Predictive Calculations of the Bulk Water Reservoir Capacity Using a Geographic Information System

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Abstract. The Tuyamuyun hydro-complex on the Amu Darya River, consisting of one in-channel and three off-channel basins with a design volume of 7.8 billion m³, was intended to improve the supply of irrigation water and electricity to the Khorezm region and the Republic of Karakalpakstan and to control the catastrophic floods in the lower reaches; it was put into operation in 1984. The water reservoir complex is in joint use by the Republics of Uzbekistan and Turkmenistan. Numerous measurements showed that the useful volume of the reservoir due to siltation decreased from 2.34 billion m³ to 770 million m³, i.e. by 67%. To partially compensate for the lost capacity, it was proposed to build-up the protective levees and to erect the new dams, where the topography of the area allowed. Using the GIS, the predictive volumes to increase the capacity of the Channel water reservoir have been proposed, depending on the water level in the reservoir, which between the marks \( V130.0 \) and \( V131.5 \) amounted to 527.3 million m³. The necessity was shown to increase the height of the following protective dams: No. 1 \( V134.5 \), No. 2 \( V134.8 \), No3 \( V136.7 \), No. 4 \( V134.4 \), No. 5 \( V136.4 \), No. 6 \( V137.9 \), No. 8 \( V138.6 \), No. 9 \( V135 \) and land dam \( 134.8 \).

1. Introduction
At present, 55 reservoir and 25 mud-water engineering systems are in operation in Uzbekistan. It is planned to build 7 new water basins and 3 mudflow reservoirs [1].

Many reservoirs in the world (including the ones in Uzbekistan) are operating for 30-40 years and during this period, due to siltation, the useful capacity of reservoirs significantly decreased [2, 3, 4, 5].

The Tuyamuyun hydro-complex was built on the Amu Darya River and put into operation in 1984. The Amu Darya River transports up to 11 kg/m³ of suspended sediments. Hydro-complex includes one in-channel - Channel reservoir and 3 off-channel reservoirs: Kaparas, Sultonsanjar, and Koshbulok with a total capacity of 7.8 billion m³ (Figure 1).
Over the past years, siltation of the in-channel basin has been intensified [6,7,8,9] (Figure 2), and water volumes and siltation have been periodically measured using bathymetric methods; the results are given in Table 1.

![Figure 1. Scheme of Tuyamuyun hydro-complex, I- Channel reservoir, II- Kaparas reservoir, III- Sultansanjar reservoir, IV- reservoir; 1, 2, 3, 4, 5, 6, 7, 8, 9 the numbers of protective levees; 9- Kaparas reservoir, 10 - filled and emptied structures of the Sultansanjar reservoir, 11 - construction of clarification (defecation) channel, 12 - Sultansanjar dam.](image)

![Figure 2. Siltation of the reservoir](image)

**Table 1. Results of capacity measurements of the reservoir**

| Years       | Water volume |          |          |          |          |
|-------------|--------------|----------|----------|----------|----------|
|             | In project   | In fact  | Annual   | Total    |          |
|             | mln.m³       | mln.m³   | mln.m³   | mln.m³   |          |
| 1983-1988   | 2340         | 1730     | 57       | 610      |          |
| 1988-1992   | 2340         | 1559     | 43       | 781      |          |
| 1992-1995   | 2340         | 1427     | 44       | 913      |          |
| 1996        | 2340         | 1346.4   | 80.6     | 993.6    |          |
| 1997        | 2340         | 1442     | -95.6    | 898      |          |
| 1998        | 2340         | 1334     | 108      | 1006     |          |
| 1999        | 2340         | 1290     | 44       | 1050     |          |
| 2000        | 2340         | 1369     | -79      | 971      |          |
| 2001        | 2340         | 1400     | -31      | 940      |          |
| 2002        | 2340         | 1316     | 84       | 1024     |          |
| 2002-2005   | 2340         | 1287.5   | 28.5     | 1052.5   |          |
| 2005-2008   | 2340         | 1070     | 72.5     | 1270     |          |
| 2008-2019   | 2340         | 770      | 30       | 1570     |          |
As seen from Table 1 and Figure 3 the last bathymetric measurements were conducted in 2008, the siltation volume amounted to 1.27 billion m$^3$, and the predictive indices for 2019 were 1.57 billion m$^3$; hence it can be seen that the siltation volume of the Channel reservoir amounted to 67%.

Siltation is one of the factors leading to a decrease in the reliability and safety of structures entering water-engineering systems [10, 11, 12].

The methods have been developed to combat siltation of reservoirs [13, 14] the main of which are:

1) constructive measures within the dead volume, 2) hydraulic washing of sediments, 3) evacuation of water at low levels of reservoirs, 4) mechanical cleaning, 5) an increase in useful capacity due to dam and protective levees reconstruction.

2. Methods

Today the technologies of geographic information system (GIS) are an integral part of many branches of industry. Using the digital elevation model (DEM) in the GIS, it is possible to determine the potential location for the reservoir construction, to estimate the volume of the reservoir build-up, to simulate groundwater, to determine possible erosion and the mudflow hazard and mudflow-resistant areas [15, 16, 17, 18, 19, 20, 21]. One of the GIS and DEM programs - the Global Mapper program – was used for the Channel reservoir of the Tuyamuyun hydro-complex.

The Tuyamuyun hydro-complex is located in the southwest of Uzbekistan, stretching between 41 degrees of latitude N and from 61 to 62 degrees of longitude E. The area approximately 85 by 35 km in size is characterized by moderate or high relief with 72 m – 144 m elevations. The area under study consists of small hills, plains, and sandy areas without high elevations. The coordinate system is UTM zone 41 north.

The normal support level (NSL) in the project was $\sigma_{130.00}$ using the GIS and RS, an analysis of protective dams’ conditions was carried out, as well as for the case of building up the NSL up to the level of $\sigma_{131.50}$.

3. Results and discussion

Using GIS and RS, the issue of increasing the volume of the in-channel basin from the project mark of NSL $\sigma_{130.00}$ to the mark of $\sigma_{131.50}$ was considered. First of all, a contour was plotted at the NSL mark and the object location (Figure 4).
Figure 4. The contour of the in-channel basin at \( \nabla_{130.00} \)

A contour was plotted for the mark \( \nabla_{131.5} \) and an area was created at this mark (Figure 5), the volumes were calculated (Table 2.) after every 0.1 m.

Table 2. Results of capacity measurements of the reservoir

| Base_height | Fill_area | Fill_volume |
|-------------|-----------|-------------|
| \( H, m \)  | \( F, sq.km. \) | \( W, mln.cub m. \) |
| 130         | 305.39    | 0           |
| 130.1       | 328.24    | 32.624      |
| 130.2       | 331.65    | 65.619      |
| 130.3       | 334.74    | 98.943      |
| 130.4       | 337.7     | 132.562     |
| 130.5       | 340.64    | 166.482     |
| 130.6       | 343.48    | 200.691     |
| 130.7       | 346.38    | 235.180     |
| 130.8       | 349.42    | 269.971     |
| 130.9       | 352.78    | 305.074     |
| 131         | 356.82    | 340.540     |
| 131.1       | 369.81    | 377.360     |
| 131.2       | 372.51    | 414.476     |
| 131.3       | 374.85    | 451.850     |
| 131.4       | 377.05    | 489.443     |
| 131.5       | 379.02    | 527.249     |
According to the data in Table 2, the dependences $F=f(H)$ and $W=f(H)$ are plotted, shown in Fig. 6 and 7.

![Figure 6. Graphic chart $F=f(H)$](image)

![Figure 7. Graphic chart $W=f(H)$ for additional volume of the Channel reservoir from $\sqrt{130}$ to $\sqrt{131.5}$](image)

Channel reservoir storage volume has been increased by 527.3 million m$^3$. The predictive marks of the required increase in building-up the dam crest and protective levees were calculated. The results are summarized in Table 3. As seen from Table 3 the crest marks of all dams increased by 1.5 m, compared to design ones.

**Table 3.** Existing and predictive marks of protective dams

| No.of dam | Existing marks | Predictive marks |
|-----------|----------------|------------------|
| Land dam  | $\sqrt{133.3}$ | $\sqrt{134.8}$   |
| No.1 dam  | $\sqrt{133.0}$ | $\sqrt{134.5}$   |
| No.2 dam  | $\sqrt{133.3}$ | $\sqrt{134.8}$   |
| No.3 dam  | $\sqrt{135.2}$ | $\sqrt{136.7}$   |
| No.4 dam  | $\sqrt{132.9}$ | $\sqrt{134.4}$   |
| No.5 dam  | $\sqrt{134.9}$ | $\sqrt{136.4}$   |
| No.6 dam  | $\sqrt{136.4}$ | $\sqrt{137.9}$   |
| No.7 dam  | $\sqrt{137.1}$ | $\sqrt{138.6}$   |
| No.8 dam  | $\sqrt{137.1}$ | $\sqrt{138.6}$   |
| No.9 dam  | $\sqrt{135.0}$ | $\sqrt{136.5}$   |
Two sites were identified where the construction of new dams No. 10 and No. 11 (Figure 8) would be required and longitudinal profiles of these sites were obtained (Figure 9). The total length of dam No. 10 along the Kaparas water reservoir is 3.5 km. On this site there are depressions, where a repeated breakthrough of the pressure front took place, so the dam construction is intended to stop the breakthroughs in the future. The length of dam No. 11 is 750 m. It is located between the dams No. 5 and No. 6.

To build-up protective dams, the siltation products (sand and silt particles) can be used. Construction can be carried out using dredgers.

Figure 8. The sites for construction of new dams No. 10 and No. 11
4. Conclusion

With an increase in the service life of the reservoirs, a decrease in their useful volume of water is observed especially on the rivers with deceptive suspended sediments of the Amudarya type.

The dynamics of the siltation of the in-channel basin of the Tuyamuyun hydro-complex on the Amudarya river is shown; from 1983 to 2019, the useful capacity volume of the Channel water reservoir decreased to 770 million m$^3$ compared to the projected value of 2.34 billion m$^3$.

Using the Global Mapper GIS program and the digital model of the Channel water reservoir, the reservoir area and additional volume were determined (527.3 million m$^3$).

The building-up of an additional reservoir volume will require an increase in the crest marks and the construction of two additional dams with a total length of 4.25 km.

References

[1] 2019 Decree of the President of the Republic of Uzbekistan “On measures to further improve of water resources management system” PP-4486 of October 9 Tashkent

[2] Rakhmatullaev Sh, Huneau F, Coustumer P, Motelica-HeiNo. M and Bakiev M 2009 Facts and Perspectives of Water Reservoirs in Central Asia A Special Focus on Uzbekistan Water 2 pp 307-320

[3] Rakhmatullaev Sh, Marache A, Huneau F, Coustumer L P, Bakiev M and Motelica-HeiNo. M 2010 Geostatistical approach for the assessment of the water reservoir capacity in arid regions a case study of the Akdarya reservoir Environmental Earth Sciences 63 pp 447–460

[4] Rakhmatullaev Sh, Huneau F, Bakiev M, Motelica-HeiNo. M and Coustumer L P 2011 Sedimentation of reservoirs in Uzbekistan a case study of the Akdarya reservoir Zerafshan River Basin Proceedings of the Workshop held at Hyderabad India IAHS Publ pp 171-181
[5] Pogorelov A V, Andrey A and Laguta 2018 Peculiarities of Krasnodar water reservoir silting evaluation based on the data of bathymetric surveys *Geographical Bulletin* **4**(47) pp 54-66

[6] Olsson O, Sorokin A and Ikramova M 2011 Modelling scenarios to identify a combined sediment-water management strategy for the large reservoirs of the Tuyamuyun hydro-complex *Irrigation and Drainage Systems* **25**(1) pp 277-292

[7] Froebrich J, Bauer M, Ikramova M and Olsson O 2007 Water Quantity and Quality Dynamics of the THC – Tuyamuyun Hydro-engineering Complex – and Implications for Reservoir Operation *Environmental science and pollution research international* **14**(6) pp 435-442

[8] Ikramova M R 2019 Runoff regulation and reorganization of channels of plain rivers *Abstract Diss Doctor of Technical Sciences (DSc)* TIIAME Tashkent pp 1-32

[9] Duhovny V A, Sorokin D A 2016 Research report *SIC ICWC Tashkent* pp 1-40

[10] Bakiev M, Kirillova E and Khujakulov R 2008 Safety of hydro-technical structures (TIAME, Tashkent) pp 1-278

[11] Bazarov D R 2000 Scientific justification of new numerical methods for calculating channel deformations of rivers, the channel of which is composed of easily eroded soils *Thesis for the degree of Doctor of Technical Sciences 2000*

[12] Yuldasheva K A 2011 Experience in combating siltation of a reservoir (review) *SIC ICWC Tashkent* pp 1-73

[13] Davronov G T, Firlina G I L 2016 A way to reduce the siltation process of small in-channel basins *Young Scientist* **23**(127) pp 37-40

[14] Kurbanbaev E, Artykov O and Kurbanaev S 2010 Integrated water resources management in the Amu Darya River Delta *GWP CAC Tashkent* pp 1-145

[15] Mukhtorov U Kh, Inomov A N and Islamov U P 2017 Geographic information systems and technologies (TIAME Tashkent) pp 1-202

[16] Skvorstov A V 2006 Geoinformation *Tomsk University* Tomsk pp 1-336

[17] Boltayev T Kh, Akbarov O M 2010 Basics of geographic information system (TIAME Tashkent) pp 1-158 (2010)

[18] Suvendu R, Sankar S A 2016 Effectiveness of basin morphometry, remote sensing, and applied geosciences on groundwater recharge potential mapping a comparative study within a small watershed *Frontiers of Earth Science* **10**(2) pp 274-291

[19] Avinash K, Deepika B and Jayappa K 2014 Basin Geomorphology and Drainage Morphometry Parameters Used as Indicators for Groundwater Prospect *Earth Science* **6**(25) pp 1018–1032

[20] Khasanov Kh, Bakiev M, Choriev J, Jahonov A and Khalimbetov A 2019 Water Reservoir Area and Volume Determination Using Geoinformation Technologies and Remote Sensing *International Journal of Recent Technology and Engineering* **4**(8) pp 5458-5461

[21] Khasanov K, Bakiev M 2019 Guidelines for determining the area and volume of a water reservoir using geographic information technologies and remote sensing (TIAME Tashkent) pp 1-32