„OVIDIUS" UNIVERSITY OF CONSTANTA
DOCTORAL SCHOOL OF APPLIED SCIENCES
FIELD OF DOCTORATE: CIVIL ENGINEERING

DOCTORAL THESIS ABSTRACT

Doctoral Advisor
Prof. univ. dr. eng. Carmen Maftei

Doctoral student
Eng. Gabriel Dobrică

CONSTANȚA, 2023

„OVIDIUS" UNIVERSITY OF CONSTANTA
DOCTORAL SCHOOL OF APPLIED SCIENCES
FIELD OF DOCTORATE: CIVIL ENGINEERING

Assessment of Hydrological Drought in the Watershed of Lake Nuntasi-Tuzla, Constanta County

- Abstract-

Doctoral Advisor
Prof. univ. dr. eng. Carmen Maftei

Doctoral student
Eng. Gabriel Dobrică

CONSTANȚA, 2023

Table of Contents

Thanks

I would like to express my special thanks to Professor Maftei Carmen Elena, PhD, Eng. habil., my scientific coordinator, who provided me with constant guidance, support, and encouragement throughout my doctoral studies and thesis writing. I am grateful to my professor for giving me the freedom to use and approach this doctoral subject in a personal way.

I would also like to express my gratitude to the members of the advisory committee during the doctoral training period for the advice and suggestions offered. I would like to thank Prof. Diane Paula Corina Vancea, PhD in Economics, Prof. Carmen-Adina Ciugureanu, PhD, and Prof. Lucica Tofan, PhD, who were my tutors for one year in the project "Academic excellence and entrepreneurial values - a scholarship system for ensuring opportunities for the training and development of doctoral and postdoctoral entrepreneurial competences (ANTREPRENORDOC), co-financed by the European Social Fund through the Human Capital Operational Program, 2014-2020, Contract no. 36355/23.05.2019 POCU/380/6/13 - SMIS code: 123847."

My thanks also go to the professors at the Faculty of Civil Engineering of the Ovidius University of Constanta, Assoc. Prof. Eng. Constantin Buta, Senior Lecturer Eng. Madalina Stanescu, and Senior Lecturer Eng. Geanina Mihai, with whom I have discussed numerous topics and issues during the elaboration of the thesis. I would like to thank the management and colleagues of the Dobrogea-Litoral Water Basin Administration for their support and professional development opportunities offered to me. At the same time, I would like to thank my children and my wife for their encouragement and support throughout the entire process of completing my doctorate."

Keywords

Hydrological drought, hydrological indices and indicators, desertification, management, Lake Nuntasi-Tuzla, Dobrogea.

1. Introduction

The hazards are divided into two categories: anthropogenic and natural. Natural hazards include hydro-meteorological hazards such as floods, droughts, heat waves, and tropical cyclones.

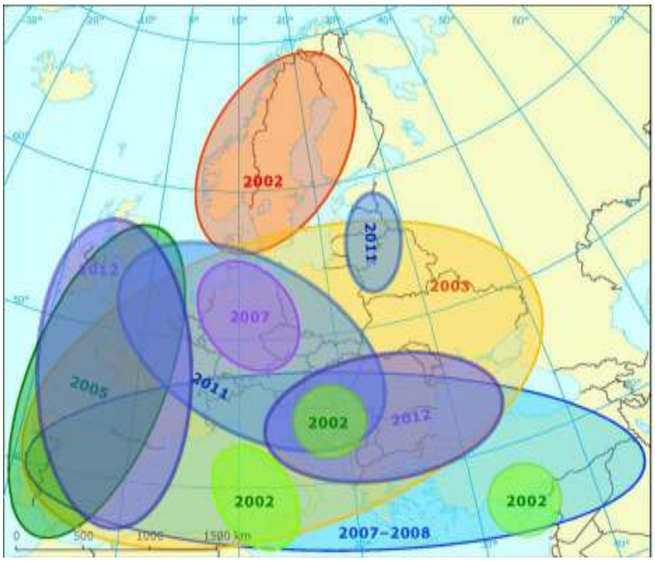

Figure no. 3 - Hydrological drought situation in Europe https://www.eea.europa.eu/legal/copyright

According to the European Environment Agency (EEA), Romania has been affected by hydrological droughts and water resource insufficiency in the following years: 2002, 2003, 2011, and 2012 (Figure 3). The forecast shows a decrease in minimum river flows with a return period of 20 years in the 21st century, which means that hydrological droughts will occur more frequently and with increased intensity.

The impact of extreme events such as droughts, heat waves, and water scarcity has a negative effect on economic and social development, as well as on human health. The influence of these types of hazards is felt not only at the local but also at the regional and even global level, due to the interdependence between societies in different regions of the world.

According to the World Meteorological Organization (WMO), between 1970 and 2019, in Europe, 3% of all natural disasters were represented by droughts and 5% by heat waves, and the five hazards that led to the most economic losses were: river floods (44%), general storms (36%), and droughts (10%). During this period, Romania reported a total of 83 natural disasters, but there is no reference in this document regarding the types of disasters or data on economic losses and mortality caused by these hazards.

A major impact of prolonged droughts combined with anthropogenic influence is the drying up of lakes; perhaps the most well-known case is that of the Aral Sea, which is considered to be one of the closed seas. The Aral Sea was once considered the third largest lake in the world, but since 1960, its surface area has steadily diminished. Examples could continue with the Caspian Sea, located on the border between Asia and Europe, which could suffer the same fate as the Aral Sea, or with Lake Urmia, an endorheic lake in Iran that was classified as the 6th largest salt lake in the world and which, since the end of 2007, has lost 10% of its surface area of 5200 km2. In 2021, its surface area has been reduced by half.

Hepites [11] mentions that in the absence of drought records, we must rely on historical documents and cites Grigore Ureche's chronicle published in "Letopiseții lui Mihail Kogâlniceanu". Since the moment when observations were recorded, they could be much more rigorous, so in the "Annals of the Romanian Academy," Ștefan Hepites shows that in Romania, the years 1894 and 1896 were among the driest years with a national average of 414 mm and 459 mm, respectively, which is below the multi-year average of 461mm. And the years 1902 (December 1901-April 1902), 1903, and 1904 were also drought years [11].

In Romania, there are several recent examples of lakes drying up. In October 2020, Lake Iezer in Călărași County completely dried up, with an area of approximately 400 hectares (figure no. 11). Lake Amara, located in Buzau County, with an area of over 800 hectares, completely dried up in June 2022 (figure no. 9), and another lake in Satu Mare County, the Moftinu Mic Lake, with an area of over 100 hectares, also dried up (figure no. 10). In Dobrogea, Lake Nuntași-Tuzla suffered the same fate in August 2020 (figure no. 12).

Figure no. 9 - Image of Amara Lake, Buzau County (photo by the author)"

Figure no. 10 - Image of Moftinu Mic Lake, Satu Mare County.

Figure no. 11 - Picture of Lake Iezerul, Calarași county.

Figure no. 12 - Image of Nuntasi Lake, Constanța County

From the presented information, it is evident that:

(i) The problem of drought is a real issue with an impact on every economic sector, ecological systems, and especially on the quality of human life; an example of this is the event that occurred on August 20, 2020, in Nuntași, BH (located in the Litoral Hydrographic Basin), when the Nuntași-Tuzla lake completely dried up. A preliminary study was conducted and presented in the chapter "Drought Land Degradation and Desertification—Case Study of Nuntasi-Tuzla Lake in Romania," published in the book "Water Safety, Security and Sustainability: Threat Detection and Mitigation" by Springer International. In that article, the authors attempted to explain the causes of this event [7];

(ii) There is a national strategy finalized in 2008 regarding the reduction of the effects of drought, but the action and measure plan does not contain any reference to the investigation or analysis method, nor to drought warning;

(iii) There is a guide for preparing drought management plans that transitions from a reactive approach (where only crisis situations are managed) to a proactive approach that involves creating an action plan based on prevention. The aforementioned guide proposes five stages for creating a "Drought Management Plan" (DMP), where at stage four "Developing and Optimizing the DMP and its Publication," seven sub-stages are included, of which two refer to establishing drought characterization indicators and establishing a warning system so that a coherent plan of measures can be established.

The main objective of the doctoral thesis is to analyze the hydrological drought of the Nuntași-Tuzla lake catchment area and its implications in the BH region. To achieve this objective, the specific objectives are:

1. Reviewing the methods for evaluating drought in such a way as to contribute to the understanding of the drought phenomenon in general and hydrological drought in particular;
2. Selecting the study area, collecting and processing data;
3. Describing/characterizing the chosen study area from both climatic and hydrological perspectives, as well as from an economic standpoint;
4. Evaluating the selected drought indices and identifying major droughts, their severity, and seasonality.

In order to elucidate the issues of drought in the study area, to achieve the objectives, and to provide details on the chosen research methods, this work presents in seven chapters the manner in which the objectives were achieved and the results obtained.

Chapter 1 presents the context in which the research on hydrological drought is carried out. Due to their economic and social impact, their importance in water basin management required by the implementation of the Water Framework Directive, and in the context of the August 2020 event when Lake Nuntași Tuzla completely dried up, we consider that the subject is important to be evaluated and analyzed.

Chapter 2 presents the methods and methodologies that have contributed to achieving the objectives of this study. To describe hydrological drought at the BH level of Lake Nuntași, three main types of data are required: digital maps, climate data, and hydrological data. These data were transformed into digital data and a data catalog was created. A review of data analysis methods also allowed us to choose the software with which we can perform the analysis.

Chapter 3 defines drought and the main indicators and indices of drought as revealed in the review of the main sources in the specialized literature. This review allowed us to choose the working method and software with which we can perform the necessary calculations that lead us to the characterization of hydrological drought in the BH of Lake Nuntași-Tuzla.

Chapter 4 contains the presentation of the BH of Lake Nuntași-Tuzla from an administrative, archaeological, climatic, hydrological, pedological, and economic point of view, as well as the presentation of the maps drawn up for this study.

In **Chapter 5**, drought indicators such as precipitation, temperature, and annual flow rates in the BH area of Lake Nuntași-Tuzla are analyzed and constituted into digital time series, thus creating a catalog that is presented in the annexes.

In **Chapter 6**, drought indices are analyzed using the Standardized Flow Index (SSFI), Standardized Precipitation Index (SPI), and Threshold Level Method (TLM), and the results of the analyses are presented.

Chapter 7 is the chapter with the general conclusions of the study, the research perspectives, and recommendations for further research.

2. Research Methods and Methodologies

The methodology used in this paper is a mixed one, based on both qualitative and quantitative methods (figure no. 15).

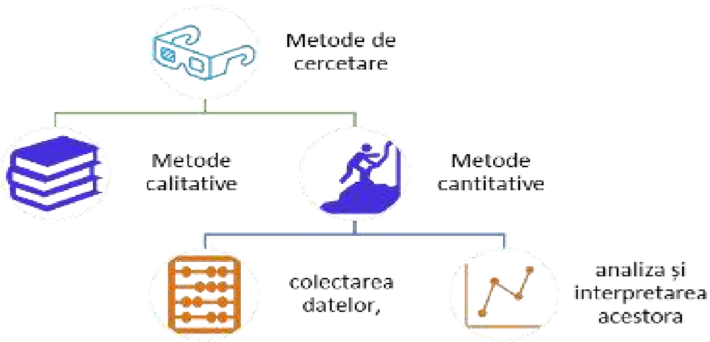

Figure no. 15 - Research Methods

- • Qualitative methods refer to: (i) exploratory methods based on document analysis from the literature on drought, drought indicators (see Chapter 3), data analysis methods (see Chapter 2.3.), and a synthesis of droughts in Romania (see Chapter 1.2.); (ii) exploratory data analysis related to Lake Nuntași-Tuzla from various documents/sources representing a review of various information published over time about the studied BH (see Chapter 4). This review will lead, on the one hand, to the characterization of the Nuntași-Tuzla BH from a morphological, hydrological, climatic perspective, etc., but also to the understanding of drought phenomena that have occurred recently.
- Quantitative methods refer to: data collection, analysis, and interpretation, determination of meteorological and hydrological drought indicators and indices. The data mainly refer to precipitation, temperatures, and mean river flow rates within the BH.

To describe hydrological drought at the level of the Lake Nuntași BH, three main types of data are needed: digital maps, climatic data, and hydrological data.

To describe the hydrological drought at the Nuntași Lake catchment area, three main types of data are necessary: digital maps, climatic data, and hydrological data.

Regarding the creation of digital maps, we will use GIS (Geographic Information System) techniques, which have proven their capabilities in recent years in terms of storing, organizing, and analyzing data from various sources and different types. We will not provide a description of the technique itself but we will mention that we are working with ARCGIS v.10.8 produced by ESRI Canada.

The implementation of GIS at the Nuntași-Tuzla Lake catchment area involves several stages, the most important of which are: (i) data acquisition and (ii) database design.

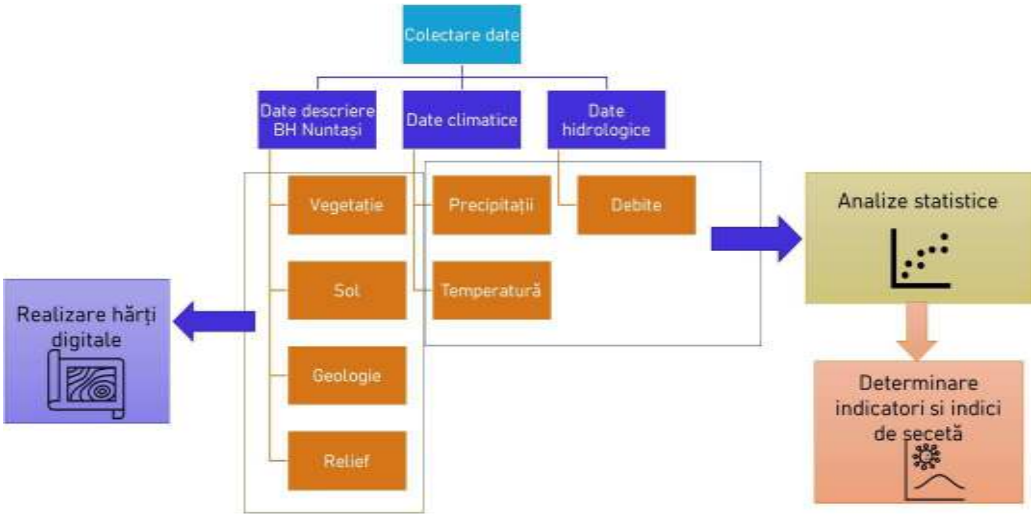

Figure no. 16 - Diagram regarding the methodology used to determine drought indices and indicators

To calculate drought indices and indicators, we will use climatic data related to precipitation, temperature, and hydrological data related to the flows of watercourses crossing the Nuntași-Tuzla lake BH.

For temperature time series, data from nearby meteorological stations should be used.

Therefore, regarding the flows, we had at our disposal three categories of records:

- Annual flows for the period 1965-1979 (from ABADL archives);
- Hard copy (daily flows recorded on measurement sheets of the "National Institute of Hydrology and Water Management" for the period 1979-2015 [3].
- Daily flows recorded automatically for the period after 2015.

3. Drought

Drought is a natural phenomenon that falls into the category of natural disasters due to its negative impact on human life and activity, with multiple implications for the economy. There are many definitions of drought, for example: "a prolonged period of dryness that causes significant damage to crops or prevents their optimal growth or a large water deficit." But none of the definitions like the one presented provide information on the beginning, end, duration or severity of this phenomenon.

Determining the parameters that describe drought is of great importance for water resource management. Regarding the parameters that can describe drought, there are two different notions: indicators and indices.

- Indicators refer to those variables or parameters used to describe drought conditions. Examples include precipitation, temperature, streamflow, groundwater and lake levels, soil moisture and snowpack.
- Indices are numerical representations of drought severity, evaluated using climatic or hydrometeorological inputs, including the indicators listed above. Indices are used to provide a quantitative assessment of the severity, location, and duration of drought events.

For the reasons stated above, two different types of definitions (conceptual and operational) have been proposed by the United States. Operational definitions are formulated in terms of indices, which provide the ability to identify the onset and end of drought as well as its severity. Operationally, the American Meteorological Society in 1997 groups the definitions into four categories:

- **Meteorological**
- **Agricultural**
- **Hydrological**
- **Socio-economic**

i. Indicators of drought

In order to describe the climatic conditions of the Nuntas-Tuzla hydrographic basin, in addition to applying exploratory and statistical analysis, it is useful to determine climographs. Essentially, a climograph is a graph that uses two or three climate indicators (precipitation, temperature, and humidity) and is generally used to identify climates. One of the most well-known is the Gaussen or ombrothermic climograph.

ii. Drought indices

In the European Union, efforts have been intensified to harmonize methods for identifying droughts based on indicators. The World Meteorological Organization (WMO) and the Global

Water Partnership (GWP) produced a "Manual of Drought Indicators and Indices" in 2016 (hereafter referred to as the Manual) [25]. In this manual, drought indices used today in the world are grouped according to ease of use into green - easy, orange - medium, and red - difficult. This grouping by the GWP [25] was based on the following criteria:

Table no. 4 - Drought indices grouped by ease of use

EASY	There is software available online Daily data is not required Missing data is allowed It is widely used
MEDIUM	Multiple parameters are required for calculations The mathematical apparatus complexity is minimal There is no software available online for this system
HARD	There is no developed calculation software Inputs can be modeled parameters with the help of other models The index is not available

Meteorological drought indices

The simplest meteorological drought index was proposed by Palmer [24], called the Palmer Drought Severity Index (PDSI), and is primarily used in the United States.

To eliminate the disadvantage presented earlier, the use of the Standardized Precipitation Index (SPI) was proposed, which is based on the probabilistic distribution of precipitation calculated at different time steps.

To eliminate this drawback, Vicente-Serrano proposes a new index: the Standardized Precipitation Evapotranspiration Index (SPEI).

To characterize agricultural drought, the Crop Moisture Index (CMI) was introduced by Palmer in 1968 [24] and is used for short periods of time.

Hydrological drought indices

The Palmer Hydrological Drought Index (PHDI)

The Standardized Reservoir Supply Index (SRSI).

The Standardized Streamflow Index (SSFI). Modarres introduced SSFI in 2007, and Telesca and others investigated it in 2012. In the initial work, Modarres described how SSFI is calculated, similar to SPI, where SSFI for a certain period is defined as the difference of flow from the mean to the standard deviation.

Streamflow Drought Index (SDI)

Surface Water Supply Index (SWSI).

Beyond this manual, the World Meteorological Organization (WMO) [25] proposes a methodology for characterizing hydrological drought that can be divided into two categories:

(i) determining the minimum flow based on the frequency curve of flows (FDC), the annual minimum flow (MAM), and the base flow index (BFI);

(ii) determining the characteristics of the deficit using the Threshold Level Method (TLM) and the Sequential Peak Algorithm (SPA).

Indicators from category (i) do not provide information on the duration of the drought period, the beginning of the drought, and its end. Methods from category (ii) provide information on the duration of the drought, severity, intensity of the event, and the minimum value of each event.

By analyzing drought indicators found in the specialized literature, we have decided to use the following categories of drought indicators for this study:

- the method agreed upon by the World Meteorological Organization, namely the Standardized Precipitation Index (SPI), and the Standard Flow/Streamflow Index (SSFI)
- methods for determining hydrological drought by determining deficit characteristics (Threshold Level Method - TLM).

The review of the scientific literature on drought indicators and indices allowed us to (i) select those parameters that are available and with which we can perform the necessary calculations, and (ii) the most suitable calculation methods.

Regarding drought indices, we have decided that, according to the available data, the SPI (Standard Precipitation Index) calculation and the SSFI (Standard Flow/Streamflow Index), as well as the TLM (Threshold Level Method) are appropriate for this study.

4. Study area

As mentioned in the previous paragraphs, in August 2020, an unprecedented ecological disaster occurred in the Dobrogea region, namely the complete drying up of Lake Nuntași-Tuzla, an approximately 850-hectare lake. In order to establish the causes that led to this event, we considered that the hydrographic basin (HB) of this lake is the most suitable for achieving the proposed objectives.

From an administrative point of view, the hydrographic basin of Lake Nuntași Tuzla overlaps the territory of several communes in Constanța County - Istria, Săcele, Cogealac, Fântânele, Grădina, and Corbu - and in Tulcea County, the commune of Beidaud. Fântânele, Cogealac, Istria, and Săcele hold 98% of the Nuntași Tuzla HB area.

According to the "Cartographic Server for National Cultural Heritage," two settlements from the late Roman era have been discovered in the study area, namely: (i) 1 km north of the Nuntaşi baths where building materials including late Roman ceramic materials were found; (ii) on the northern bank of the Nuntași stream, at the bridge on the Năvodari-Mihai Viteazu road (300 m E-SE), ceramic elements from the same period were found.

The studied region is part of the Central Dobrogea Plateau, the Istria Plateau subunit, and has a coastal plain aspect (Prispa Hamangia) developed between the Casimcea plateau and the Black Sea, being a combination of marine plains (Săcele and Chituc), sandy barriers, and shallow lakes (Sinoe, Histria, and Nuntași).

Based on the DTM, we obtained the slope map, which shows that the average slope of the terrain in the Nuntași HB is 3.7%.

Table no. 9 - Slope class

Class	Area (mp)	%
0-2	69386410	35%
2-6	91116720	47%
6-9	27186560	14%
9-10	6786094	3%
10-30	1176719	1%
Total	195652503	100%

From the above table (table no. 9), it can be seen that more than 80% of the area is occupied by slopes between 0-6% and only 18% of the basin area is occupied by slopes over 9%. Geologically, the region belongs to the Moesian platform - the Istria formation from the Ediacaran geological period (approximately 635-538 million years ago). The study area is located between the Ostrov-Sinoe fault and the Capidava-Ovidiu fault. The area is made up of limestone and calcareous sandstones, calcareous shales, and marl covered with thick layers of loess ranging from 2 to 30 meters. In the valleys of the Nuntas and Sacele rivers, green shales predominate. These can also be found on a relatively small portion of the eastern shore of the lake.

The climate in the area is temperate continental with marine influences, with average temperatures of 11°C and annual precipitation of approximately 400 mm. There is very little information about the climate of Dobrogea before the region was reintegrated into Romania after 1877. The Annals of Dobrogea 1878-1928 [16] show that the annual average temperature of the city of Constanța, calculated over 30 years (1886-1915), is 11.1°C. The annual average temperature (1886-1915) in Sulina is 11.0°C, and in Balcic it is 11.7°C. In western Dobrogea, the average temperatures are lower (Galați 10.5°C, Brăila 10.8°C, Călărași 10.9°C), which led authors to state that the climate is milder on the coast than in the rest of the territory.

Previous studies on temperature time series from the main meteorological stations in Dobrogea for the period 1965-2005 showed a break in 1998. For the period 1998-2005, the temperature increased on average by 0.8°C, which is in agreement with comparative observations between the two maps. The precipitation map for Dobrogea for that period was obtained by georeferencing the map in ArcGIS. If we analyze this map, we find that precipitation on the coast ranges from 400-500 mm, including the study area of Lake Nuntași-Tuzla. The precipitation values for the investigated period by Hepites are: 406 mm in Mangalia, 412 mm in Constanța, and 431 mm in Cogealac. The Delta area is located below the 400 isohyet; Sulina's average for the period 1884-1899 was 338 mm, and the southern zone is also located in the 400-500 mm range.

Regarding evaporation, data recorded over a period of 25 years (1970-1995) at stations in Constanța County at Mamaia, Siutghiol Lake, and Techirghiol Lake showed that they vary around the multi-annual average of 859-927 mm, which would mean an annual deficit of approximately 400 mm. There are no temperature measurements in BH Nuntași-Tuzla, so we will determine evapotranspiration based on the temperatures recorded at the Jurilovca station.

The natural vegetation of the region is characteristic of the steppe zone.

Table no. 10 - Types of vegetation

Types of vegetation	% din total
Water accumulations	0.03%
Swamps	0.96%
Natural meadows	1.13%
Secondary pastures	4.78%
Discontinuous urban space and rural space	5.30%
Arable land	82.04%
Predominantly agricultural land mixed with natural vegetation	0.42%
Industrial or commercial units	1.98%
Vineyards	2.04%
Areas of complex crops	1.34%

Captain M.D. Ionescu specifies in his work that the main use of Lake Tuzla (today Nuntasi-Tuzla) was for salt production "by capture", given that the lake had salt water. Until 1897, there were five salt deposits on the shore of the lake. Today, this economic activity no longer exists. In the same document, he also shows that after animal husbandry, the main economic activity in Dobrogea was fishing. In the period prior to 1989, the existence of sapropelic mud [4] contributed to the development of therapeutic tourism.

Today, the region's economic activity is based on agriculture and animal husbandry, accounting for over 60%, and 15.3% in industry (mainly construction).

For a long time, it was believed that Lake Nuntasi-Tuzla was formed as a result of marine transgression and coastal processes [4], like most lakes on the Black Sea coast. However, recent research based on archaeological and geomorphological studies conducted by researchers from the University of Bucharest has shown that Lake Nuntasi-Tuzla is of tectonic origin.

Lake Nuntasi-Tuzla is part of the Razim-Sinoe lagoon complex. This lagoon complex is formed on the old Halmiris gulf and is connected to both the Black Sea and the St. George branch. Gâștescu and Braier [18] state that the main channels that connect to the St. George branch are Lipovenilor, Dunavăţ, Dranov, and indirectly, the Perișor-Belciug canal. The connection to the Black Sea is made through the so-called "gates" or "periboine." These are Gura Portiţei - in front of Lake Goloviţa -, Periteșca Leahova in front of Lake Razim, and in front of Lake Sinoe, Periboina and Edighiol.

This area has undergone major transformations in the last 120 years. Human interventions in this area could be divided into three categories: canalization phases, construction phase of polders. The Danube Commission, established in 1856, introduced the idea of developing agriculture in the Danube Delta with the stated goal of transforming this area into the granary of Europe.

The Razim irrigation system, known as the Razim Irrigation Complex, is comprised of the following units: (1) the Razim hydrotechnical system (72,500 ha) and (2) six irrigation systems (121,089 ha), and operated at maximum capacity from 1976 to the 1990s.

The BH (water intake) of Lake Nuntas-Tuzla is located within the Sinoe irrigation system (57,162 ha). The water source is a feeding station (SPA Sinoe) located on Lake Golovita, designed for a flow rate of 46.1 mc/s and a pumping height of 55.7 m.

In the following table, we have synthesized some of the geometric parameters and relief parameters referring to the BH of Lake Nuntas-Tuzla. The surface area and perimeter of BH, altitude and average slope, and length of watercourses are extracted using ArcGIS software and have extremely precise values..

Table No. 11 - Geometric Parameters of the Nuntasi-Tuzla Water Basin

Geometric Parameters of the Nuntasi-Tuzla Water Basin		**Valoare**
Surface area	A	195.791km^2
Perimeter	p	84.46 km
Gravelius coefficient	c_f	1.70
Equivalent rectangle Length Width Equivalent rectangle index	 L_d B_d I_d	 36,93km 5,30km 6,96
Relief parameters		
Altitude	H	100,6m
Mean slope	i_{med}	3,7%
General slope (global slope index)	i_G	0,43%
Morphometric parameters		
Length of watercourses	$L_p+\Sigma l_i$	52090,54m
Drainage density	D_d	0.000266

5. Time series data

For the study of drought in the Nuntasi-Tuzla lake basin area, meteorological data (precipitation and temperature) and hydrological data (discharge) were obtained from the National Meteorological Agency (ANM) and the National Institute of Hydrology and Water Management (INHGA), respectively. As mentioned in previous chapters, the time series of precipitation, temperature, and discharge cover the following time intervals:

Table no.12 - Time series data

Parameter	station	period	type
Precipitation	Nuntași and Săcele	1965-1978	Monthly averages
		1978-2021	Daily averages
Temperature	Jurilovca	1965-2021	Monthly averages
Flow rates	Nuntași and Săcele	1965-1978	Annual averages
		1979-2021	Daily averages

Based on these series, we have created the following types of digital time series for each parameter, thus creating a catalog presented in the annexes:

• **Precipitation:**

o Annual series from 1965 to 2021

o Series of annual maximum/minimum values from 1965 to 2021

o Series of monthly averages from 1978 to 2021

o Series of daily averages from 1979 to 2021

o Series of multi-annual monthly averages

o Series of multi-annual monthly minimum and maximum values

• **Temperature:**

o Series of annual averages from 1965 to 2021

o Series of monthly averages from 1965 to 2021

o Series of annual maximum/minimum values from 1965 to 2021

o Series of multi-annual monthly averages

o Series of multi-annual monthly minimum and maximum values

• **Flow rates:**

o Annual series from 1965 to 2021

o Series of monthly averages from 1979 to 2021

o Series of daily averages from 1979 to 2021

o Series of annual maximum/minimum values from 1979 to 2021

o Series of multi-annual monthly averages from 1979 to 2021

o Series of multi-annual monthly minimum and maximum values

The multiannual average of precipitation for the period 1965-2021 at the two hydrometeorological stations does not differ much (448 mm at Nuntași station compared to 435 mm at Săcele station). By performing a weighted average (with surface area), it is found that the average precipitation on the BH Nuntași-Tuzla is 444.6 mm.

Also based on visual analysis, the following observations can be made: (i) during the period 1965-1979, the recorded values for annual precipitation are above average (10 values at Nuntași station and 12 values at Săcele station out of 15 recordings), (ii) during the period 1980-1994, the annual precipitation is generally below average (10 values at Nuntași and 10 at Săcele out of 15 recordings), (iii) during the period 1995-2010, there is an increase in the value of annual precipitation above average (11 values at Nuntași and 11 values at Săcele out of 16 recordings), (iv) after 2010 there is a period of low values, below the multiannual average, except for the year 2021.

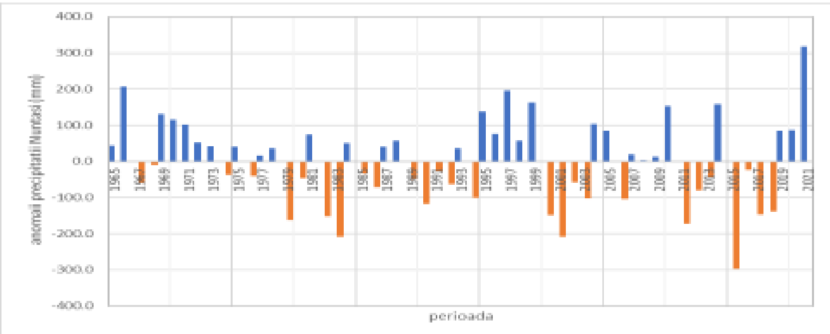

Figure no. 51 - Anomaly graph compared to the average at Nuntași station

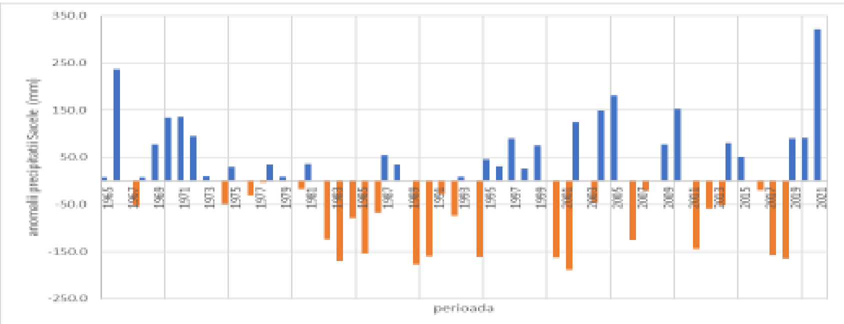

Figure no. 52 - Anomaly graph compared to the average at Săcele station

Analyzing the two graphs presented in figures 51 and 52, we can see that out of the 57 recordings at the Nuntas and Sacele stations, 30 and 31 years respectively are above the average and 27 and 26 years respectively are below the average, which means that approximately 47% of the time represents periods of aridity/drought. As observed from the visual analysis of the precipitation variation graphs over time at the two stations, several distinct periods can be detected, namely: (i) 1965-1979, a period with more positive anomalies, indicating a rainy/wet period (10-11 cases out of 15); (ii) 1980-1994, a period with negative anomalies that can be considered a drought period - with 10-11 years below average out of 15 cases; (iii) 1995-1999, a rainy period; (iv) 2000-2018, a period dominated by periods of negative anomalies (12 and 11 out of 17) and (v) 2019-2021, a period with positive anomalies.

Analyzing the graph presented in figure 55, we can see visually that starting from 2004, there are no temperatures below the multiannual average of 11.3°C.

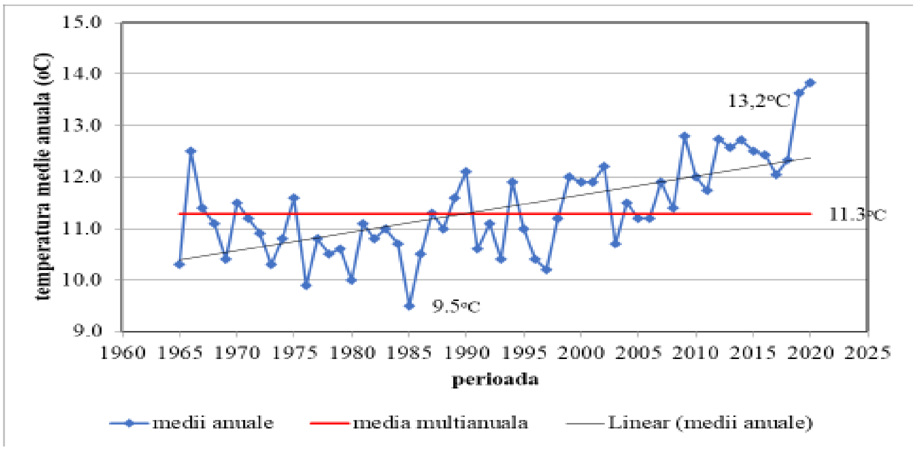

Figure no. 55 - Temperature variation at the Jurilovca station

For the annual mean temperature series, the test shows that the series has two breaks, one in 1997 and one in 2006, confirming the results of the Lee & Heghinian and Pettitt tests.

As a result of testing for the existence of breaks, the series is divided into three subsets. The multiannual average temperature for each subset is 11.6°C, 12.6°C, and 13.3°C, respectively. Consequently, the temperature has increased by approximately 1.7°C after 1997.

The below graph (Figure no. 58) shows the multiannual average minimum, maximum, and mean temperatures at the Jurilovca station, along with variations in the main meteorological factors.

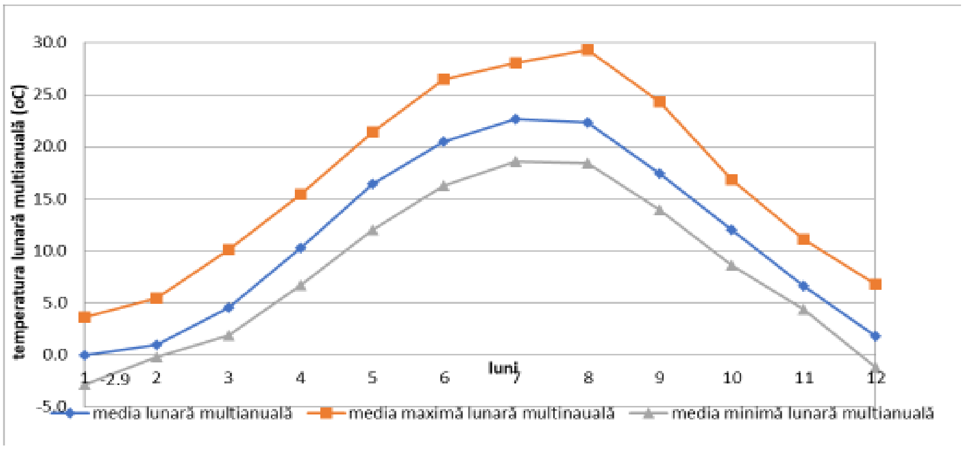

Figure no. 58 - Representation of the variations of the main meteorological factors

We note that the multianual monthly averages of temperature range from -0.3°C (January) to 22.7°C (July). The multianual monthly minimums range from -2.9°C (January) to 18.6°C (August), while the multianual monthly maximums are between 3.6°C (January) and 29.2°C (August). The coldest month is January, and the warmest are July and August.

As shown in Figure 63, we present the variation of annual average flows at the two hydrometric stations, Nuntași and Săcele. We remind that we have the annual series for the period 1965-1978 and the daily series for the period 1979-2021. Based on the daily series corresponding to the period 1979-2021, we determined the monthly average flows and calculated the annual flows. The multianual average flow for the Nuntași river is 0.348 m3/s and 0.082 m3/s for the Săcele river.

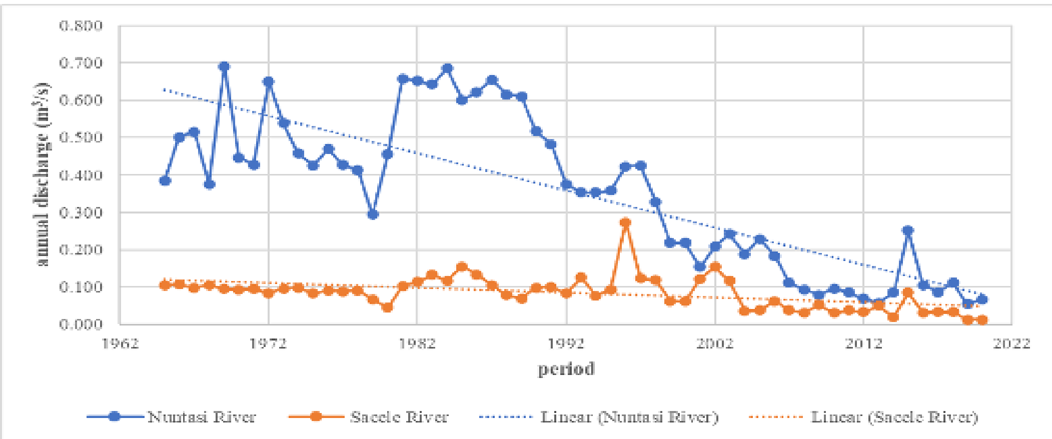

Figure 63 Shows the variation of annual flows at the Nuntași and Săcele stations

As shown in the following table (Table 14), the calculated average for each detected sub-series period through the Hubert procedure corresponded to different stages of hydraulic works implemented in the study region and described in the previous subsection.

Table no. 14 - Multi-year averages for each sub-series detected with the Hubert test

Hydrometric station	**Subseries**	**Multianual means (m3/s)**	**Observations**
Nuntași	1965-1980	0.467	Before the operation of the irrigation system (IS)
	1981-1989	0.638	(IS) in operation
	1990-1996	0.409	Partial interruption of (IS)
	1997-2006	0.239	Total interruption of (IS)
	2007-2020	0.092	Temperature increasing
Săcele	1965-2003	0.104	Smaller and more compact BH
	2004-2020	0.037	

For the Nuntași River, during the maximum period of exploitation of the irrigation system (1981-1989), the multiannual flow rate average is 1.4 times higher than the previous period (1965-1980). This increase is due to the infiltration resulting from the water used for irrigation. The borehole installed in the region by the former Office of Land Improvement showed an increase in the groundwater level. Moreover, after 1989, the multiannual flow rate for the period 1990-1997 returned to the baseline level (1965-1980) and continued to decrease, reaching a dangerous level (6.75 times lower than the average annual flow rate for the period 1965-1980).

We cannot deduce why the Săcele River has a different behavior, but it is certain that the surface area of the Săcele BH is 2.8 times smaller than that of the Nuntași BH (S. B.H. Săcele = 51,028 km^2), and the decrease in the flow rates of the Săcele River is only 3.1 times.

The analysis carried out for the three indicators allows us to determine the water budget of the Tuzla-Nuntași lake BH (figure no. 69).

From the presented figure, it is evident that the annual budget is negative, and starting from 1998, the amount of water brought by the two tributaries (Nuntași and Săcele) has significantly decreased. The volume of precipitation has increased since 2012, but the losses through evapotranspiration are much higher than the increase in precipitation. There is no information regarding the groundwater regime and its proportion in the water budget.

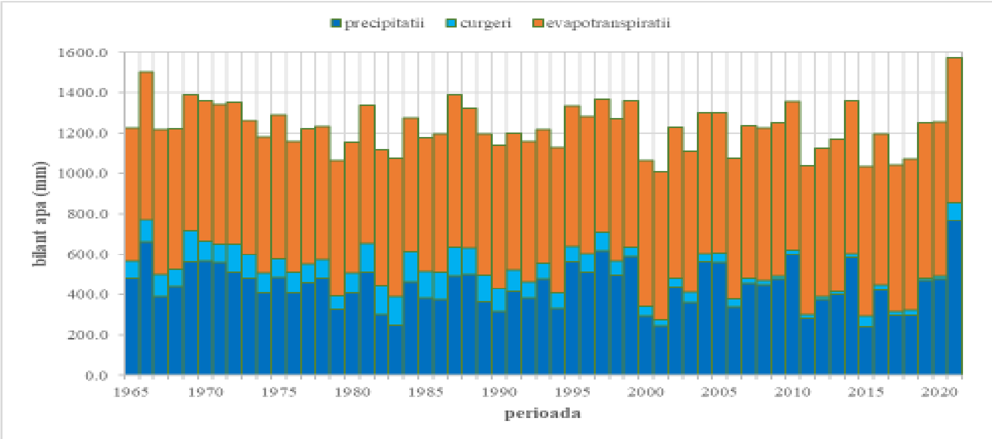

Figure no. 69 - Water budget for the Nuntași-Tuzla lake

6. Calculul indicilor de secetă

After creating the time series, the analysis of indicators (precipitation, flow rates, temperatures) was carried out, which was presented in the previous chapter (Chapter V). After the analysis, the next step was to calculate drought indices.

From the analysis of the methods that can be used (presented in the methodology chapter), for this study, the Standardized Precipitation Index (SPI), the Standardized Streamflow Index (SSFI), and the Threshold Level Method (TLM) were used based on 56 years of monthly observations of precipitation and flow rates recorded at the two existing hydrometeorological stations in the Nuntași-Tuzla lake watershed..

Table no. 15 - Classes of variation for the SPI index

Anomaly	Value range	Regime	Cod
positive	SPI>2	Very wet	FU
	1.5<=SPI<=2	Wet	U
	1.0<=SPI<=1.5	Moderately wet	MU
normal	1<=SPI<=0	Slightly wet	UU
	-1<=SPI<=0	Mild drought	SU
negative	-1.5<=SPI<=-1	Moderately dry (moderate drought)	SM
	-2<=SPI<=-1.5	Dry (severe drought)	SS
	SPI>-2	Extremely dry (extreme drought)	SES

Some conclusions can be drawn from these graphs (figure no. 73 and table no. 16) and the results can be divided into the following periods:

• 1965-1979 (May 1979): a 14-year period in which most of the observations are in the area of an SPI-12 greater than zero, with periods above the value of 1; the period can be characterized as slightly wet. Only the year 1968 was slightly dry (with an average SPI-12 of -0.05) and the year 1974 (with an average SPI value of -0.23).

• 1979-1995: in this 17-year period, periods of drought alternated with wet ones in which drought periods predominated, but which on average only occasionally exceeded SPI-12 values of -1. In other words, this period was marked by a slight drought with a few months of moderate drought in 1980 and 1983.

• 1997-1999: a six-year period with higher humidity, which can be classified as a wet period, with SPI-12 values ranging between -0.8 and 2.36.

• 2000-2003: a period that falls between moderate and severe drought.

• 2004-2016: a period of alternating drought and wet periods, but the frequency of droughts is higher, with values that exceed -4. Moreover, the year 2018 can be characterized as one with extreme drought.

• 2019-2020: a period characterized as wet; the year 2020 has SPI-12 values between 0 and 1, so the period was slightly wet.

The frequency distribution of drought occurrences for the classes in the above table (table no. 15) is almost normal. From figure no. 73, it can be seen that 69% of SPI values are in the normal class, of which 29% refer to mild droughts. The other types of drought add up to 17% compared to 14% of values in the area with SPI-12 greater than 1, of which 3% are represented by severe droughts, with an index above -2. The longest drought periods are presented in table no. 16.

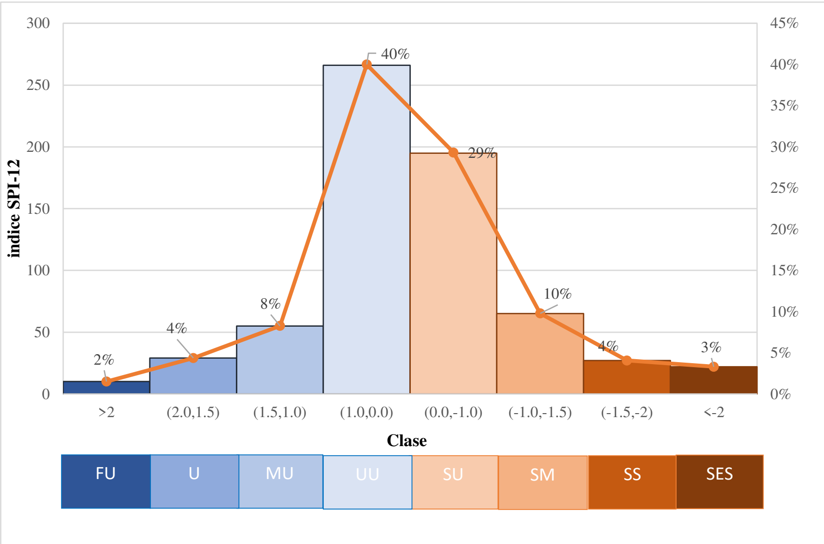

Figure no. 73 - Distribution of absolute and relative frequencies at the Nuntasi station

Table no. 16 - Characteristics of droughts at the Nuntasi station

Nuntași / SPI-12 interval	start	end	duration (months)	maximum SPI-12	average SPI-12	Code
>-1	12/1/1979	3/1/1981	15	-1.39	-0.94	SU
	1/1/1983	4/1/1984	15	-1.7	-1.13	SM
	9/1/1990	7/1/1991	10	-1.11	-0.68	SU
	1/1/2001	1/1/2003	24	-2.02	-1.3	SM
	5/1/2007	11/1/2007	6	-1.58	-1.27	SM
	10/1/2011	10/1/2013	24	-1.21	-0.72	SU
	12/1/2015	12/1/2016	12	-2.45	-1.25	SM
	5/1/2017	9/1/2019	28	-4.93	-2.6	SES

As in the case of the results from Nuntași station based on Table 18, the study period can be divided into several sub-periods, namely:

• 1965-1973 is a period in which there are almost no drought periods or they are minor droughts (with values ranging from 0 to -1), the period being declared, on average, a moderately wet period; this period is shorter than at the Nuntași station;

• 1974-1999 is a period that can be declared as more drought-prone with mild droughts, which presents several episodes of moderate and even severe droughts; it can be subdivided into sub-periods;

• 2000 September - 2003 August is a period of moderate drought with sub-periods of extreme drought;

• 2003-2006 is a period that varies from slightly wet to moderately wet;

• 2006-2021 is a period in which drought periods alternate with wet ones, but we can notice that the droughts become much more severe towards the end of the period (2017-2018), when the SPI-12 values reached values above -2; in the period 2020-2021, the SPI values are above 0, and 2021 is characterized as being wet.

At the Săcele station, as in the case of the data from the Nuntași station, the frequency distribution of drought occurrence is almost normal. We observe (Figure 76) that 66% of the SPI-12 index values are in the normal class, of which 31% represent mild droughts. We note that 9% represent moderate droughts, 8% severe droughts, and 2% extremely severe droughts.

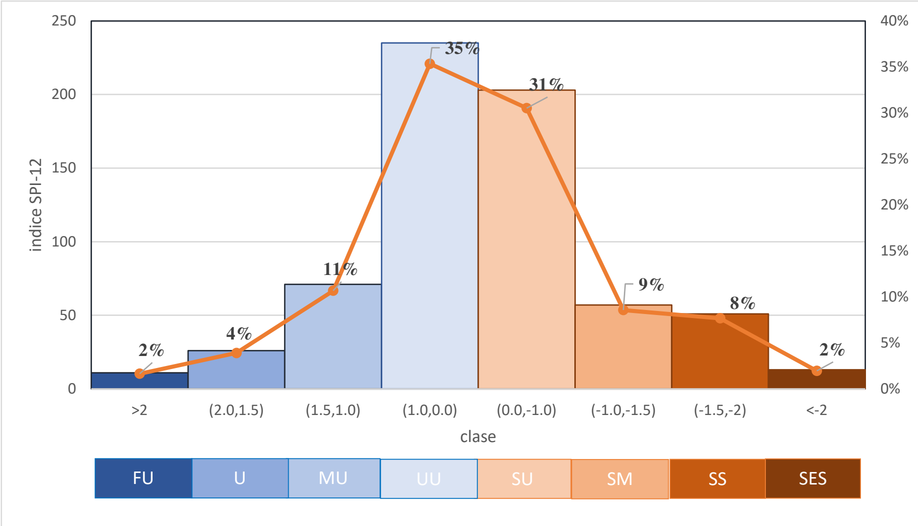

Figure no. 76 - Distribution of absolute and relative frequencies at the Săcele station

Table no. 18 - Characteristics of droughts at the Săcele station

Sacele / SPI-12 interval	start	end	duration (months)	maximum SPI-12	average SPI-12	Code
>1	5/1/1974	8/1/1975	15	-1.09	-0.32	SU
	2/1/1983	7/1/1987	53	-1.82	-0.79	SU
	7/1/1989	7/1/1991	24	-1.5	-1.19	SM
	7/1/1994	11/1/1995	16	-1.43	-0.78	SU
	12/1/2000	9/1/2002	21	-2.02	-1.48	SM
	2/1/2007	4/1/2008	14	-2.31	-1.21	SM
	5/1/2013	9/1/2013	4	-1.15	-0.76	SU
	5/1/2017	9/1/2019	28	-4.94	-2.33	SES

Regarding the duration of droughts, we observe that there are long periods of drought, the longest (53 months) being between February 1, 1983 and July 1, 1987. The shortest period was in 2013 between May and September. On average, drought lasts 21.8 months.

As for the variation of the SSFI-12 index for the Nuntași river throughout the calculation period, we note that from 1979 to 1999 (21 years) the Nuntași river only presented values up to 1, except for the period 1981-1984 when the values were above 1, even above the value of 2 (in 1981 and 1982). From 1990 to 1999, the values of the SPI-12 index decreased constantly, and starting from 2000, the Nuntași river entered into a prolonged drought, in which the SPI-12 values constantly decreased (with the exception of the period 2004-2007 when the values were on average -0.2), culminating in SPI-12 index values ranging from -1.07 to -2.81 in the period 2018.

The absolute and relative frequency distributions are presented in the following figure (Figure 78). As with the SPI-12, the frequency distribution approaches a normal distribution. More than half of the Nuntași river discharges fall into different forms of drought. We find that 61% of the values are classified in the (1.0) and (0,-1) classes, of which 30% are mild droughts, 22% are moderate droughts, 1% are severe droughts and there are no extreme droughts.

At the Săcele station, the situation is somewhat similar to that at Nuntași, in the sense that we observe a wet period that begins in 1982 and, with very short periods of drought, lasts until 2004, after which a prolonged drought period follows, until the end of the study period.

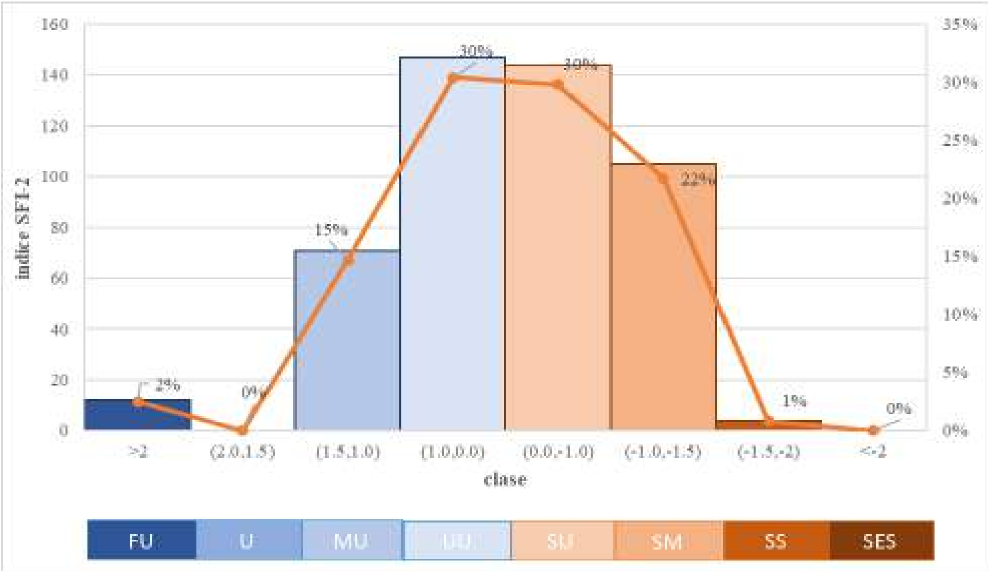

Figure 78- Absolute and relative frequency distribution for the Nuntași river

From the point of view of frequency distribution, as in all cases, it is almost a normal distribution with 68% of the recorded values located in the normal period, of which 22% are mild droughts. 12% are moderate droughts and 5% are severe droughts. Unlike the Nuntași station, at Săcele there are 2% extremely severe droughts (Figure 80).

Table 19 - Characteristics of droughts at Săcele station

Săcele / SSFI-12 interval	**început**	**sfârșit**	**durata (luni)**	**SSFI-12 maxim**	**SSFI-12 mediu**
>-1	8/1/2008	11/1/2015	87	-2.66	-1

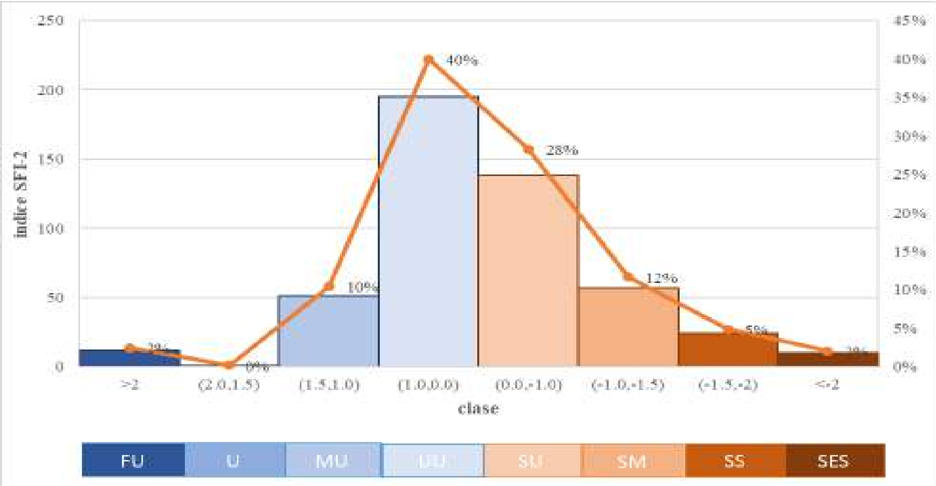

Figure no. 80 - Distribution of absolute and relative frequencies for the Săcele river

As there are no more than two hydrometeorological stations in the studied area, we cannot evaluate the drought phenomenon spatially. However, we can affirm that after the year 2000, a period has been established in which BH Nutași-Tuzla is characterized by a medium-level meteorological drought (-1.16) when medium and/or severe meteorological droughts occur. We mention the following periods: 2001-2003, 2012-2013, 2015-2016, 2017-2019. If the average duration of drought in the period from 1979-1991 was 15 months, in the period after 2000, they were on average 19 months. As the SPI-12 indicator has the ability to demonstrate the influence of precipitation deficiency on hydrological factors, such as river discharge, these droughts in the BH of the Nuntași-Tuzla lake undoubtedly had repercussions on the hydrological regime.

The Threshold Level Method (TLM) is a method that involves determining excesses/deficits in a time series based on the existence of a characteristic level and comparing each value in the series with this level. In the case of hydrological time series, this threshold can be determined by:

• Determining the flow-frequency curve and extracting the values corresponding to the probabilities of exceeding 75%, 80%, 90%.

• Using the technique of separating base flow from total flow.

• Analyzing the decreasing curves of the discharge hydrographs.

For this study, we chose to determine the "Flow-Frequency Curve" (FDC), a curve that is created using the probabilities of exceeding and the corresponding flows and shows the percentage in which the flow of a river is likely to equal or exceed a specified value. As Tallaksen [20] stated, probabilities from the 70-90% range are reasonable to be used for rivers with permanent flows. For this study, we determined the values of the flow corresponding to the probability of 90%, 80%, and 75%, noted as Q90%, Q80%, respectively.

Table no. 20 - Values corresponding to probabilities for the Nuntasi and Sacele stations.

P_Q (%)	Q ($m^3 s^{-1}$) - Nuntași	Q ($m^3 s^{-1}$) - Săcele
90	**0.056**	**0.02**
80	**0.083**	**0.03**
75	**0.108**	**0.03**

To begin with, we calculated with a constant threshold value, by introducing the flow values corresponding to probabilities of 90% (according to table no. 20). The input data are represented by daily mean flows. The results obtained for the Nuntași sub-basin using a Q90% threshold of 0.056 m3/s reveal that there was no flow deficit until August 2007.

Moreover, the calculation shows that, for the Nuntași River, there were 61 periods of hydrological drought with durations ranging from 1 day to 225 days (in 2021), in the period 2007-2021, not considering the period January 2017 - March 2018, for which we do not have data. Figure 83 below shows the evolution of flows and deficits for the years 2013, during which 200 days of hydrological drought were recorded. On the other hand, if in the period 2007-2011 the number of drought days was below 100, after 2011 the situation worsened in the sense that the number of days of hydrological drought increased to over 200 days.

At the Săcele station, 42 periods of drought were identified, of which the period from 2017 to March 2018 had to be eliminated because there are no records for that period. Unlike Nuntași, there is a small drought period at Săcele in the period 1979-1982, with a maximum of 5 days (1979). Repetitive periods of hydrological drought began in 2000, reaching highs in 2007 (51 days), 2014 (119 days), 2019, and 2020.

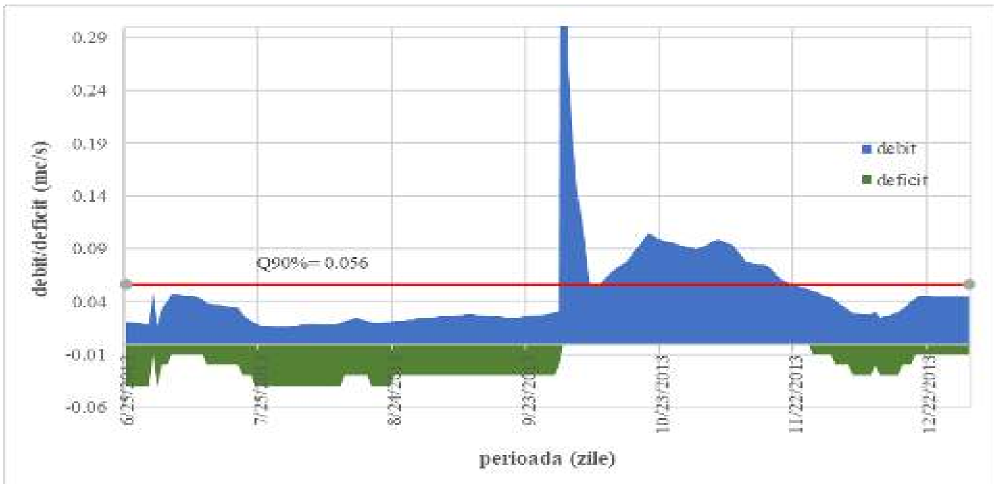

Figure no. 83 - The evolution of flow rates and deficits in 2013 at the Nuntași station

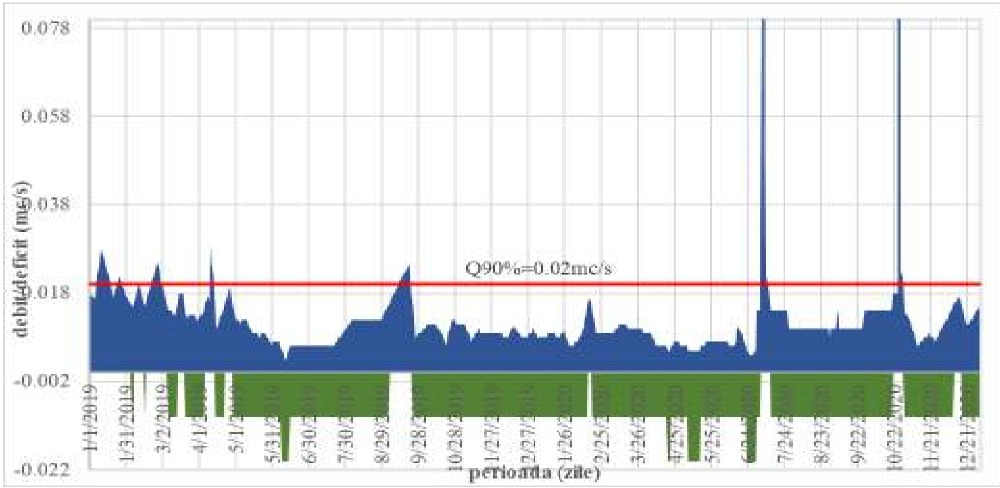

Figure no. 85 - The evolution of flows and deficits for the year 2019 at the Săcele station

What we noticed is that generally, the droughts identified by both SSFI-12 methods coincide with the droughts known in the literature from 2002, 2003, 2007, 2012, etc. For the Nuntași-Tuzla BH, we did not identify the hydrological drought from 2003 by the TLM method with a constant threshold, and then we thought to improve the results by applying a variable threshold. We chose the daily threshold with a value equal to Q90%, which is the flow with a probability of 90%. The results obtained for the Săcele sub-basin indicate 360 (excluding the years 2017 and 2018) periods of drought ranging from 1 day to 468 days. The advantage of choosing this type of threshold is not only the partial elimination of daily hydrological droughts but also the identification of droughts from before the year 2000.

It is certain that until the year 2000, there were no periods of hydrological drought. Certainly, the cause was the increase in flows from both rivers, either by increasing the base flow, as a result of the infiltration of irrigation water and the increase of groundwater flow, or even by discharging water from the irrigation systems at the end of the irrigation season. It practically took 10 years from the decrease in the functioning of the irrigation systems, and 4 years from the total interruption of their functioning, until the BH began to react. Everything culminated in the actual drying of the Nutași-Tuzla lake in August 2020.

7. General conclusions and research perspectives

This work was conducted in the context of the complete drying up of the Nuntași-Tuzla Lake in August 2020. This situation, combined with (i) studies showing that periods of meteorological drought in Romania over the past two decades have led to significant material damage and forecasts for the coming decades are favorable for temperature increases of over +1˚C (see Chapter 1), (ii) Romania's National Drought Strategy, published in 2008, which is practically not being implemented, and (iii) although the European Commission has proposed that river basin management plans include drought risk management (at least the RBMP for Dobrogea for the period 2016-2021), they do not contain elements that would lead us to believe that the EC's recommendations have been put into practice. In this context, I aimed to contribute to understanding the phenomenon of drought, especially hydrological drought, in the Nuntași-Tuzla Lake area through the obtained results. The methods and methodology used can be included in future management plans by the Romanian Waters-ABA Dobrogea-Litoral and can be transferred to other areas of Dobrogea for the characterization of hydrological drought and other river basins.

The final conclusion is that there were no periods of hydrological drought until 2000. The cause is certainly the augmentation of the river flows, either by increasing base flow due to the infiltration of irrigation water and increased groundwater flow or even by discharging water from irrigation systems at the end of the irrigation season. We do not rule out the idea of illegal use of water from the two rivers for irrigation of gardens in the surrounding localities. Everything culminated in the actual drying up of the Nutași-Tuzla Lake in August 2020.

Wondering if there were other such partial droughts in other years, a study was conducted which is not fully discussed in this thesis, but deserves to be discussed. This study refers to the determination of the surface of the Nuntași-Tuzla Lake using remote sensing. For this study conducted by Prof. Serban Cristina and Prof. Maftei Carmen, satellite images were used for the period 1984-2020, and it was determined that the lake area decreased in the summer of 2013 when practically the southern part of the lake (Tuzla Lake) disappeared and in the summer of 2012 when part of the Tuzla Lake area decreased.

n the context presented in this study, a drought management plan needs to be developed for the entire Dobrogea region. The main purpose of such a plan is to ensure both the protection of the natural ecosystem and the implementation of measures to reduce the impact of natural hazards such as droughts. Based on the methodology and methods used in this work, such a plan should contain:

• The current stage of the analyzed area containing a thorough analysis of all conditions: meteorological, hydrological, pedological, ecological, geological, social, etc.

• Making an inventory of data and analyzing this data

• Permanent monitoring of parameters that lead to droughts

• Determination of droughts by drought indicators and indices in accordance with the inventoried data.

• Determination of drought risk

• Creating a warning system

• Determination of a plan of measures

To conceive such a plan, good cooperation and communication must be ensured between research institutions, universities, and administrative institutions, including involving the population..

Personal contributions

Essentially, the study conducted and presented in this doctoral thesis is one that has not been done before for the Nuntași-Tuzla hydrographic basin. We do not consider it unique, but it provides a series of personal contributions that can be divided into the following categories:

- Conducting a thorough study of the main indicators and indices used today worldwide for drought detection, which allowed us to use the most appropriate methods and tools to achieve the stated objective;
- Developing a relevant methodology to achieve the stated objective;
- Conducting a chronological study of drought in Romania based on older documents such as Chronicles, information from Hepites, the founder of Romanian meteorology, and current information; using the first meteorological maps made in Dobrogea after 1877, georeferencing them and transforming them into digital maps, we managed to classify the Nuntași-Tuzla hydrographic basin from a meteorological perspective into temperature and precipitation classes from that time;

- Creating an adequate digital database for:

  Studying and characterizing the Nuntași-Tuzla lake hydrographic basin; we created a number of 14 digital maps.
- o Meteorological and hydrological parameters needed in drought studies; we created a digital data catalog that includes daily precipitation and flow data for the two stations in the studied hydrographic basin and a catalog of monthly temperature data for the station near the Nuntași-Tuzla hydrographic basin for the entire study period.

- Characterizing the Nuntași-Tuzla hydrographic basin from an administrative, climatic, hydrological, geological, pedological, vegetation, and economic point of view. The final conclusion is that the function of Nuntași-Tuzla Lake, that of therapeutic tourism, can no longer be maintained.
- Conducting a chronological study of human intervention in the study area.
- Determining meteorological and hydrological drought with the identification of major hydrological droughts that led to the August 2020 even.

Perspectives

This work opens up new horizons and new challenges, future research should focus on:

- Testing the TLM method for determining deficit/excess flow using different threshold values, to define a clear methodology for using this method;
- Testing the Sequential Peak Algorithm (SPA) method that was not used in this work and comparing the results with those obtained using the TLM method;
- Determining drought risk;
- Using remote sensing methods to extract temperatures and precipitation because obtaining these values from specialized institutions is often difficult if not impossible.
- Using drought indices derived from satellite images such as NDVI (Normal Difference Vegetation Index) and comparing the results with drought indices calculated by classical methods.
- Using another program that uses a different function than the Gamma function to improve the results of SPI modeling.

An important problem that has emerged recently is rapid drought ("flash drought"). This type of drought is short-lived and its theoretical concept is not yet fully defined but it arouses great scientific interest.

Selective Bibliography

1. Administratia Bazinala de Apă Dobrogea-Litoral (2019) Proiect “Reducerea eroziunii costiere Faza II (2014-2020)”

2. Administrația Națională „Apele Române”. (1956) Insitutul Naţional de Hidrologie şi Gospodărire a Apelor. In: INHGA. https://www.hidro.ro/

3. ANM Administrația Națională de Meteorologie. https://www.meteoromania.ro/

4. Ariadna Breier (1976) Lacurile de pe Litoralul Românesc al Mării Negre. Studiu Hidrogeografic. Editura Academiei Republicii Socialiste România, București

5. Carmen Maftei, Alina Bărbulescu (2008) Statistical Analysis of Climate Evolution in Dobrudja Region. Proceedings of the World Congress on Engineering 2

6. Carmen Maftei, Alina Bărbulescu (2009) Frequential Models for the Precipitation Evolution in Romania. Analele Universitatii Ovidius, Seria Construcţii 1:73–81

7. Carmen Maftei, Gabriel Dobrică, Constantin Cerneagă, Nicușor Buzgaru (2021) Drought Land Degradation and Desertification—Case Study of Nuntasi-Tuzla Lake in Romania. In: Water Safety, Security and Sustainability. Advanced Sciences and Technologies for Security Applications. Springer International Publishing, Cham, Switzerland, pp 583–597

8. Constantin Brătescu (1928) Pământul Dobrogei, 1st ed. Editura Cultura Națională, București

9. Cristina Șerban, Carmen Maftei, Gabriel Dobrică (2022) Surface Water Change Detection via Water Indices and Predictive Modeling Using Remote Sensing Imagery: A Case Study of Nuntasi-Tuzla Lake, Romania. Water 2022 14:556. doi: https://doi.org/10.3390/w14040556

10. Gustard A. (1983) Regional variability of soil characteristics for flood and low flow estimation. Agricultural Water Management 6:255–268. doi: https://doi.org/10.1016/0378-3774(83)90013-6

11. Hepites C. Stefan (1906) Secetele în România. In: Buletinul Societăţei Geografice Române., Anul XXVII. Bucuresti

12. IDMP (2013) Integrated Drought Management Programme in Central and Eastern Europe

13. Lena M. Tallaksen, Henny A.J. Van Lanen (2004) Processes and estimation methods for streamflow and groundwater, 1st ed. Elsevier, Amsterdam

14. Maftei C, Barbulescu A (2008) Statistical analysis of climate evolution in Dobrudja region. In: Proceedings of the World Congress on Engineering. pp 2–4

15. Maftei Carmen (2013) Hydrological Drought Assessment in the Dobrogea Region. In: Statistical Hydrology. Kos Island, Greece

16. Michael J. Hayes (2006) Drought Indices. In Van Nostrand's Scientific Encyclopedia. doi: https://doi.org/10.1002/0471743984.vse8593

17. Nicolae Grumezea, Cristian Kleps, Corneliu Tușa (1990) Evoluția nivelului și chimismului apei freatice din amenjările de irigații în interrelație cu mediul înconjurător. Întreprinderea poligrafică Oltenia, București

18. Petre Gâștescu, Ariadna Breier (1973) Complexul Razim - Sinoe - Geneză, morfometrie şi regim hidric. Peuce Journal 49–76

19. Ștefan C. Hepites (1896) Repartițiunea ploaiei pe districte și pe basinuri în România. Buletinul societații politehnice 350–353

20. Tallaksen L. M., Van Lanen. H.A. (2004) Hydrological Drought. Processes and Estimation Methods for Streamflow and Groundwater, Developments in Water Science. Developments in Water Science 48:579

21. V. U. Smakhtin (2001) Estimating continuous monthly baseflow time series and their possible applications in the context of the ecological reserve. Water SA 27:213–218

22. Valentin Bulgăreanu, Gh. Momea, Lucia Momea (1974) Unele considerații

23. Wayne C. Palmer (1965) Meteorological Drought. In: Research paper no.45. U.S. Depatament of commerce, Washington, p 58

24. Wayne C. Palmer (1968) Keeping Track of Crop Moisture Conditions, Nationwide: The New Crop Moisture Index. Weatherwise 21:156–161. doi: https://doi.org/10.1080/00431672.1968.9932814

25. WMO, GWP (2016) Handbook of Drought Indicators and Indices. Global Water Partnership, World Meteorological Organization

26. WMO (2012) Standardized Precipitation Index User Guide. In: WMO-No. 1090. p 24

27. WMO-No. 168 (2020) Guide to Hydrological Practice

28. World Bank (2018) From Uneven Growth to Inclusive Development : Romania's Path to Shared Prosperity. World Bank, Washington

29. World Meteorological Organization (WMO) (2008) Manual on Low-flow Estimation and Prediction. Geneva

30. Zbigniew W. Kundzewicz, Alice J. Robson (2000) Detecting trend and other changes in hydrological data. World Meteorological Organization 45:168