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# Assessment of Hydrological Conditions of Water Bodies for Recreational Purposes by the Example of Tbilisi Water Reservoir Paper

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## To cite this article:

David Kereselidze, Vazha Trapaidze, Giorgi Bregvadze. Assessment of Hydrological Conditions of Water Bodies for Recreational Purposes by the Example of Tbilisi Water Reservoir Paper. *Earth Sciences*. Special Issue: New Challenge for Geography: Landscape Dimensions of Sustainable Development. Vol. 6, No. 5-1, 2017, pp. 68-72. doi: 10.11648/j.earth.s.2017060501.20

**Received:** July 1, 2017; **Accepted:** July 4, 2017; **Published:** August 2, 2017

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**Abstract:** Urbanization has significant effect on the environment, management of water resources and waste systems, air pollution, road infrastructure etc. Tbilisi water reservoir is an important recreational resource that is why the assessment of its ecological and qualitative state is necessary for implementation of available resource potential. Assessment of hydrological conditions is important for use of aquatic eco-systems of water reservoirs and adjacent territories for recreational purposes. Cause and effect relationships between recreational load and hydrodynamic characteristics of water are analyzed in this article; also the attractiveness index is established that enables us to identify vulnerable sectors and issues.

**Keywords:** Water Body, Hydrological Condition, Tbilisi Water Reservoir

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## 1. Introduction

Assessment of water bodies for recreational purposes has to be made through identification of its fitness for different kinds of rest, since certain kinds of recreation need different natural conditions.

Tbilisi water reservoir (Tbilisi sea) is a multifunctional water body, which is used both for irrigation and for water supply of Tbilisi and Rustavi and for recreation. It is the most important and strategic water body of the Eastern Georgia, which experiences increasing anthropogenic load. Tbilisi housing development and change of its border caused getting of water reservoir within borders of city. Population of Tbilisi exceeded 1,5 mln people and the use of Tbilisi sea for recreational purposes becomes more and more active, especially in summer period.

## 2. Main Body

Tbilisi water reservoir is located to the north-east of Tbilisi city, the other side of Makhati mountain at 548 meter height above the sea level. Tbilisi water reservoir length is 9 km,

average width 1,2 km, maximum width – 2,5 km, average depth 26 m, maximum depth 45 m. Reservoir surface area is 11,6 sq. km, water volume – 308 mln cub.m. Water reservoir is nourished by water obtained from upper main channel of Zemo Samgori irrigation system and Zhinvali water-conducting tunnel. Filling of “Tbilisi Sea” has started in 1951-1952, while its operation in 1955. Water reservoir belongs to the off-stream storages. Concrete and earth dams were erected in its north-west and south-east parts in order to reach its designed volume [1].

Water reservoir consists of “big” and “small” seas, which are connected to each other by artificially deepened channel. Length of the “big” sea is 7 km, maximum width is 2,2 km, depth is 45 m; length of the “small” sea is 2,8 km, maximum width is 1,2 km, and maximum depth is 20m. The bottom of “big” sea is slightly inclined to the north-west and is flat. Ilguniani and Kukia salt lakes were in this part before the reservoir was filled, while nearly in the middle part of “small” sea was located Avlabari Salt Lake. Water reservoir bed is made of sandstones and aleurites. Dead storage of the

reservoir is a half of its total volume. The basin is geologically made of sandstones, marls and conglomerates.

When using Tbilisi water reservoir for recreational purposes special attention has to be paid to its hydrological conditions, and for their assessment must be determined the

following factors: lithological composition of coastal ground and bottom sediments in coastal zone, width of coastal zone, water flow velocity, water plants, bathing season duration, coastal slopes etc [2, 3]. Characteristics are assessed by single points table 1.

**Table 1.** Assessment of water area (aquatory) and beach for swimming.

Lithological composition of ground Coastal area & Shallow zone	Width of lower water level, m	Current speed, m/sec	Coastal area occupied by water plants, in percent per each 100 meters of shallow zone of reservoir perimeter	Number of days, when daily water temperature is 18-22°C, in percent in terms of 90 days	Assessment, points
Sandy	5-10	0	0	80	4
Finely broken-stone	10-20	0-1	0-10	60-80	3
Bouldery	20-40	1-2	10-50	50-60	2
Clayey	40-100	2-3	50-80	30-50	1
Silty	>100	>3	>80	<30	0

In order to determine the effect of water area (aquatory) and beaches on bathing (A) is used the model based on coastal characteristics.

$$A = A_{\max} \sum_{i=1}^5 (n_i k_i), \tag{1}$$

where,  $A_{\max}$  is maximum attractiveness of the coast;  $n_i$  is

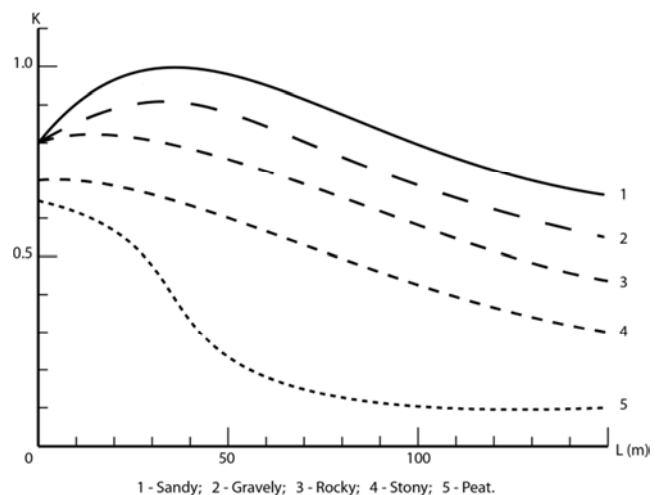
the indicator of specific part of  $i$  characteristic ( $\sum_{n_i} = 1$ );

and  $k_i$  is relative value of  $i$  characteristic for specific beach ( $0 \leq K1$ ). Bottom quality and its inclination ( $n_1 = 0.3$ ), types of coastline grounds ( $n_2 = 0.2$ ), coastal inclination ( $n_3 = 0.2$ ), water ( $n_4 = 0.15$ ) and coastal ( $n_5 = 0.15$ ) vegetations are considered as the changeable characteristics of the coast. Relative attractiveness of the coast decreases nearly by 60% in case of the lowest values of mentioned characteristics. Coast location relative to horizon sides can reduce its relative attractiveness by 5-10% in the worst possible case.

Duration of bathing suit season is determined by climate conditions and temperature regime of water reservoir. Water temperature has to be no less than 17°C, while water with 20-24°C temperature is the most comfortable for bathing. Water with 17-19°C temperature is acceptable for all categories of holiday-makers, water with 20-24°C temperature is warm for bathing, while 25-27°C and higher temperature is considered as very warm. Bathing conditions in lakes and water reservoirs located in mountains are much more limited than in water reservoirs located in the lowlands.

Central part of coastal band, on which the maximum of recreational load falls, is quite advantageous for rest. As a rule it is free from vegetation. Upper part of beaches can be used for games, for promenade etc. Width of shallow zone and lithological composition of bottom sediments are important characteristics of coastal water area in bathing suit places (figure 1). Shallow zones with the width up to 50 meters having sandy bottom deserves relatively high assessment.

In children bathing places the depth must not exceed 0,7 meters, while in adults bathing places – 1,5 meters. The bottom has to gradually deepen and it has not to be characterized by ledges, inclination of bottom in bathing zones must not be more than 1:5 that predetermines necessary width along the coast (roughly 15 meters). No whirlpools and no outlet of ground waters with low temperature must be in bathing zone. Water flow velocity has not to exceed 0,5-1,0 m/sec. In case of bigger velocities must be foreseen such facilities, which will reduce its velocity. Direction of along shore streams, area of turbid water spreading must be also taken into account when arranging beaches; at the same time the fact should be considered that water keeps its turbidity within 2-3 days after intensive storms at lakes and water reservoirs. In case of abundance of weeds and floating matters at beaches and water area is necessary to carry out bottom-improvement works and engineering preparation of beaches.



**Figure 1.** Dependence of relative value of the shore on the level and breadth of the zone.

Flow velocity, low water temperature, and character of bed are among factors impeding bathing at mountain rivers.

Level mode is an important hydrological characteristic of bathing zone. First of all, it refers to rivers, water reservoirs

and aft bays of hydrounits. Fluctuation of water level causes change of coasts, destruction of coastal vegetation, increases water turbidity, complicates access to the water and may be hazardous for holiday-makers' life. Strict control over water body level mode is necessary during bathing seasons. Average monthly water level of Tbilisi water reservoir fluctuates from 811-839 cm (September-November) to 1024-1082 cm (April-July). Average fluctuation amplitude is 635 cm.

Acceptable amplitude of water level when organizing summer beaches is 1,5 meters, while in case of sandy grounds – 2 meters. In peak periods fluctuation of water level has not to exceed 0,3-0,8 meters.

Surface area of water body is another important factor, which predetermines use of water reservoirs for other types of rest (yachting, boat, motorboat and water ski trips etc.). It should be no less than 3-4 sq. km for yachting sport (sailing), while for other water sports – at least 2 sq.km.

Landscape diversity of coasts, availability of convenient bays and accesses is no less important for development of different types of rest at water reservoirs, than climate characteristics and water reservoir area [4]. Optimal change of coastal landscapes is determined by movement rate of yachts, boats, and motorboats. Attractiveness of water tourism (boats, canoes, rafts etc.) is depended on different kinds of obstacles: rapids, rush currents, waterfalls, shallows etc.). Rivers with 5 ‰ inclination are relatively complicate for development of river tourism. Favorable conditions for water tourism development are available at rivers, inclination of which is nearly 2 ‰, while water discharge is 100 cub.m/sec. At that, augmentation of water rate at rivers in case of one and the same inclination increases complexity of routes and makes them more hazardous.

Also is important that hydrochemical and microbiological characteristics of Tbilisi reservoir water are featured by high mineralization indexes [5, 6]. Sum of principal ions averagely equals to 325 mg/cub.dm per year, at that it varies within 290-360 mg/cub.dm, while at the bottom – within 300-511 mg/cub.dm. Water contains  $Ca^{2+}$  (1.25-2.77 mg/cub.dm),  $Mg^{2+}$  (0.09-2.81 mg/cub.dm),  $Na^+ + K^+$  (0.13-3.00 mg/cub.dm),  $HCO_3^-$  (1.90-2.90 mg/cub.dm),  $SO_4^{2-}$  (0.07-0.51 mg/cub.dm) ions etc (figure 2).

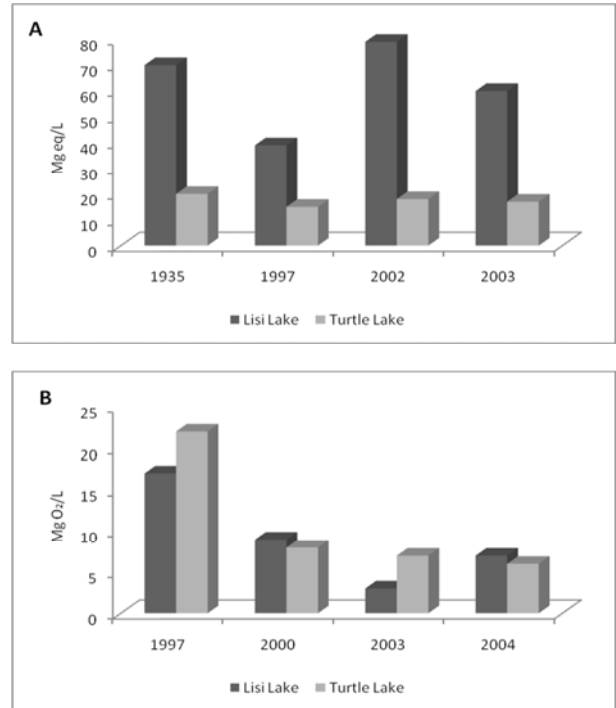


Figure 2. Hardness index of water (A); Dissolved oxygen index (B).

Water temperature is also very important characteristics for water ski and diving (underwater swimming). It can be assessed the same way as in case of bathing. Diverse submarine relief with rich water fauna and clean transparent water is also necessary for underwater swimming.

Favorable weather for yachting is when wind velocity equals to 4-8 m/sec, while for other sports the wind is not desirable. High tides even 3-4 meters height can generate at lakes and water reservoirs during stormy winds. Fluctuation of water level is undesirable for rowing, motor boat trips, though it is less important, than in case of bathing. This factor is related to safety of holiday-makers. Flash rising of water level, impoundment in rivers etc. are hazardous for water tourism.

Corresponding depth, water area sizes, landscape diversity of coasts, number of natural monuments and other sights are very important during water reservoir excursions by diesel boats [7, 8].

Table 2. Assessment of water area for yachting, rowing and motor-boating sports.

Aquatory area, sq. km		Frequency of landscape change on the coast (number of natural landmarks falling on 1 km of the coast)			Assessment, points
Yachting	Motor-boating, rowing, water ski	Rowing	Motor boat	Yachts	
>8	>5	3-4	6-8	3-5	4
6-8	3-5	2-3	4-6	6-8	3
4-6	2-3	2	3-4 or 8-10	8-10	2
3-4	1-2	1-2	10-12	10	1
<3	<1	1	12	1	0

In water reservoirs intended for amateur fishing quantity of fish is highly valued first of all that is determined by many factors, primarily by hydrological nature of water reservoir. Water reservoir levels or unfavorable temperature regime are in direct relation with natural reproduction of fishes. Relatively productive is the water reservoir zone, depth of

which does not exceed 3 meters.

Other kinds of recreation are also used in water reservoirs: for instance, for skating, fishing, water fowling in the winter etc. These types of rest are not developed at Tbilisi water reservoir [9, 10].

The main goal of assessment of natural conditions is

identification of the degree of environment attractiveness. In order to establish attractiveness of natural environment is used the following dependence

$$y = x^z \tag{2}$$

where  $y$  is attractiveness index of given natural component and it varies from 0 to 1 ( $0 \leq y \leq 1$ ).

When  $y=1$ , recreational attractiveness attains theoretically maximum level, and if  $y=0$ , then selected natural X component has no recreational attractiveness at all. In order to receive large numerical value of  $y$ , X has to be varied in the same numerical limits, i.e. from 0 to 1, while Z index can have positive numerical values of any quantity. Based on the mentioned principle is clear that when  $Z < 1$ ,  $y$  coefficient approaches 1, while in the case of  $Z > 1$  – vice versa.

The described method allows us to determine a parameter, which characterizes selected element of environment, establishes the effect of this component on attractiveness coefficient without necessity of use of strict boundaries. The more is attractiveness determining parameter, i.e. the more are criterion properties, the more increases the value of Z index. When  $0 \leq X \leq 1$  and  $Z \gg 1$ , then the value of  $y$  coefficient in  $y = x^z$  function sharply decreases, while when  $Z \rightarrow 0$ , then values of  $y$  increases (figure 3).

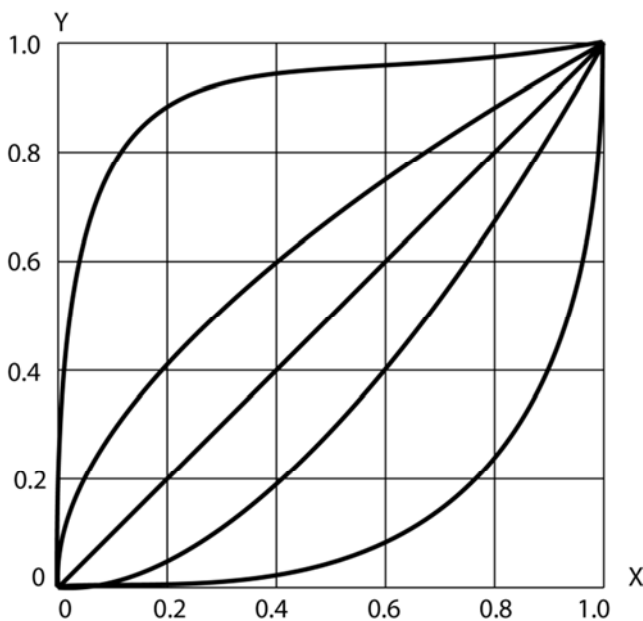


Figure 3. Function schedule  $y=x^z$ .

In order to establish the attractiveness and possibility of water reservoirs use for recreational purposes we apply  $y = x^z$  formula, where values of X and Z are expressed by morphometrical characteristics of water reservoirs. In  $y = x^z$  formula we have

$$X = \frac{H_{ave}}{H_{max}} \tag{3}$$

where,  $H_{ave}$  is average depth of water reservoirs (m);  $H_{max}$  is maximum depth of water reservoirs (m).

$$Z = r \frac{F-f}{f} \tag{4}$$

where  $F$  is the area of catchment basin of water reservoir (sq. km);  $f$  - surface area of water reservoir, (sq.km);  $r$  - correction index.

Thus, calculation formula for water reservoir attractiveness coefficient will finally be as follows:

$$N_w = \left( \frac{H_{ave}}{H_{max}} \right)^{r \frac{F-f}{F}} \tag{5}$$

The value of correction index is determined as follows: if  $H_{ave}$  of water reservoir equals to 2 meters, then coefficient of attractiveness  $N_a = 0.5$ . It is accepted that if average depth of water reservoir is 2 meters, then is possible to use it for recreational purposes (bathing, water sports). Based on this, if attractiveness coefficient of water reservoir ( $N_a$ ) is 0.5 or even more, then this water body has high recreational potential.

Providing that  $\frac{F-f}{F} \approx 1$ , then the value of  $r$  also can be easily calculated:

$$r = \frac{\log N}{\log \frac{H_{ave}}{H_{max}}} = \frac{\log 0.5}{\log \frac{H_{ave}}{H_{max}}} \tag{6}$$

The value of ( $N_a$ ) establishes the possibilities of water reservoir use for recreational purposes. Variation of this value depends on Z indicator, which depends on basin and surface areas of water reservoir located at given territory. As a result of studies carried out via mentioned method was established recreational attractiveness of lakes and water reservoirs located within territories adjacent to Tbilisi that implies the possibilities of their use for recreational purposes. Results are given in Table 3.

Table 3. Main morphological characteristics of lakes and water reservoirs situated at the territory of Tbilisi TRS.

Lake, water reservoir	Height, m (asl)	Surface area $f$ , km <sup>2</sup>	Basin area $F$ , km <sup>2</sup>	$H_{max}$ , m
Bazaleti	878	1.22	14.4	7.0
Lisi	624	0.47	16.1	4.0
Turtle lake	690	0.0095	0.4	1.7
Tbilisi		11.8	26.2	45
Sioni		10.4	551	67.3
Zhinvali		11.5		72.5

Table 3. Continue.

Lake, water reservoir	$H_{ave}$ , m	$V_{min}$ , m <sup>3</sup>	$\frac{F}{f}$	$\frac{H_{ave}}{H_{max}}$	Recreational attractiveness $N_y$
Bazaleti	4.5	5.55	11.8	0.64	0.52
Lisi	2.6	1.22	34.2	0.65	0.52
Turtle lake	0.7	0.64	42.1	0.41	0.51
Tbilisi	26.2	308	2.2	0.58	0.69
Sioni	31.4	325	52.9	0.47	0.51
Zhinvali	33.6	520		0.46	0.51

### 3. Conclusions

Several problems, causing degradation of aquatic eco-system, were identified during study of Tbilisi water reservoir: fluctuation of water levels, fast silting and degradation of eco-systems and biotas. Preliminary analysis of obtained results also revealed typical correlation relationships between following characteristics: reservoir water volume, transparency, concentration of floating solid matters and polluting agents, and number of populations living in catchment basin. Despite this fact Tbilisi water reservoir has the greatest possibilities and, respectively, the biggest coefficient of attractiveness. Its coefficient of attractiveness equals to 0,69. The coefficient of recreational attractiveness of the rest of lakes and water reservoirs is above the average and their use for recreational purposes is also expedient for all kinds of recreational activity.

Resource potential of Tbilisi water reservoir is high and adapted to local conditions taking into account increasing natural and anthropogenic load.

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