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FLUCTUATIONS OF ANNUAL PRECIPITATION AND WATER RESOURCES QUALITY IN UKRAINE

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Abstract. The article focuses on examining the influence of fluctuations in annual precipitation amount on the quality of surface waters. Water quality was estimated with data on BOD, COD and phosphate-ion concentration within five selected regions of Ukraine. Analysis of the precipitation data (1991–2010) showed different regional trends. Using the statistics, determination of the interconnection between precipitation amount and water resources quality were done. The obtained regularities and associated uncertainties can be used for prediction of changes in water resource quality and as a guide for future adaptation to possible climate change.

Keywords: annual precipitation amount, surface water quality, correlative analysis, Ukraine.

1. Introduction

Evidence of climate change is quite perceptible worldwide [1-4], including Europe [5-7] and Ukraine [8-10]. Considerable work has addressed the issue of drought, relevant connections to Atlantic Ocean and tropical Pacific sea surface temperature anomalies, and the potential influence of climate change for Europe [6, 11-14]. Evidence of an increase in the frequency of extreme European precipitation events has been documented [7, 15]. Climate change influences the state of ecosystems, soils and air quality, agricultural practice and leads to the increasing of the number of natural disasters and cataclysms [4]. Its impact on water resources is considerable [16, 17] and introduces challenges for water resource managers [18]. At the same time, scientific research regarding interconnections between fluctuation of annual precipitation and water resources quality in Ukraine is rather limited [19, 20] despite the fact that these data are extremely important for prompt management reaction to changing observations and for taking adequate adaptation measures.

Existing research works about climate change and consequences in Ukraine mainly address air temperature variations and related influences on the repeatability of catastrophic natural phenomena [21], but the interconnection between water quality indexes has not been sufficiently investigated. This research is designed to address a little studied topic of national importance, provide useful information for water resource managers, and enable future water resource modeling and forecasting for Ukraine.

The paper presents a comparative analysis of fluctuations in annual precipitation amount in different parts of Ukraine with a relation to corresponding water quality indexes using standard statistical methods.

2. Experimental

2.1. Study Area

Data for the period from 1991 until 2010 collected from fifty co-located meteorological and hydrological observation stations situated across Ukraine are used in the analysis. The station locations are shown in Fig. 1. For further analysis the territory of Ukraine is divided into the five regions: Central (C), Eastern (E), Western (W), Southern (S) and Northern Ukraine (N) (Fig. 1).

2.2. Materials and Methods

Water body contamination is determined according to: (a) the value of the chemical demand of oxygen (COD), (b) the biological oxygen demand during five days (BOD) and (c) the concentration of phosphate-ion concentration in water [20, 22]. The selection is done in order to represent the relation between the meteorological (precipitation) and hydrological (BOD, COD and phosphates) parameters. The precipitation level is chosen as the representative value for the evaporation/humidity processes. The BOD, COD and phosphate-ion concentration values are determined according to standard methods [22]. The choice of the three indexes is conditioned by data availability and by the fact that COD and BOD are fundamental indexes for the characteristics of surface waters. The phosphate-ion concentration index is selected based on the idea that phosphate-ion concentration is one of the main contaminants of agricultural origin for the water resources in Ukraine [22]. Data observations representative of a short time frame (days to weeks) are totaled (precipitation) or averaged (water quality) to determine an annual index for use in this statistical analysis.

Fig. 1. Geographic location of meteorological and hydrological stations across Ukraine

To determine the interdependence between the fluctuation of annual precipitation and water resources quality indexes in Ukraine, standard statistics methods (regression analysis, correlation determination) are used with subsequent interpretation of the results. To examine variation in temporal and spatial aspects of the analyzed indexes variations, a graphic method of results presentation is used [23]. Using the water quality data and annual precipitation amount data, the coefficients of Pearson correlation (*r*) and confidence level for the relationship are calculated. In order to investigate for the potential of stronger non-linear relationships, a paired polynomial regression analysis was chosen.

3. Results and Discussion

Data on long-term fluctuations in annual precipitation amount are presented for the five regions of Ukraine in Fig. 2. The graphed results show that trends in annual precipitation are different across the Ukraine regions. There is an increasing trend for the western, northern, and central regions whereas visual analysis of the graphs indicates a decrease in annual precipitation for the southern and eastern regions. An increase of approximately 300 m is evident in the Western Ukraine, whereas the increase is about 150 mm in Northern and approximately 50 mm in Central Ukraine. In the Eastern and Southern Ukraine, the decrease over the two analyzed decades is about 200 mm to 250 mm. As expected, the time series of annual precipitation data are characterized by considerable year-to-year variation.

The chemical parameters vary depending on the location of the hydrological stations and the year of the measurement. Therefore, the mean BOD value (mgO_2/l, Fig. 3) in the Central and Western Ukraine changes from 2 to 7. In the Southern and Northern Ukraine, this parameter is from 1.9 to 3.7. In the Eastern Ukraine, mean BOD is from 2.1 to 4.8. The maximum BOD values (mgO_2/l) are measured in Southern (4.4), Northern (3.9) and Eastern Ukraine (7.9) for 1996, in the Central Ukraine (9.8) for 1992, and in the Western Ukraine (10.3) for 1995.

The mean COD value (mgO_2/l, Fig. 4) is less variable among the hydrological stations. In the Central and Western Ukraine it is from 28 to 38; in the Southern and Eastern – from 20 to 38; and in the Northern – from 22 to 45. The maximum COD value is up to 54 mgO_2/l in the Central, Northern and Southern Ukraine for 2001, 2003 and 2006, respectively. These parameters are measured at the level of 50 mgO_2/l in the Western Ukraine in 1997 and 45 mgO_2/l in the Eastern Ukraine in 2005. The slight evaluation of COD value is observed from 1991 to 2010 at all hydrological stations.

The mean phosphates concentration (mg/l, Fig. 5), in the Central, Western and Northern Ukraine is changing from 0.27 to 0.48; in the Southern Ukraine – from 0.31 to 0.64 and in the Eastern Ukraine – from 0.7 to 1.2. The maximum phosphates concentration is up to 0.62 mg/l in the Central, Western and Northern Ukraine for 1994, 2000 and 1996 respectively. This parameter is measured at the level of 0.9 mg/l in the Southern Ukraine in 2000 and at the level of 1.6 mg/l in the Eastern Ukraine in 1992. Among all studied station the highest contamination of surface water is observed for the Eastern Ukraine.

The spatial and temporal variations of BOD, COD and phosphates show the difference in water quality parameter of natural waters along Ukrainian territory, what links to the alteration between natural conditions (climate, hydrology, geology, *etc.*) and anthropogenic pressure (wastewater discharges, water extraction, *etc.*) observed for surface waters [22].

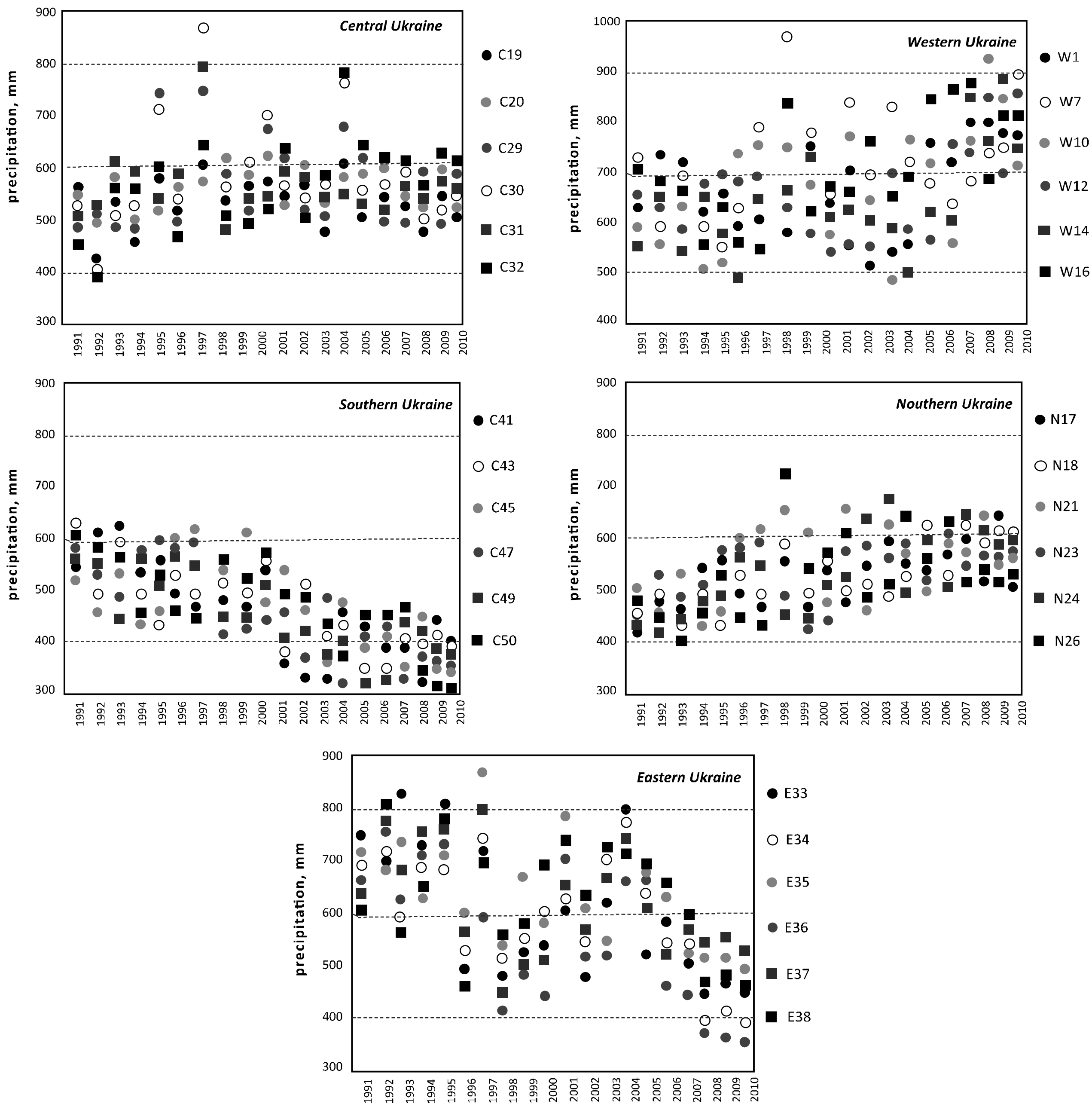

Fig. 2. Precipitation level (mm) variations on meteorological and hydrological stations from 1991 to 2010

The next stage of the research analyzes the relationship between the precipitation amount and the selected indexes of water resource quality, BOD, COD and phosphate-ion concentration.

The strength of a linear relationship between annual precipitation and water quality (irrespective of year) was estimated by Pearson correlation coefficients; the *r*-values and corresponding equations are shown in Table. Traditionally, values significant at 95 % and 99 % confidence level are highlighted. Based on data record ($n = 20$) and a two-tailed *t*-test ($df = 18$), the COD and phosphate values are not significant at 95 % confidence level and the BOD value is only one.

A result of paired polynomial regression analysis to investigate non-linear relationships for each of the five regions is shown in Fig. 6. In general, this statistical approach provides a slightly better fit with the data, but in some cases, the physical interpretation of the relationship becomes an intellectual challenge.

In two regions with a strong increasing trend in annual precipitation (Western and Northern), the graphs suggest a dilution effect with a decline in the value of the water quality indicators with higher values of precipitation. For Southern and Eastern Ukraine, precipitation trends document a decline in annual totals, the opposite is observed for the period with higher rainfall, which is associated with larger values of the water quality indices.

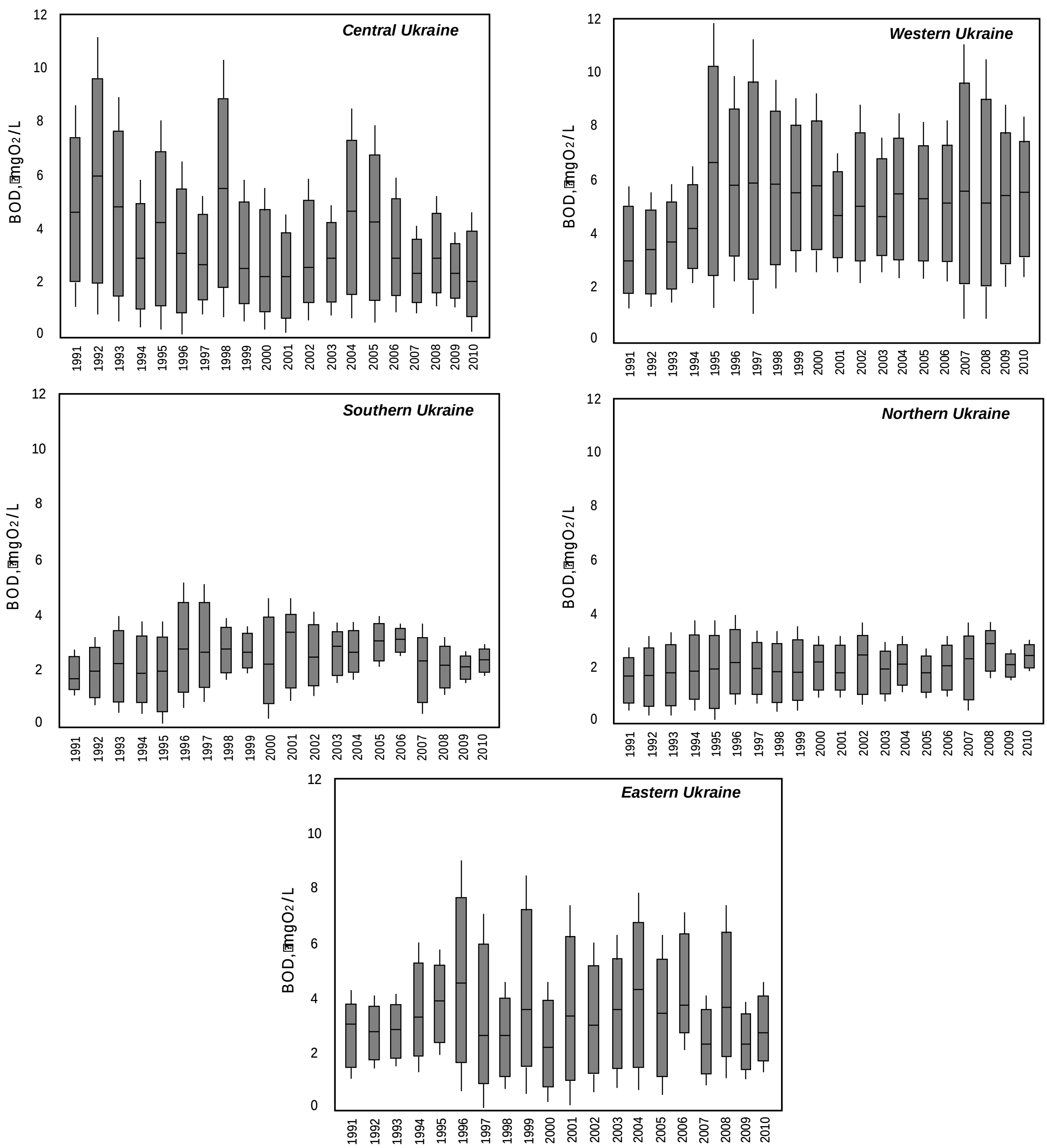

Fig. 3. Boxplots of temporal trends in Biological Oxygen Demand (BOD, mgO_2/l) on hydrological stations in Ukraine

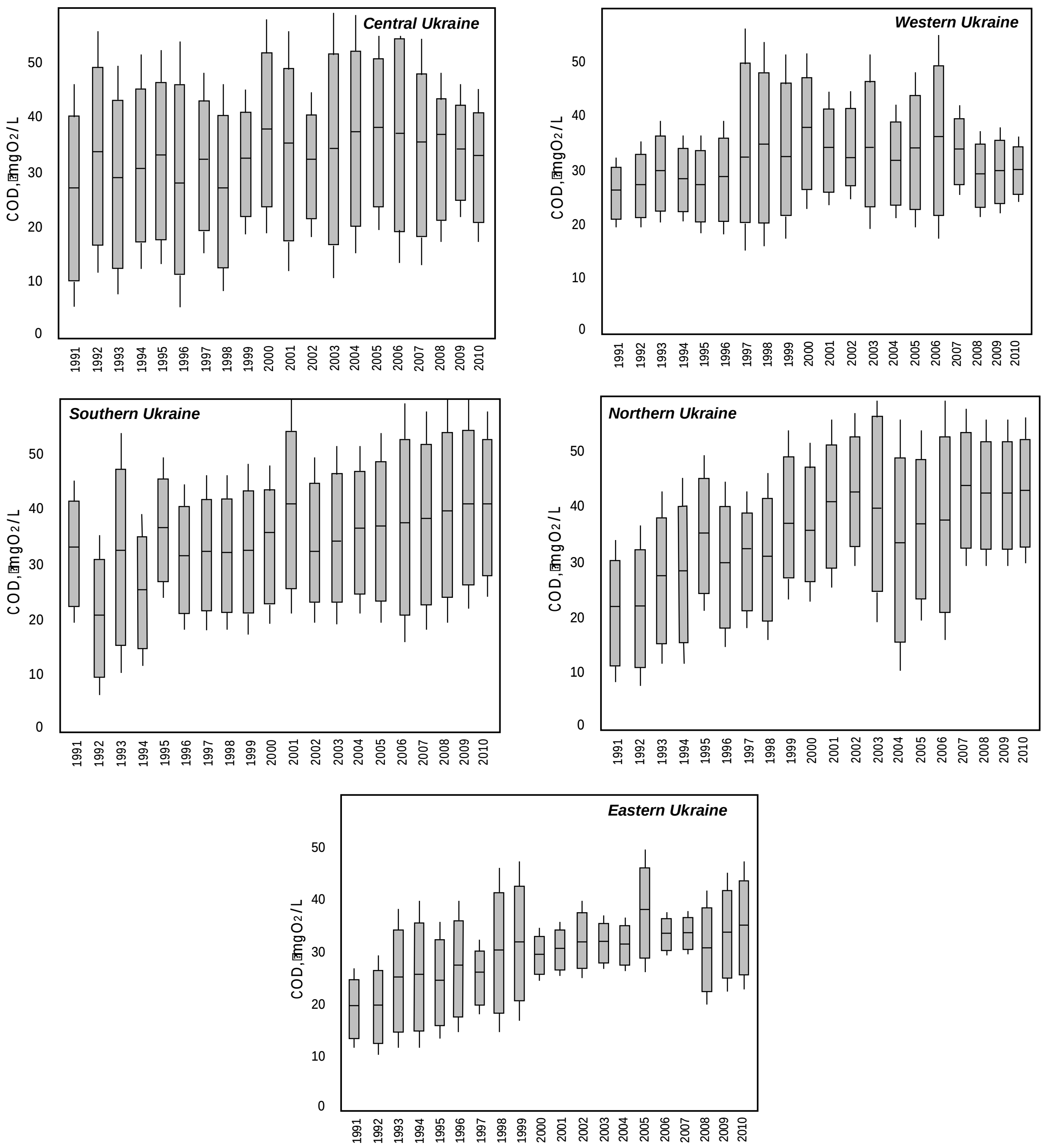

Fig. 4. Boxplots of temporal trends in Chemical Oxygen Demand (COD, mgO_2/l) on hydrological stations in Ukraine

Table

Pearson correlation coefficients and the equation for the interconnection between precipitation amount and indices of water resources quality

Indices	Pearson coefficient, *r*	Linear equation
BOD	0.62	$y = 0.001x + 1.742$
COD	0.55	$y = -0.009x + 30.13$
Phosphates	0.54	$y = 132.4x + 452.4$

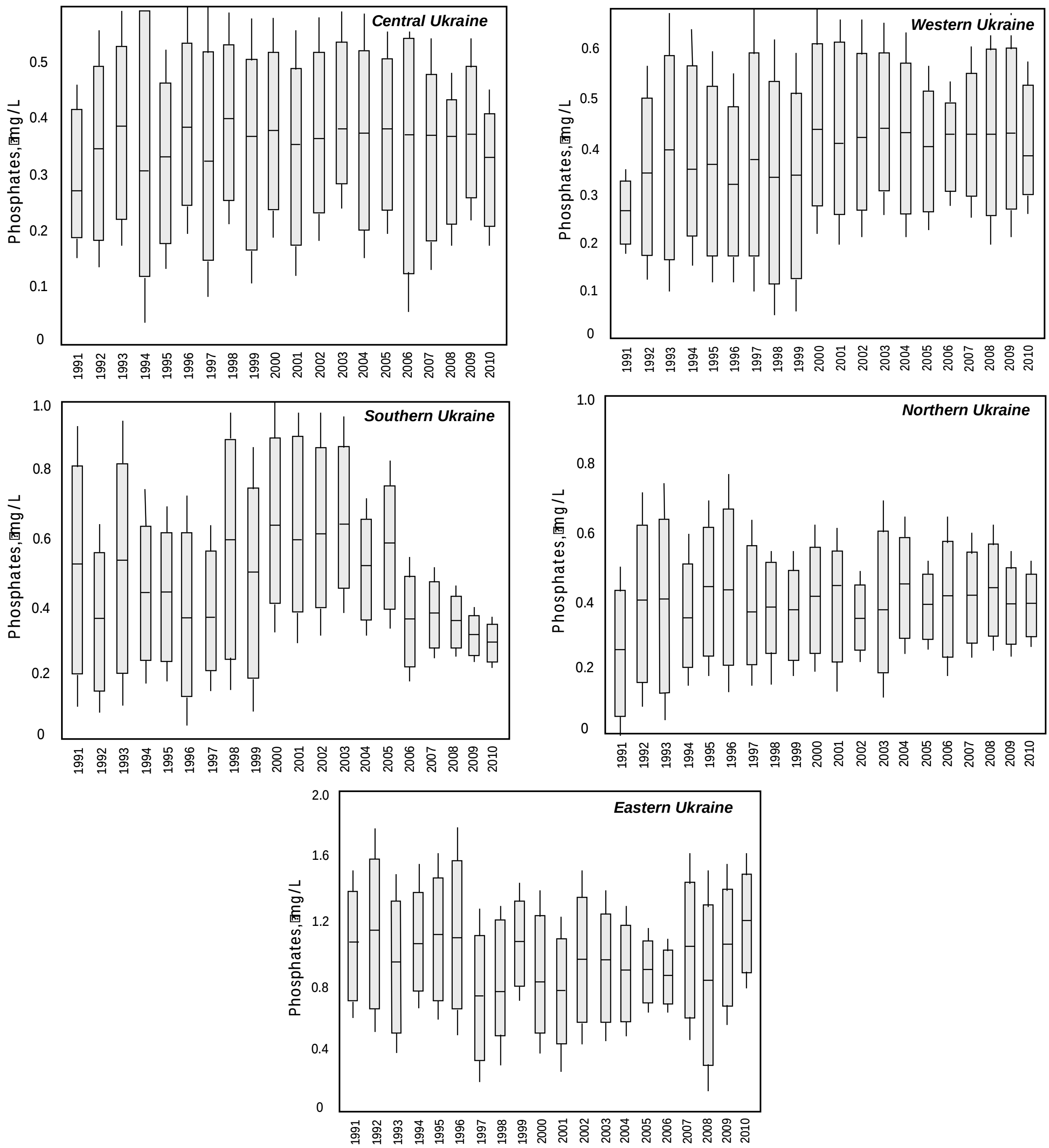

Fig. 5. Boxplots of temporal trends in phosphates concentration (mg/l) on hydrological stations in Ukraine

Data presented in Fig. 2 show the expected inter-annual variability in annual precipitation. In Central Ukraine there is a large inter-annual fluctuation of precipitation amount but only a slight upward trend for the studied two decades. In Eastern Ukraine, there was considerable year-to-year variability in annual precipitation from 1995 to 2004 along with a clear downward trend in precipitation amount. A similar negative trend in precipitation amount is observed for Southern Ukraine; however, the downward trend is not as strong as for Eastern Ukraine. If these trends continue, adverse phenomena, such as water shortages, declines in water quality, and droughts are to be expected to be more likely in Eastern and Southern Ukraine in the future.

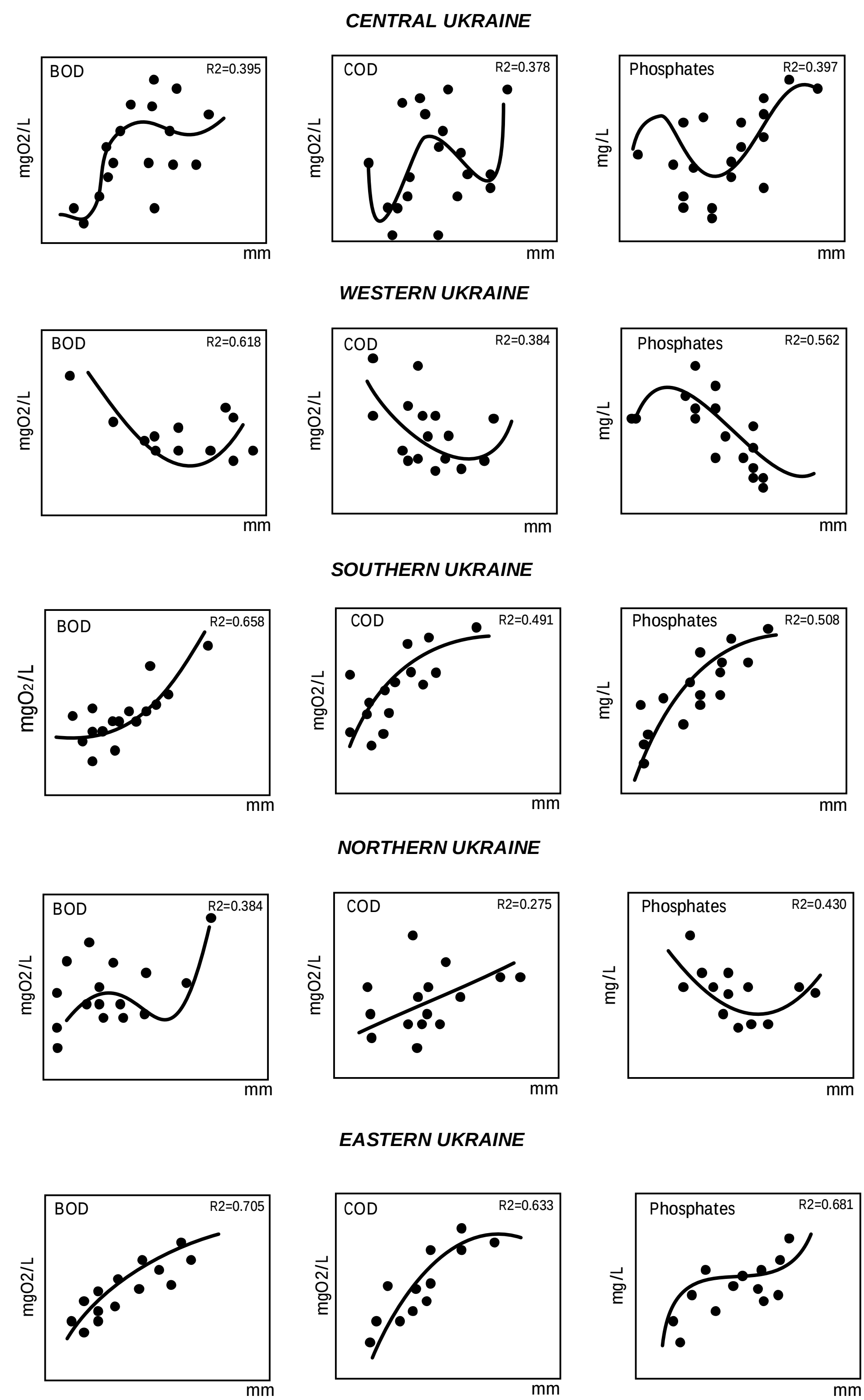

Fig. 6. The regression lines and approximation values (R2) between COD (mgO_2/l), BOD (mgO_2/l), phosphates (mg/l) and the precipitation level (mm)

On the contrary, in Western Ukraine a clear trend towards an increase in annual precipitation is evident during the period of observation. From 1995 till 2005 considerable inter-annual variability in precipitation amount take place, and since 2006 there has been a rapid increase of precipitation amount. A similar upward trend in annual precipitation is observed in Southern Ukraine, though in this case the increase is not as large. The highest fluctuations in annual precipitation in Southern Ukraine are observed in the period from 1995 till 2001. The identified trends in precipitation fit well with our understanding of the geography of climate change [4]. As observed elsewhere and suggested by climate modeling analysis, dry areas are getting drier and wet areas are becoming more wet.Analyzing the Pearson correlation coefficients and confidence levels of the two analyzed indices (Table) it can be concluded that the best correlation is observed in the case of BOD (r = 0.62), and the linear fit is least tight in the case of phosphate-ion concentration (r = 0.54).

The analyzed data from 1991 until 2010 may be useful in development of further water quality change scenarios associated with ongoing global climate change. If conditions in Eastern and Southern Ukraine continue along present trends toward increasing dryness, then the values of BOD, COD, and phosphate-ion concentration will likely decline as well.

Climatic change presents many challenges for water resource managers [24]. One potential issue relates to abrupt changes, tipping points, or non-stationary in climate system functioning [20]. Visualization of the data obtained for this analysis does not indicate an issue with non-stationary for Ukraine water resources at this time. Other concerns involve whether or not enough aspects of the climate system are built into our development of ideas related to potential drivers of system changes. Previous research [25] in the analysis of data for Ukraine and Russia suggest that solar radiation data may also be needed to address the soil moisture component of the hydrologic cycle.

The research reported in this paper has examined trends and relationships between precipitation and indexes of water quality. Evans *et al.* [26] addressed increasing trends in dissolved organic carbon and identified a number of possible drivers of those increases, including rising temperature and rainfall. The temperature and water quality record from shallow lakes in Estonia documents both warming and an increase in nutrient loading [27]. Since water resources are vital to human occupancy of the planet, more research on climate change and related water quality impacts are desirable and it is imperative that this work be completed on a local-to-regional scale.

4. Conclusions

Changes in climate and associated trends in annual precipitation are a concern for many areas of the planet. Analysis of fluctuation of annual precipitation in Ukraine related to air temperature during the period from 1991 till 2010 made it possible to determine the spatial pattern of variation in five different regions of Ukraine. For Central Ukraine precipitation amount increased slightly during the observation period, for Northern and Western parts of the country a significant increase in precipitation has been found, which was especially strong in Western Ukraine. For Eastern and Southern Ukraine, on the contrary, a considerable decrease of precipitation is observed, and the strongest precipitation reduction occurred in Eastern Ukraine. Using the statistics, determination of the interconnection between precipitation amount and water resources quality was done. It can be concluded that the best correlation was observed in the case of BOD and the fit was least tight for phosphate-ions concentration. The obtained regularities and associated uncertainties can be used for prediction of changes in water resource quality and as a guide for future adaptation to possible climate change.

A problem not addressed in this research is determination of possible regularities between other meteorological parameters – such as changes in air temperature or solar radiation and the selected indexes of water resources quality (BOD, COD and phosphate-ions). There is a need for continued research to examine the interconnections between climatic parameters and changes in water resource quality. Future research could address other metrics of water quality, such as concentration of chloride-ions, heavy metals, or pesticides. In addition, relationships identified in this research should be updated as more annual observations become available.

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КОЛИВАННЯ РІЧНИХ ОПАДІВ ТА ЯКОСТІ ВОДНИХ РЕСУРСІВ В УКРАЇНІ

Анотація. *Вивчено вплив коливань річної кількості опадів на якість поверхневих вод в Україні. Якість водних ресурсів для п'яти обраних регіонів країни оцінено за показниками БПК, ХПК і концентрації фосфат-йонів. Аналіз даних кількості опадів (1991–2010) засвідчив різні регіональні тенденції. Використовуючи статистику, встановлено взаємозв'язок між кількістю опадів та якістю водних ресурсів. Отримані закономірності і пов'язані з ними невизначеності можуть бути використані для прогнозування змін якості водних ресурсів та для розроблення заходів із адаптації до можливих змін клімату.*

Ключові слова: *річна кількість опадів, якість поверхневих вод, кореляційний аналіз, Україна.*