Analysis of changes in hydrometeorological variables of Techirghiol Lake

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Abstract. Techirghiol Lake is one of the most important hypersaline lakes in South East region of Europe due in particular to its therapeutic properties. The principal threats of this ecosystem are: climate changes and watershed changes due to human activities, which result in pronounced changes of this lake. The analysis of changes (via parametric and nonparametric approaches) is one of the keystones for understanding the long term variability of this ecosystem and the factors influencing it. To analyse the evolution of lake processes the hydro-meteorological variables was investigated, spanning the 1953-2015 period. The preliminary results shows a strongly influence of anthropic impact corroborate with climate changes on hydrological lake variables.

1. Introduction
The importance of saline lakes in human health, countries economy and environment is well known [1]. Salty lakes are very sensitive of various threats such as climate changes and human activities (agricultural purposes, watershed changes). These threats are reflected especially by lake changed size and salinity increasing [2-5]. Among the most famous examples we can include: Great Salt Lake (North America), the Dead Sea and the Aral Sea (Asia), etc., where the principal effects are a pronounced desiccation of this water body and an increasing of salinity. The consequences such as: ecosystem changes, pollution, salt-dust storms have a great influence of crop and human health in this area [6,7].

In this paper is presented a different behavior of the mainly Romanian salty lake: Techirghiol Lake through an analysis of changes in hydrological regime via parametric and nonparametric approaches. Principal hydro-meteorological time series which participate in hydrological balance of this lake are: precipitation, evaporation, overland inflow and groundwater inflow was investigated spanning the 1993-2015 period. Differences in hydrological pattern are closely related to changes in salinity. For this reason evolution of salinity time series is also investigated.

2. Materials and methods
This study is focused on Techirghiol Lake, the most important hyper saline lake of Romania, which is situated in the south east of country (Dobrogea region) near the Black Sea Littoral (figure 1).
2.1. Study area
In terms of genesis Techirghiol Lake is a fluvial-marine liman [8]. According with Breier [9] the catchment of Techirghiol Lake is quite large (160 km²) with an altitude ranges between 5 m and 85 m. The Techirghiol watershed is situated in South Dobrogea Plateau characterized by temperate continental climate influenced by Black Sea with annual temperature ranges between 10.3°C and 13.4°C [10] and annual rainfall between 200 and 700 mm [11]. The lake is situated at the confluence of several important valleys but the hydrographic network was not permanent. The groundwater is situated in Sarmatian limestone (a free level aquifer) and in limestone and dolomite sediments (under-pressure aquifer). The morphometric features are: length – 8 km, the maxim breadth is 4.4 km, the depth of Techirghiol Lake varied between 1.50 m and 9.50 m, the maxim depth is 9.75 m and the average depth is 3.6 m. The lake salinity is 4 times greater than that of the Black Sea (68.15‰ in average). Due to the hypersaline water and the existence of sapropelic mud, Techirghol Lake is well-known for its therapeutic properties. Here is developed starting in 1889 an important Center dedicated to balneology and medical recovery.

2.2. Data analysis
Hydrological time series data for Techirghiol Lake were collected by National Administration “Romanian Water” Dobrogea-Littoral Branch on station situated in Techirghiol watershed boundary area. Meteorological time series data are collected by National Meteorological Agency on Constanta station (situated at 14km from Techirghiol area). The meteorological and hydrological time series data from 1953 to 2015 used in this study refers to: precipitation, temperature, evaporation, overland flow, groundwater and lake level. We will try to detect also the influence of variation of these parameters on lake salinity evolution.

The non-stationary series corresponds to three types of situations: (i) a break presence on the average; (ii) a tendency or (iii) a sudden change on variance [12]. In analysis of time series data a set of different tests was used in order to identification of discontinuities (breakpoints). To detect the change on average we used Pettitt test (a non-parametric test) which offer also the moment of break. „U”- Buishand, and Lee & Heghinian tests are applied under the assumption of normality of time series data. The advantage of Lee & Heghinian test is that it offers also the moment of break. These tests consider only one change point in time series data. In order to detect multiple breaks on average it used the Hubert’s segmentation procedure. These entire tests are incorporated in Khronostat software [13]. Changing Point Analysis (CPA) procedure [14] is also used in order to detect multiple
changes in time series data. The CPA procedure is based on CUSUM (cumulative sum) chart combined with bootstrap rank statistic [14] procedure which gives the possibility to calculate the occurrence of change points based on the confidence level.

In order to understand the impact of climate variable and human activities on Techirghiol Lake behavior is important to known the principal human intervention in area (table 1).

**Table 1. Information about the important human activities in Techirghiol watershed.**

| Year  | Human activities in Techirghiol watershed |
|-------|-------------------------------------------|
| 1889  | Techirghiol Balneotherapy Center          |
| 1953-1956 | Construction of water supply and sewerage systems |
| 1960-1970 | Construction of “Danube Black-Sea” navigation channel and irrigation channel “Basarabi - Negrul Voda” which loss 60% of water through infiltration |
| 1977-1979 | 1st stage of protective works: intercepted fresh groundwater through existing drillings and pump water directly into the sea; |
| 1983-1986 | 2nd stage of protective works: intercepted fresh water by a new set of drilling groundwater and pump water into irrigation system |
| 1988-2005 | 3th stage of protective works: construction of the Techirghiol dam, drainage of the fresh water, construction of small dams on tributary rivers; 1998 is the last year when irrigation system is in operation. |

Due to dams’ construction, today the Techirghiol Lake surface is divided in 3 water bodies (figure 1): fresh water, brackish water and hypersalin water.

The evolution of principal hydrological parameters is presented in figure 2.

**Figure 2.** Evolution of inputs (a), outputs (b) salinity and lake level (c).

It can be seen in figure 2 some patterns in evolution of the hydro-meteorological parameters: precipitation increase starting with 1994; the overland flow has the greatest value in 1971-2000 period.
and groundwater values increasing starting 1980 until 2001-2002 (figure 2(a)). The most important effect of this perturbation in Techirghiol water budget was the increasing of water level into the lake (in 1970 the level become positive in relation with sea level) and a dramatic decreasing of salinity (figure 2(c)). In consequences, the administration has decided to increase the volume of pumped water starting with 1978 (figure 2(b)) in order to preserve the chemical properties and the lake level in normal parameters.

3. Results and discussion

The break tests results are given in table 2. “Yes” signifies that the null hypothesis (there is no break in the data series) is accepted. “x” signifies that the test was not performed because the normality was not reached through variable transformation. “No” signifies that the null hypothesis is not accepted and a break exists.

| Test type          | "U" Buishand | Pettitt | Lee Heghnan | Hubert |
|--------------------|--------------|---------|-------------|--------|
| water level        | x            | 1976    | x           | 1969   |
| rainfall           | yes          | 1994    | 1994        | 1994   |
| overland flow      | x            | 1999    | x           | 1971   |
| groundwater        | no           | 2001    | 2007        | 1981   |
| evaporation        | no           | 1997    | 1997        | yes    |
| salinity           | no           | 2000    | 2008        | 1975   |
| temperature        | no           | 1998    | 1997        | 1998   |

The interpretation of CPA results needs some experience. Figure 3 shows the results of CPA analysis for a time series. The analysis detects 3 changes.

| year | Confidence Interval | Conf. Level | From | To  | Level |
|------|---------------------|-------------|------|-----|-------|
| 1965 | (1954, 1970)        | 91%         | 792.75 | 934 | 3     |
| 1977 | (1974, 1978)        | 100%        | 934   | 764.67 | 2 |
| 1998 | (1996, 2009)        | 100%        | 764.67 | 895.72 | 1 |

Figure 3. Results of CPA on a time series data.
Table 3. Results of CPA procedure.

| Year of break | temperature | rainfall | overland flow | groundwater | evaporation |
|---------------|-------------|----------|---------------|-------------|-------------|
| 1998          |             |          | 1971 1999 1978| 1981 2009 2001 1964 | 1977 1998 2001 |

Compared the results (tables 2 and 3) we can specify:

- for precipitation all the procedures gives the same break moment in 1994 when the value of volume incoming increase of 1.5 times compared to the previous period;
- the overland flow data series present a multiple changes: 4 in Hubert’s segmentation and 3 in CPA analysis; the break moments of 1971 and 1999 are gives by Hubert segmentation and CPA procedure; in 1971 the two important tributary of Techirghiol Lake (Biruinta and Urlichioi) became permanent and after 1970 to 1999, the overland flow value increased to an average value of 632 mm (the increase was about 14 times), after 2000 it returned to the average value of the 1953-1970 period (40.8 mm) due to dams construction; we consider that this to moment are the two important changes in overland flow time series data, the others correspond to different hydro works carried out in Techirghiol watershed (figure 4);
- groundwater time series data have also a multiple break: 3 in Hubert’s segmentation and 4 in CPA procedure and three of them coincide; figure 5 shows the three sub series and we could note that measures (table 1) taken in 1977-1986 period have not reached their goal, and the values of ground water increase 1.9 times. After 2000 value decreasing 2.6 times in average (figure 5) of previous period due probably to stopping irrigation in the area in 1998;
- Hubert test does not find a break for evaporation series in on when CPA find 3 breaks in 1976, 1998 and 2001; Pettitt and Lee & Heghenian find a break in 1997 which is appropriate with the break gives by CPA in 1976;
- for temperature all statistical tests gives the same moment of break: in 1997 or 1998. CPA procedure gives the same moment (1998). Maftei & Barbulescu (Maftei 2008) gives 1997 at breakpoint for 10 meteorological stations investigated in Dobrogea area. In respect with the study mentioned we consider that the change in temperature time series is in 1997.

Figure 4. Overland flow subseries.  
Figure 5. Groundwater flow subseries.

CPA procedure could check series data for outliers and for violation of assumption. Salinity and water level data appears to violate the assumption of independent errors which affect the analysis. With 100% confidence errors both time series data have a positive correlation. That means the analysis indicate false breakpoints. In order to eliminate the errors CPA suggests two ways: by sampling less frequently or by averaging the values over more extended time series [15]. With this consideration the results obtained are: salinity time series have 3 break points (1976, 1992 and 2008) and water level
time series only one in 1977. The breakpoints identified by CPA analysis for salinity data correspond to the results obtained with the others.

The changes in water level variation require several interpretations. 1969 was the last year when the lake level is under “0” sea level which correspond with the first breakpoint estimated by Hubert’s segmentation (table 2 and figure 1). Irrigation start in 1970 and overland flow increase immediately starting with 1971. Only in three years (from 1971 to 1973) the freshwater inputs from two tributaries increase from 53 to 593mm. After 10 years (in 1981) the inputs of freshwater from aquifers increase from 469 mm to 888mm. To conclude, from 1970 till 1983 the lake level increase faster (the rate is +9cm/year in average). So the breakpoints identified by all test (1975, 1976, 1977 and 1979) correspond to 1970-1983 period. From 1983 to 1995 the water level varies in small limits due probably to pumping water from lake to sea and intercepting the ground water, upstream of the lake, through wells. Interruption of irrigation in 1997-1998 and the dams built on small valleys lead to a decreasing of overland flow and contribute to a reduction of water level in the next period. Starting with 1999 the lake level decrease with 8 mm rate and in 2015 the level was + 22 cm above Black Sea level (figure 6).

![Figure 6. Variation of water level and salinity in Techirghiol Lake; there are marked the changes.](image)

For this reason in our opinion the water level series could not be divided in 4 sub-series. We consider only 3 subseries: 1953-1983 period when water level increase rapidly, 1983-1998 period of stagnation and 1999-2015 period of decreasing.

Salinity data have the following evolution: from 1953-1990 decrease and in 1975 at three years from irrigation beginning salinity have an abrupt decreasing from 75 to 64 ‰; in 1991-2015 the values increase (figure 6). One observation could be made: in 1953-1975 period the salinity values is not measured systematically.

4. Conclusion
Impact of climate changes is reflected in increasing of precipitation and temperature in the last decade of XX century. Even the temperature increase which leads to an increasing of evaporation a lake desiccation did not appear but maybe has contributed to improving the value of salinity in addition to the hydro works carried out in the 3th period (table 1). Even the precipitation increase after 1994, this increasing is not reflected in an increasing of water level into the lake. To conclude we consider that
the water budget of Techirghiol Lake is strongly influenced by human activities (agriculture and hydro works carried in its watershed).

We consider that the statistical analysis of changes in principal hydro meteorological time series have a major contribution in understanding the complex behavior of Techirghiol Lake. But nevertheless, the CPA analysis could not identify all the changes in water level variation. In fact, any test could not identified the changes of water level time series in 1998-1999, when the lake level starting to decrease so other statistical test must be performed.

Techirghiol Lake is a sensible ecosystem very vulnerable to the changes. Given the case, some questions can arise: (i) how would the ecosystem behave only to climate change? (ii) if it is able to adapt to the climate changes? and (iii) how it could be find, in the arid zone, a way between agriculture development and the preservation of ecosystems?

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