ASSESSMENT OF WATER SUPPLY OF THE CITY OF SOFIA AND ITS SUSTAINABILITY IN TERMS OF CLIMATE CHANGE

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Abstract

The purpose of the present research is to assess the vulnerability of Sofia city in terms of climate change risk for water resources and the possible accompanying risk and consequences for the water sector. An answer is given to the following question: In case of using only the available water resources in the system of Water Supply and Sewerage Company "Iskar", does a risk exist to repeat the crisis situation in the water supply and the envisaged water consumption which occurred in the period 1990-1994?

***Key words**: water supply, water use, responsibility, vulnerability, sustainability*

Introduction

Water sector in Bulgaria functions within three basic economic activity areas: water supply and sewerage (plumbing, sewerage and water purification), hydro-irrigation (irrigation, drainage and protection against harmful effects of water) and hydropower systems and facilities. The operation of each of these economic sectors depends on the type, quantity and quality of water resources. Sustainable development of the water sector depends on how far and in which aspect they will be affected by climate change. On the other hand, each one of these three areas has the potential to adapt to the changes.

A scheme description of the cascade "Iskar" and the water-supply system of Sofia

Hydro-technical Complex "Iskar" (Fig.1) consists of the water-supply system of Sofia and the cascade "Iskar". It is a complex combination of hydro-technical facilities which has two purposes: the first one is to use the water power of the Iskar River to bent "Pancharevo" and the second one – very important and responsible task – to provide water for the capital city of the country.

Fig.1 Scheme of the cascade "Iskar"

The first of its facilities is Rila Water Pipeline, built in 1933, which brought to Sofia up to 2100 l/s. The volume of the dam "Beli Iskar" is 15,1mln m³ and it was launched in 1949 with the aim to level the flow rate of Rila Water Pipeline. It gave the possibility - after passing through the WPS (Water Power Stations) "Beli Iskar" and "Mala Tsarkva" – 55mln m³ of water per year to come to Sofia, which was enough for the city at that time.

The basic facility of the Complex is the dam "Iskar" [7] whose volume of 655mln m³ is enormous for the scale of our country and its purpose was to almost fully regulate the average runoff of 320mln m³ of the river Iskar. It was completed in 1956 and its waters were initially used for energy production, irrigation and water supply of Sofia, later the energy production was transformed into a subordinate regime. At present irrigation is not performed and the main purpose is water supply.

From the dam "Iskar"- through a water-intake tower and a tunnel – the water runs into the apparatus chamber of the WPS "Pasarel". There starts the water pipeline "Iskar" (8500 l/s) which transfers part of the runoff from the tunnel to the facility PPSV (ПСПВ) "Bistritsa". From the shutter chamber the other part of the water runs through the small turbine of the WPS "Pasarel" and via the water pipeline "Pasarel" (3700 l/s) it heads to the facility PPSV (ПСПВ)

"Pancharevo". The third "emergency" connection, starting from the apparatus chamber of the WPS "Kokaliane", can bring up to 5000 l/s to the facility PPSV (ПСПВ) "Pancharevo". The waters which have gone through the big turbines of the WPS "Pasarel" and the turbines of the WPS "Kokaliane" flow into the lake of the bent "Pancharevo" and they can be used for irrigation. Thus the biggest part of the water which has been transferred for water supply of Sofia (the quantity which runs through the Water Pipeline "Iskar") is not used for energy production. Through all the connections mentioned above and the two purifying stations from the dam "Iskar" 12 m³/s can be transferred to Sofia. At present only 6m³/s on the average are transferred.

Assessment of the available water resource in the dam "Iskar"

The assessment of the available water resource in the dam "Iskar" has been carried out on the basis of the inflow in the dam registered during operational calculation of its daily balance (Fig. 2 and Fig. 3). As the almost horizontal trend demonstrates that there is maintenance of a constant averagely available volume in the dam.

Fig. 2 Graph of the monthly runoff use volume of dam "Iskar" for the period 2001-2019

Fig. 3 Graph of the annual inflow to the dam "Iskar" for the period 1960-2011

The maximum runoff from the dam is 19,5 m³/s. It is limited by the pass ability of the turbines of the WPS "Pasarel". The maximum outflow through the basic exhausts is 128m^3/s, but according to a decision of Sofia Municipality from the year 2005 the released runoff after the dam must not exceed 40m³/s. This means that practically the dam must not overflow. This can only be ensured by constantly keeping the retentive volume empty which can intake a high wave with a security rate of at least 1% or even better – 0,1%, at the simultaneous operation at the time of the wave's break-through of the maximum water intake of 19,5 m³/s and a release of 40 m³/s. For this purpose it is necessary to reserve free volume so that the dam never be full to the elevation of the overflow.

In the period 1960-1990 the waters of the dam were used for three independent users – energy production, irrigation and water supply. As a consequence of the consumption and losses the dam's volumes varied widely – from 500mln m³ to 180mln m³, i.e. the regulatory volume was approximately 320mln m³. The dam has never gone down to dead volume and has never overflown. Only once – in 1975-76 its volume reached 635mln m³.

The period 1991-2010 was characterized by a substantial change in the regime for using the dam which occurred after the water crisis in 1994. Its balance showed that the reason for the crisis was the lack of control when draining the dam's waters through the WPSs "Pasarel" and "Kokaliane" in 1993 until the end of 1994 although its volume, still in 1993, was such that it had to provide water just for the water supply of Sofia. Lack of determined limits for exhausting the dam for water supply and for WPSs according to its available volume contributed substantially to the crisis.

The period after 1994 until 2010 was characterized by the reverse tendency – a very cautious exhaust of the dam. The exhaust regime consisted just of regular water supply with subordinate energy production through the small turbine of the WPS "Pasarel" and providing water for energy production through WPSs "Pasarel" and "Kokaliane" only: when there was high water; for ensuring free volume; for overflow prevention. Almost over the whole period the dam was full of approximately 500mln m³, as its volume balances (се сработва) within the limits around 200mln m³ in the very dry year 2001. At the same time the maximum volume was allowed to reach approximately 550mln m³ - 105mln m³ under the swollen volume (завирения обем) of the dam – thus preventing conditions for overflow.

Using statistical analysis of the numbers for flow by months the characteristic years (average, averagely dry and dry) have been defined [1]. The results are given in Fig. 4.

Fig4. Runoff (in millions of cubic meters) for the characteristic years (average, averagely dry and dry)

An assessment has been performed of water consumption during that period [2, 3]. Based on data from water economic balance, it can be assumed that Sofia's water supply during the last 3-4 years has been approximately 180mln m³. Since 1990 water for irrigation has not been provided and according to experts from the company "Irrigation Systems" there is no chance to do that in near future. At present energy production is under subordinate regime.

A prediction estimate has been performed of Sofia water supply demand at three levels – 160, 180 and 200 million m³ per year. At present for Sofia the second level is valid. It has been assumed that energy producers can receive water from the dam as independent consumers for production of guaranteed energy. Therefore, at these three levels three variants for consumption of two water consumers with different priority have been envisaged - Water Supply and Sewerage and WPSs (Water Power Stations). These are Water Supply and Sewerage – with 160, 180 and 200 million m³ and WPS respectively with 110, 90 and 70 million m³ per year.

These prediction estimates have been made by applying /the method of/ the maximum efficient/useful volume of the dam, for retaining of high wave with repeatability once in 1000 years. This is imperative under the conditions of the dam "Iskar" – for overflow prevention.

Demographic development of Sofia from the point of view of water consumption

As a result of the specific role of Sofia as the capital city of Bulgaria and the biggest city in the state, as well as having in mind the economic growth in the world and in our country, which was characteristic of the first 7-8 years of the 21 century, in that period a rapid development of the economy of Sofia Municipality took place. Foreign investment increased and demand for building sites grew. All these lead to increased migration to Sofia and Sofia Municipality and the number of permanent population rose [6]. Thus, according to data of the National Statistical Institute (Table 1) Sofia's population in 2007 was 1 241 000 people and it reached 1 535 819 people in 2012. This exceeded the demographic prediction of the Master Plan of Sofia Municipality from 2003 which predicted this number to be reached in the year 2020. The population number covered people who had registered as permanent residents. Most of them lived in the city of Sofia. Approximately 83000 people lived in the rest of the towns and villages (Sofia Municipality, Amendment of Master Plan of Sofia Municipality, 2009).

Fig. 5 Tendencies in the growth of population number

Table 1. Number of population in Sofia *(Source: National Statistical Institute)*

The dynamics (Fig.5 and Table 1) in the number of population of the Municipality demonstrates constant increase of the population of the compact city due to predominantly mechanic growth caused by internal migration. In addition, the Municipality has approximately 140 000 temporary residents, who keep their permanent registration in other towns and villages. A big part of them are students and university students. Apart from them, according to experts, 30-35 000 people per day commute from the neighboring Sofia and Pernik regions. Almost the same number of people daily visit cultural, administrative and other institutions (Sofia Municipality, Amendment of Master Plan of Sofia Municipality, 2009). This means that there

are approximately 1 550 000 people in the Municipality every day and they consume water for various needs. Table 2.

Table 2. Predicted data for the number of Sofia residents

The gross rate for drinking and domestic water consumption amounts to 310 l per capita daily. This implies a significant consumption in perspective. But the reality is different. For the period 2011-2015 a constant decrease was noticed in the average registered consumption of liters per residents per day (l/r/d/) - from 135 l/r/d/ in 2011 to 126,6 l/r/d in 2015. A decrease has also been noticed in the registered annual consumption. 75% of the consumers take active measures to minimize unnecessary water consumption and they replace old water pipes in buildings which reduces leakage. This trend is also related to the use of modern sanitary and domestic appliances and water-consuming household appliances [4].

Analyses of real water loss

The large water lost along the water transmission network and the necessary measures to overcome it should also be noted. Expected estimated loss according to the company "Sofiyska Voda" is shown in Table 3.

Table 3. Water loss forecast (*according to "Sofiyska Voda"*)

The category "Real (physical) water loss" is formed by leaks along the water transmission network which occur along leading and distributing water pipelines, reservoirs and pipes in buildings. The estimated physical share of total water lost/loss is 70% or 50,7mln m^3 in the year 2015 (Total = 72,5mln m^3), on the average 4,2mln m^3 per month or on the average 139 000 m^3 per day).

Assessment of maximum annual volume for water supply provided for Sofia by the dam "Iskar"

The amount of maximum annual volume that can be provided by the dam for water supply of Sofia, depends on the required security by years and the probability that it or more of it will be available in a variety of possible implementations of flow in the forecast period. Following the calculations in item 3, the result is that the maximum volume which can be provided for Sofia at 100% in 95% of these realizations /457 samples/ is 278mln m^3. The middle influx of these samples ranged from 353mln m^3 to 273mln m^3 per year. The average annual evaporation is between 16 and 24mln m^3. In the multi-year flow regulation, the initial volume is especially important.

Therefore, the calculation of the balance [3] for each sample was made for several indications of the initial volume. The results of the study are shown in Fig.6.

Conclusions

1. The main sources of drinking and conditionally clean water, as well as the main facilities, bringing in water and the water pipelines for the city of Sofia have been built. 80% of the population is served by the dam "Iskar" and 20% of the dam "Beli Iskar". The water supply network serves almost 100% of the population of Sofia Municipality. There is no need to build major reservoirs that require significant investment and terrains.
2. With proper management of the "Iskar" cascade, the available water sources can provide for the water supply of Sofia and the surrounding area in the next 40 years.

3. Although the population in the city of Sofia is increasing, water consumption is decreasing.
4. Uncertainty about the expected changes in rainfall due to climate change is much greater than the expected rise in temperatures. The distress may result from the expected changes in the hydrologic cycle of the planet and their regional dimensions in countries with markedly transient nature of climate, such as Bulgaria, can trigger crises with unexpected consequences.

Therefore, it is necessary to make investments after detailed analysis, ensuring the prevention of damage caused by natural disasters related to water scarcity or over-wetting, landslides, floods, etc.

For Sofia, as the capital of Bulgaria and a million city , it is especially important to provide additional water supply opportunities in the future.

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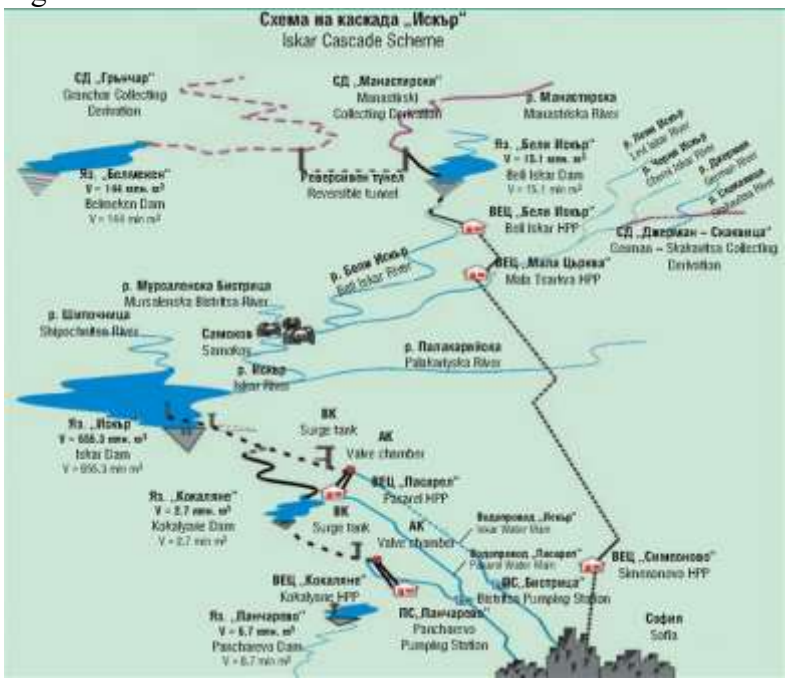
Fig.1 Scheme of the cascade “Iskar”



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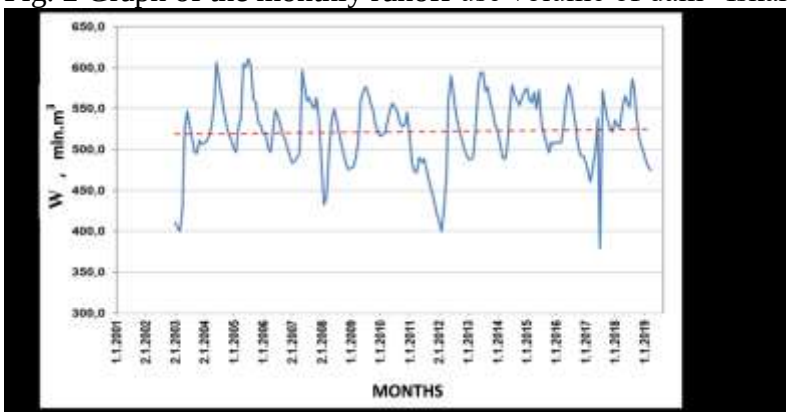

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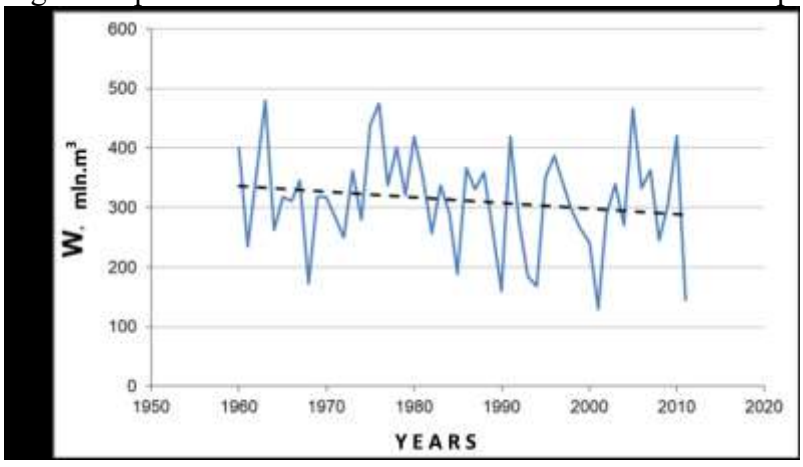

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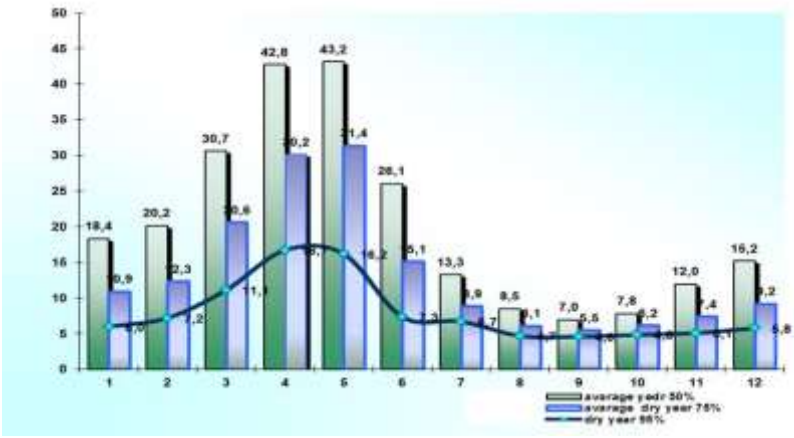

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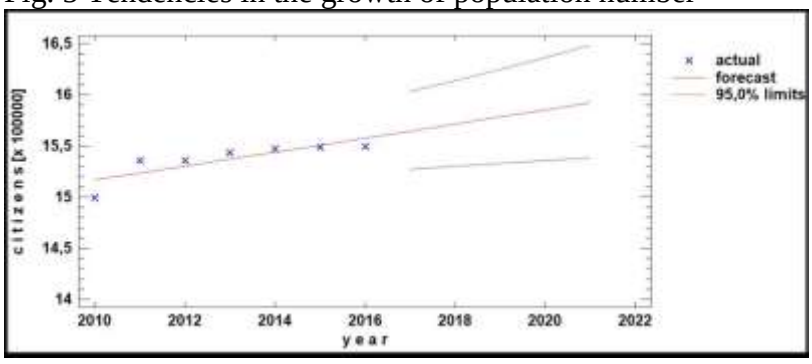

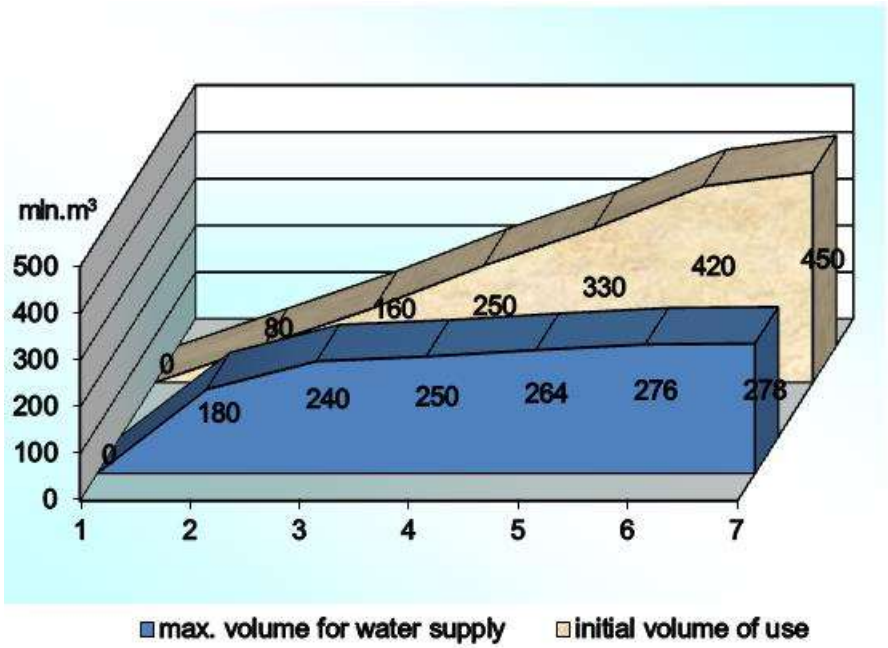

Table 1. Number of population in Sofia *(Source: National Statistical Institute)*

Y E A R	2010	2011	2012	2013	2014	2015	2016
Total population In the end of the year	1 499 301	1 535 819	1 538 842	1 543 377	1 547 472	1 548 795	1 549 659

Table 2. Predicted data for the number of Sofia residents

Y E A R	Number of residents
2017	1 564 450
2018	1 571 360
2019	1 578 310
2020	1 585 280
2020	1 592 290

Table 3. Water loss forecast (*according to "Sofiyska Voda"*)

year	2011	2024	2038	2039
Water loss, %	58,6	47,6	31,2	30,0