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TOTAL RUNOFF OF SURFACE WATERS IN NEW CLIMATIC CONDITIONS ON THE REPUBLIC OF MOLDOVA'S TERRITORY

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Key words: Water resources, climatic changes, hydrographical basin, intensity and frequency climatic parameters.

Abstract. Although it is considered that the socio-economic impact over the last decades on surface water quality is significant, the role of changing regional climate that is manifested by the intensification of desertification process is crucial. In this context, it is important to know the current trends of change in total runoff of surface of surface waters in the context of increase of desertification degree of the regional climate attested in recent years.

Introduction

Water resources and their quality are in continuous decrease, and these aspects constitute a severe constraining factor for both our country and on the international level, especially if we take into account the increase of aridity due to global warming, forecasted by certain scenarios and climatic models (Albu, 2009, Nedealcov, 2012, Anuar, 2015, 2016, Bejan et al, 2017). These scenarios estimate that droughts would persist in the regions with critical climate in Europe, especially in Southern Europe, as well as in Northern America, and the above-mentioned regions would suffer from severe droughts, heat spells, water deficiency and decrease in agricultural production. Another scenarios evaluate the impact of global climatic changes in Republic of Moldova, demonstrating that the drought would be more pronounced during the vegetation period in southern and south-eastern part of the country (Nedealcov, 2012), which does not come into contradiction with the estimations conducted for the southern regions in Europe (Marinov, 1964, Madjar et al, 1995).

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Surface waters from Republic of Moldova's territory constitute mainly from (nearly 98% of the total area of drinking water's resources) from the waters from the Dniester and Prut Rivers basins. The network of the rivers consists from nearly 3.6 thousands of rivers and streams with total length of nearly 16 thousands km. Natural regime of waters of both big rivers and small ones was modified by dams and reservoirs for flood prevention, capture of sediment, water supply for agricultural, industrial and domestic intake, as well as for fish farms. Each of approximately 100 of reservoirs has a capacity to store water of more than 1 million m^3. Also, there are two big reservoirs in Republic of Moldova: Costești-Stînca on the Prut River (which is the biggest one; 678 mil. m^3), managed jointly by Romania and Republic of Moldova, and Dubăsari (235 mil. m^3) on the Dniester River (Bejan et al, 2017, Proiect de Gestionare a Districtului Bazinului Hidrografic Nistru, 2014).

Dniester's hydrographical basin occupies 2/3 from the country's territory, has absolute values for the country's ecological balance, and comprises natural reservations, small rivers, lakes and other water bodies. Water is the crucial resource for these landscapes and wildlife, and is vital for those who dwell and work there. Considerable conjugated efforts were made were made to protect and maintain the conditions of these natural areas, but a number of issues still need to be resolved in order to ensure the desired improvements (Proiect de Gestionare a Districtului Bazinului Hidrografic Nistru, 2014).

The Danube-Prut River and Black Sea hydrographic basin have a great diversity of physico-geographical conditions due to its geological structure, geomorphologic characteristics and climatic conditions. The latter significantly determine hydrological and hydrochemical characteristics of the ground and surface waters. An important feature of the Prut River basin is its hydrological origin in a mountainous region in as much as its flow is sufficient to cause frequent floods. The total area of the Danube-Prut and Black Sea region within the borders of the Republic of Moldova is 14 770 km^2, making 43,6% from the country's total area. Absolute maximum quota of the basin is 429,5 m, minimal one - l,6m (Bejan et al, 2017).

Although it is considered that the socio-economic impact over the last decades on surface water quality is significant, the role of changing regional climate that is manifested by the intensification of desertification process is crucial (Marinov, 1964, Madjar et al, 1995). In this context, it is important to know the current trends of change in total runoff of surface of surface waters in the context of increase of desertification degree of the regional climate attested in recent years.

Initial materials and surface waters monitoring

The State Hydrometeorological Service is the national institution responsible for hydrobiological, hydrochemical and hydrological monitoring of surface waters. The systematic monitoring of surface water quality in the Prut river basin was carried out in 14 monitoring sites by 2013, and starting with 2014, according to DCA 2000/60, another monitoring program is being implemented for the Prut river basin which consists of 30 monitoring stations: 8 locate on the Prut River, 1 – on the artificial lake, 2 – on the natural lakes and 19 - on tributaries. In the process of development of the monitoring program data and information from the joint expeditions in the JFS I-III pilot hydrographical basin and national monitoring programs conducted in the Prut river basin (MD) were used.

Physical and chemical monitoring includes the following parameters: temperature, pH, conductivity, transparency, turbidity, coloration, dissolved oxygen content, saturation, biochemical oxygen demand, chemical oxygen demand with dichromate, chemical oxygen demand with manganese, nitrate nitrogen, mineral nitrogen, mineral phosphorus, total phosphorus, chloride ions, sulphate ions, total iron, phenols, petroleum products, anionic detergents, alkalinity, calcium ions, magnesium ions, total hardness, sodium ions, potassium ions, sum of ions, silicon, heavy metals (copper, zinc, nickel, lead and cadmium), polyaromatic hydrocarbons and organochlorine pesticides. Biological monitoring includes: for rivers: bacterio-plankton, phytoplankton, including chlorophyll "a", benthic macro invertebrates, phytoobenthos and zooplankton; for lakes: bacterio-plankton, phytoplankton including chlorophyll "a", benthic macronutrients, phytobenthos, zooplankton, macrophyte vegetation.

Cross-border monitoring with Romania on the Prut River is carried out in accordance with the Bilateral Co-operation Regulation with the National Administration "Apele Române" and the Prut-Bîrlad Basin Department (Iaşi) in seven monitoring sections. Monthly common sampling and equivalent sharing of information with Romanian experts takes place in the following locations: Ungheni, Valea Mare and Giurgiulesti; the quarterly common sampling and the exchange of information with the Romanian experts are carried out in the following locations: Lipcani, Costesti, Leova and Cahul. Cross-border monitoring with Ukraine on the Prut River: the joint quarterly monitoring of sampling and information exchange on the Prut River with Ukraine was resumed starting with 2009. The joint water sampling program at the border between the Republic of Moldova and Ukraine was elaborated by the Moldovan-Ukrainian working group and approved jointly with the national laboratories involved in the joint sampling and exchange of information.

Sampling and information exchange at the "Mamăliga-Criva"(border-crossing point) monitoring station on the Prut River is carried out together with the Dniester-Prut River Basin Direction for Water Resources Management of the State Agency for Water Resources of Ukraine. Water Resources Management in the Dniester - Prut River Basin (Cernauti town). Within the Transnational Monitoring Network (TNMN), 5 monitoring sites (Lipcani, Costeşti, Branişte, Valea Mare and Giurgiuleşti) were selected on Prut river for the purpose of monthly analysis and evaluation of a set of hydrochemical and hydrobiological parameters, as well as of some quality indicators of aquatic alluviums [3]. Surface water resources of the Prut River are assessed on the basis of data from three hydrological stations: Şirăuţi (located on the border with Ukraine), the Costeşti-Stînca and Ungheni hydroelectric power stations. The Ungheni Hydrological Station offers the most comprehensive series of data for a period of 55 years. In the proposed article, initial data on surface water runoff in hydrographic and total water basins, atmospheric precipitation and seasonal evaporation in km^3 were used for the period 1977-2016.

Analysis of the obtained results

A necessary approach regarding the total surface water runoff can be considered as estimations related to a series of hydrological data made from different variables, including from the separate hydrographic basins on the territory of the Republic of Moldova. Generally, the time series can be composed of stochastic and non- stochastic elements. Non- stochastic items in the series may appear as one or more of the following:

- tendency;
- stochastic movement around the tendency;
- seasonal variations;
- Determinant component (generally measured by the correlation coefficient of the series).

The general idea of the trend is that of a slow movement of a chronological series that extends over a long period of time. In hydrological chronological series, a trend detected in a given series may be due:

• a slow and continuous variation in meteorological conditions (climatic variations) or a long periodic cyclical variation of climate. In general, the time series is an increasing or decreasing branch of a cycle;

• a change in the physico-geographic conditions of the basin due in particular to human activity.

In the first case, this is a subject for a complex climatic analysis, which is extremely necessary in order to highlight the impact of climate change on the quality of surface waters. In the latter case, the change is permanent as long as human activity continues at the same level. This destroys the homogeneity of the dataset and has to be taken into account in the data evaluation.

Therefore, the analysis of hydrological data by the State Hydro-meteorological Service allowed to highlight the multi-annual course of values reflecting the dynamics of the runoff on separate river basins and the total runoff for the last period of time - period (1977-2016) in which climatic fluctuations and the process of desertification is essential.

Therefore, within the boundaries of the Dniester basin (fig.1a, b) there is a tendency to decrease the runoff by -0.0623km^3/year, based on the real values that characterize this hydrological parameter, which undoubtedly will affect the state of natural ecosystems in the future decades, as well as in other regions of the world (Zaharieva et al, 2012, Yordanova).

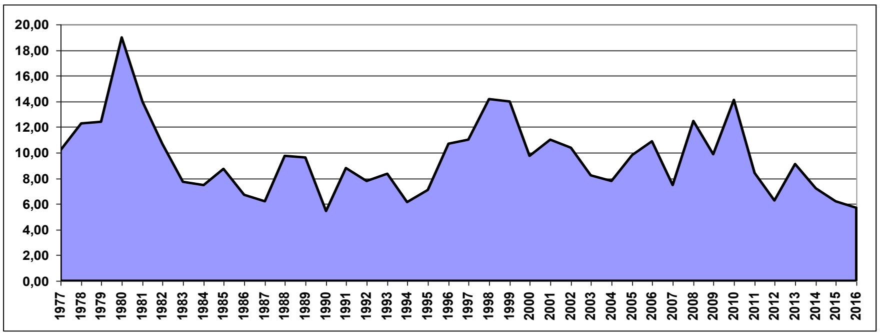


Fig. 1 a. Multiyear dynamics and change trend of total water runoff (km^3) of the Dniester River (1977-2016)

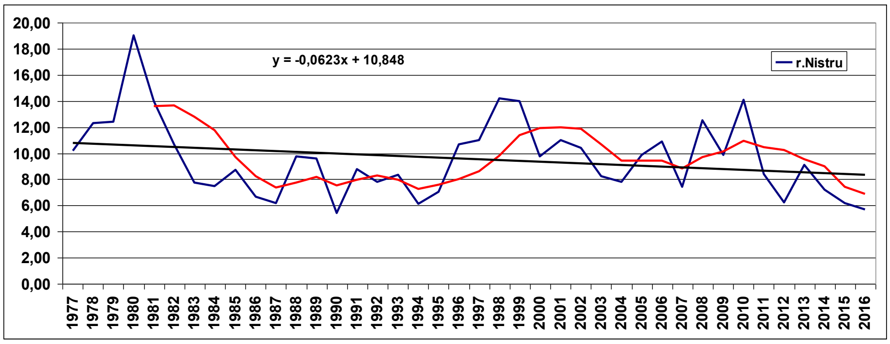


Fig. 1 b. Multiyear dynamics and change trend of total water runoff (km^3) of the Dniester River (1977-2016)

The period when the total runoff values were below the trend line belongs to the years 1982-1998 and the last years (2011-2016), explained to a great extent by the anthropic factors and natural ones, namely the frequent occurrence of the dry years and significant hydrological droughts (Yordanova, 2003, Ivanov, 2013).

Practically the same trend is preserved for the values that characterize the runoff in the Prut River basin, but these distribution particularities are much more pronounced than the above-mentioned data. Thus, within the boundaries of the Prut River basin there is a tendency of runoff decrease, but it is more pronounced compared to that in the Dniester River Basin (fig.2 a, b). We consider that this value, namely -0,0246 km^3/year, based on the real values that characterize this hydrological parameter, reflects also the impact of the manifestation of long dry periods within this basin, also mentioned in the regional and international researches (Dunkel, 2000, Dyakov et al, 2012, Duca et al, 2017, a, b,).

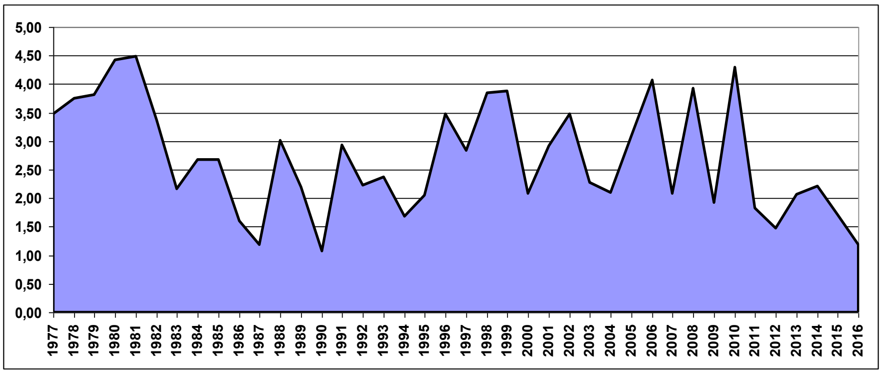


Fig. 2 a . Multiyear dynamics and change trend of total water runoff (km^3) of the Prut River (1977-2016)

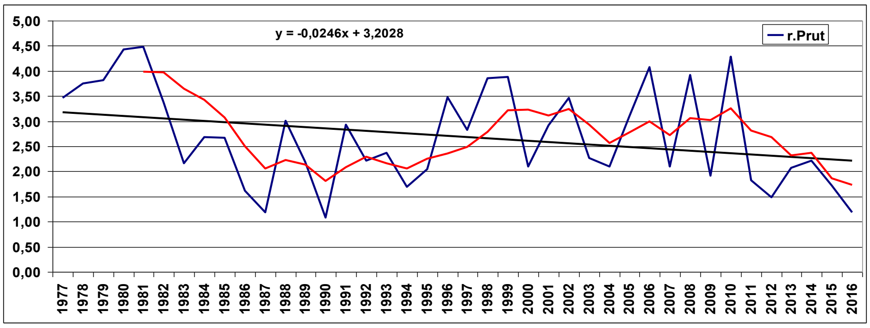


Fig. 2 b . Multiyear dynamics and change trend of total water runoff (km^3) of the Prut River (1977-2016)

The simultaneous analysis of the dynamics of the total runoff, of the atmospheric precipitation and of the average evaporation from the sum of the seasonal evaporation in km^3 reveals that the values of these parameters, starting with 2010, "distance" substantially, meaning that the particularities of the water balance in the Republic of Moldova (fig. 4) is quite different from other time periods.

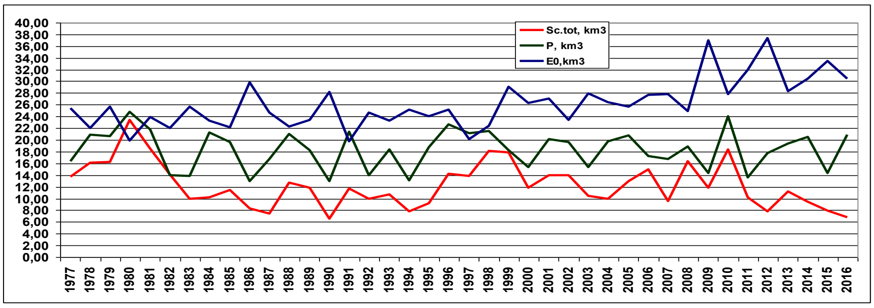
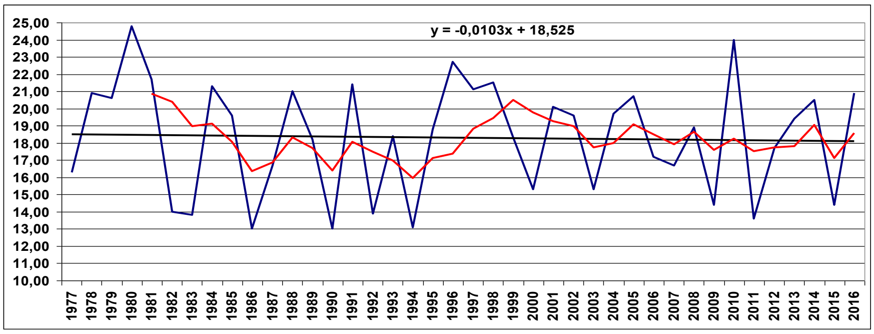


Fig. 4. Dynamics (1977-2016) of total surface water runoff, of atmospheric precipitation and of the average evaporation from the sum of the seasonal evaporation, km^3

Thus, within the Republic of Moldova, in seasonal aspect, there is a tendency of decrease in the amount of atmospheric precipitation by -0,0103 km^3/year (fig. 5 a) and a significant increase in the values that characterize the average evaporation from the sum of the seasonal evaporation with 0,2293 km^3/year (fig. 5. b). The most essential values of 31-37 km^3 are recorded in the years 2009, 2011, 2012, 2014 compared to the multi-annual average of 25.9 km^3. So there is no doubt that increasing the evaporation rate will negatively affect the balance of water resources in the coming years.

At the same time, we find that the characteristics of runoff vary from season to season, from month to month, which is extremely important to know. Therefore, spring runoff (high water levels and debits) are generally determined by snow reserves accumulated during the winter period. The conditions of snow melting and runoff of waters originated from snow melting and rain are also important. These factors and their combination are considered for each year. For example, meteorological conditions have led to the formation of low water levels and debits compared to multiannual average values in the winter of 2015-2016, in the basins of the upper part of the Dniester and Prut rivers (Ukraine). According to the data of the State Hydrometeorological Service (Anuar, 2016). March is the month in which there are the high spring waters - a hydrological phenomenon characterized by slow long lasting water level increase in the rivers, which is repeated almost frequently (in the same season), conditioned by snow melting and overlapping rainfalls in the basins' plains in spring, as well as snow melting and overlapping rainfalls in the mountains; as a consequence, the low land is flooded, usually the major river bed. The earliest periods for the beginning of large spring waters are attributed to the third decade of January (1977, 1979, 1981, 2002) and the latest ones are attributed to the third decade of March - the first decade of April (1973, 1977, 1980, 1989, 1991, 1993, 1996, 1998, 2005, 2006). In case of the early start of the high spring waters, the high waters are already observed in March, and the number of which increases in nearly 2 - 3 times in comparison with February. We believe that the construction of large spring water reservoirs could ensure the adhering territories with water required for irrigation in the early months when a pluviometric deficiency can occur. Thus, for example, for the whole observation period, the low water flow of Bic, with values of 3.0-10.0% of the norm, was recorded in 1968 (2.9%), 1974

a



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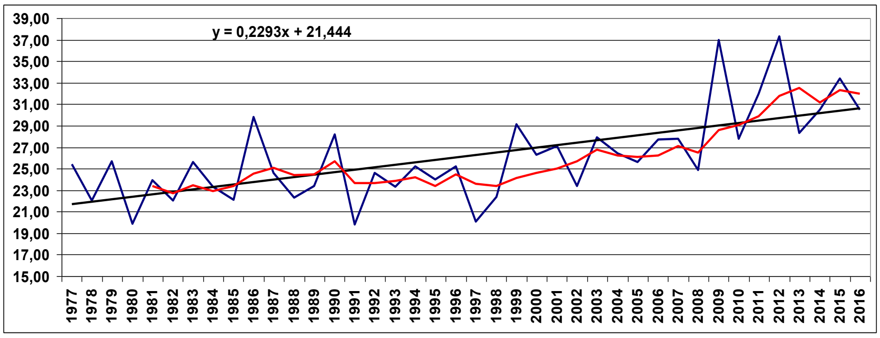

Fig. 5. Atmospheric precipitations (a) and average evaporation from the sum of seasonal evaporation (b), km^3

(3.2%), 1975 (5.5%), 2007 (9.3%), 2008 (7.82%) and 2010 (2.23%) of the multiannual average values. At the same time, the presence of water-collecting lakes could store high waters, including those during summer seasons with the purpose of using them in dry periods, which are frequently alternating with regular rainy ones in the conditions of the Republic of Moldova. In addition to the rainfall observed during the summer months, there's also *summer flood*, which represents nothing but level and the flow of water in rivers is maintained below the norm during at least 10 days, which, we should mention, can be observed in autumn season. Taking into account the fact that the previous researches (Nedealcov, 2012, Dyakov et al, 2012) show the increase of the summer and autumn temperatures on the background of the decrease of atmospheric precipitation, we consider that this tendency is preserved in the future.

Therefore, the indexes of the statistics that characterize the total surface water runoff within the territory of the Republic of Moldova (tab.1.) reveal that it is 12.26 km^3 during the last 40 years (1977-2016). The significant variability of the year-to-year total runoff is also explained by the standard deviation (3,8) from the climatic norm but also by the coefficient of variation (30,8%).

Table 1. Statistical indices that characterize the total surface water runoff (km^3)

Statistical indices	**Values**
X	12,26
σ	3,8
Cv	30,8%
Minimum	6,51
Maximum	23,4

The filtering of the statistical dataset [14, 18, 19, 21, 22] within the limits of three sigma points out the range of total runoff variability in which it is observed that the number of cases is insignificant along the central line (fig. 6).

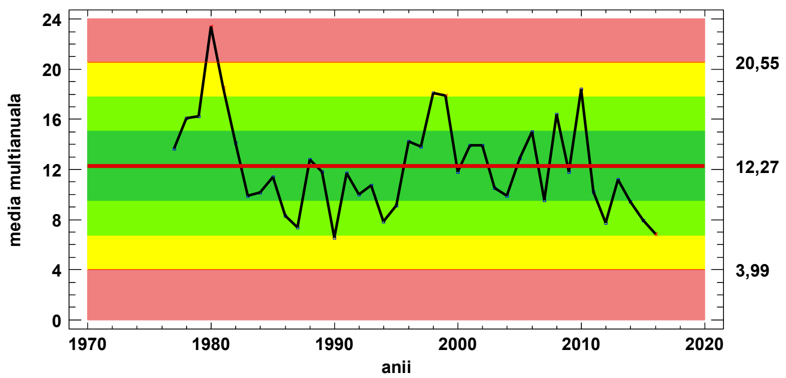

Fig. 6. Annual variability of total runoff, km^3

Table 2. The register of the years with the total significant and low runoff (km^3) of surface waters within the limits of the Republic of Moldova

Year	Moderately-Significant runoffs (0.5σ)	Significant runoffs (σ)	Moderately-low runoffs (-0.5σ)	Low runoffs (-σ)
1977				
1978	1978			
1979	1979	1979		
1980	1980	1980		
1981	1981	1981		
1982				
1983			1983	
1984			1984	
1985				
1986			1986	1986
1987			1987	1987
1988				
1989				
1990			1990	1990
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2003				
2004			2004	
2005				
2006	2006			
2007			2007	
2008	2008	2008		
2009				
2010	2010	2010		
2011			2011	
2012			2012	2012
2013				
2014			2014	
2015			2015	2015
2016			2016	2016

Thus, according to Table 2, we conclude that the years with moderately significant runoffs were observed in 1978, 1979, 1980, 1981, the last 3 years also being in the list of years with significant runoff. In the temporal aspect, we observe that such years on the time axis were 2008 and 2010 in the last period of time.

Moderately low runoffs were observed in the years 1983, 1984, 1986, 1987, 1990, 1992, 1994, 1995, 2004, 2007, 2011, 2012, 2014, 2015, 2016. In the last decades the runoff rating was estimated to be low, which is also an argument for such research.

The alternation of "significant-low" antipodes of surface waters runoffs characteristic for the years of 2012, 2015, 2016 once again confirms that we are on the verge of substantial climate change (Nedealcov, 2012).

According to the quintile graph (fig.7) we observe that the weight of extremes at the limit of low values (i. e. low level runoff) is distributed proportionally, which once again indicates the accumulation over time of the years, when the total runoff values are below the multiannual average, therefore we consider that the role of desertification in the decrease of the surface water runoff is also significant together with the anthropogenic impact.

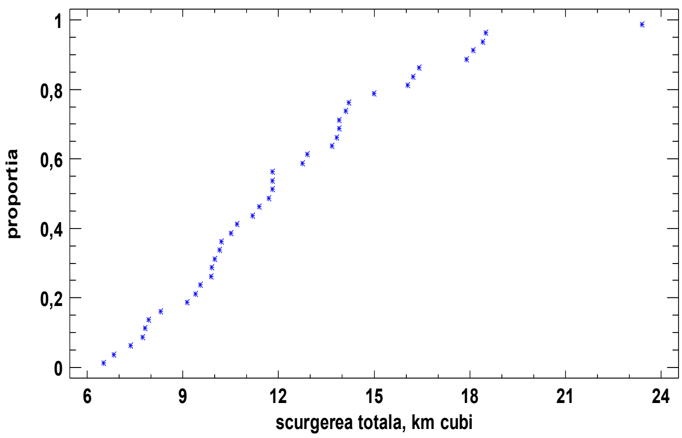

Fig.7. The quintile graph on the total runoff, km^3 for the territory of the Republic of Moldova

The analysis of the frequency and intensity of the empirical values characterizing the total runoff within the territory of the Republic of Moldova (tab. 3) confirms the above mentioned facts. The data included in the table demonstrates the major frequency of years when the runoff is below the climate norm. The results obtained are extremely necessary in order to estimate the impact of desertification on the quality of surface water.

The analysis of the percentiles reveals the fact (tab. 4) that once in 10 years the total runoff on the territory of the Republic of Moldova may amount to only 7.7 km^3 and at the same time in the wetter periods (90% percentile) this value can be 18.0 km^3, compared to the multi-annual average of 12.26. It is important, however, in our opinion, that the values indicating the way of surface water runs off once in 4 years (75% and 25% percentiles) in different climatic conditions. So, once in 4 dry years (25% percentile), total surface water run-off values can be 9.7 km^3.

Taking into account the fact that the territory of South-Eastern Europe is one of the areas most exposed to desertification, it is necessary to estimate this process based on appropriate eco-metric indicators. It is a crucial issue if we consider that the damage caused by drought and desertification has had a major impact on the economy and welfare of the population in the last decades. Appropriate management of water resources will only be possible through the use of advanced knowledge of their origin, quantity and quality. The informing, advising and regular public alerting on the future variability of water resources will facilitate the implementation of the first steps in improving the current conditions within this area.

Table 3. Intensity and frequency of the total runoff within the territory of the Republic of Moldova, on km^3 (1977-2016)

Class	**Lower limit**	**Upper limit**	**Frequency**	**Relative frequency**
1	5,8	7,3	2	0,0500
2	7,3	8,8	5	0,1250
3	8,8	10,2	8	0,2000
4	10,2	11,7	5	0,1250
5	11,7	13,2	5	0,1250
6	13,2	14,7	6	0,1500
7	14,7	16,1	2	0,0500
8	16,1	17,6	2	0,0500
9	17,6	19,1	4	0,1000
10	19,1	20,5	0	0,0000
11	20,5	22,0	0	0,0000
12	22,0	23,5	1	0,0250

We mention that harmonization of water legislation with the European Union Water Framework Directive (WFD) is taking place in present in the Republic of Moldova. The main purpose of this Directive is to achieve a good state of all water resources and provide an innovative approach to water resource management based on a basin approach, taking into account the natural boundaries of river basins.

Table 4. Percentiles of total surface water runoff in the Republic of Moldova, on km^3 (1977-2016)

Percentiles	Total surface water runoff
1,0%	6,5
5,0%	7,0
10,0%	7,7
25,0%	9,7
50,0%	11,7
75,0%	14,1
90,0%	18,0
95,0%	18,4
99,0%	23,4

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