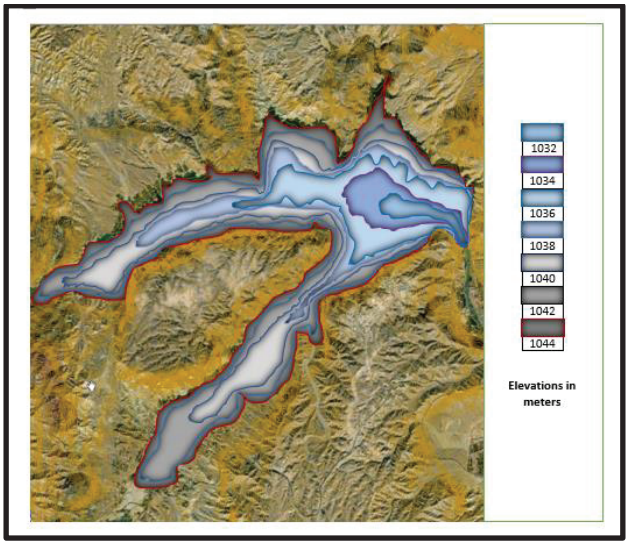

Fig. 3. Elevation map of bed of Naghlu Reservoir prepared from bathymetric survey in 2020.

3.3 Sediment Survey

As said earlier, sediment samples were taken with the help of the Van Veen grab sampler from all 34 sites. The samples were collected in specified containers and taken to laboratories in Kabul City for analysis.

3.4 Data Processing

Sieve analysis was conducted for the collected sediment samples at the Elite Engineering Tests Laboratory in Kabul City and the Soil Mechanics Laboratory at Salam University in Kabul City. The results were analyzed using Fig.ical and statistical methods. The ArcGIS software program determined the water elevation in the collected samples' locations.

3.5 Sediment Grain Size and its Classification

A better understanding of the sediment origin, transport history, and depositional environment of the Naghlu Reservoir depends mainly on the grain size analysis technique. Generally, according to the abundance of the sediments from the highest to the lowest percentages, the bed of the reservoir is mainly composed of silt (45%), clay (19%), gravel (20%), and sand (16%). The surface area of the bottom of the reservoir is covered by 80.8% clay, 9% sandy silt, 8% gravel, and 2.2% sand sediments (Fig. 4).

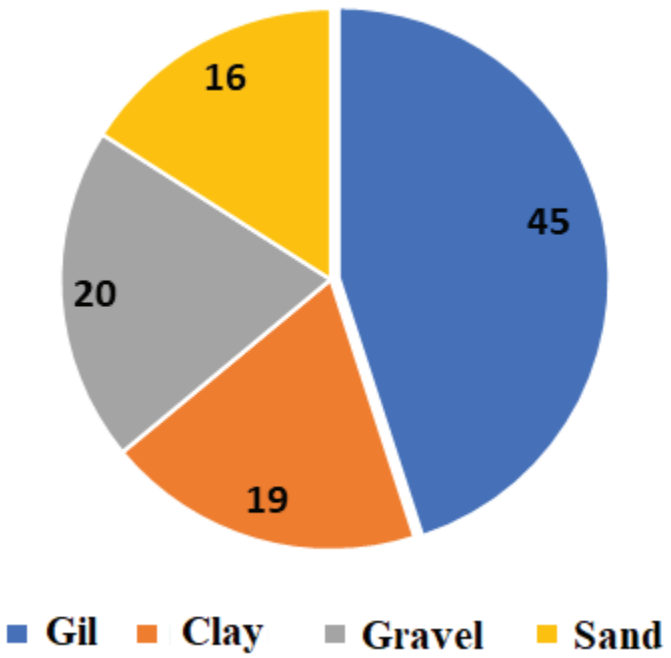

Fig. 4. Sediments at the bottom of the Naghlu reservoir

The clay sediments are composed of silty clay (77.6%), silty sandy clay (10%), sandy, gravelly silty clay (1.2%), and gravelly sandy, silty clay (1%). The gravel sediments (sandy, silty clayey gravel, and sandy gravel) are deposited on the shorelines of both the reservoir's upper wings, which may be due to the wave actions. The gravelly silty clayey sand and

gravelly sand are mostly deposited near the dam area of the reservoir. More than 60% of the sand5y silt sediments are deposited near the entrance of the Kabul and Panjshir river wings. About 30 to 40% of the clay sediments are deposited near the dam site.

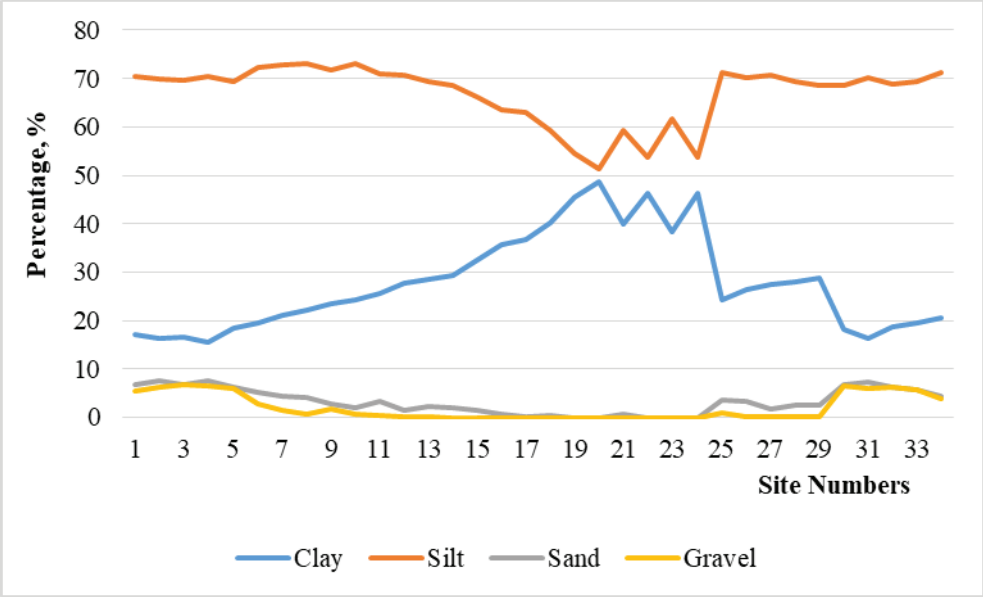

Fig. 5. Sediment grain distribution percentages per sample site

It has been concluded from the standard deviation values of the sediments that (70.4%) of the deposited sediments in the reservoir are very poorly sorted (VPS) and (17.4%) are extremely poorly sorted (EPS), and the rest of the sediments are poorly sorted (PS) which forms only (12.2%) of the total deposited sediments.

4 Conclusions

Naghlu Dam is one of the biggest dams in Afghanistan. It started operating in 1968. Its reservoir has a surface area that reaches 15.5 square kilometers.

Thirty-four bottom sediment samples were collected from the bottom of the reservoir using Van Veen grab. Grain size distribution analyses indicated that the reservoir bed mainly comprised 20 % gravel, 16% sand, 45% silt, and 19% clay. Mud and silt were the main components of the samples. The distribution of the sediment covering the bed was: 80.8%, 9%, 8%, and 2.2% of clay, sandy silt, gravel, and sand sediments, respectively.

The sediments are fine-grained, poorly sorted, strongly coarse skewed, and mesokurtic.

The bed deformation of the Naglu reservoir was determined by performing a bathymetric survey, alluvial sediment analysis, and comprehensive erosion studies in the Kabul River Basin using the RUSLE empirical model and ArcGIS software. The sediment delivered to the reservoir throughout operation (1968–2020) is estimated at 220 million m^3, which is equivalent to an annual loss of design capacity of 0.83%. With this development of events, the reservoir will be completely silted up to a normal retaining level by 2088.

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