MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESSA STATE ENVIRONMENTAL UNIVERSITY

METHODOLOGICAL INSTRUCTIONS

FOR PRACTICAL WORK ON THE EDUCATIONAL DISCIPLINE

«IMPACT OF CLIMATE CHANGE ON THE SECTORS OF UKRAINE'S ECONOMY (WATER MANAGEMENT)»

for full-time and part-time students

specialty 103 "Earth Sciences"

Approved
at a meeting of the specialty support group
Protocol № _10_from "13th" _May_ 2024.
The head of the group
__________________ Shakirzanova, Zh. R.

Approved
at the meeting of the department of
hydroecology and water research
Protocol № _8_from "_12_" __04__2024
The head of the department
______Loboda N.S.

Odesa – 2024

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESSA STATE ENVIRONMENTAL UNIVERSITY

METHODOLOGICAL INSTRUCTIONS
FOR PRACTICAL WORK ON THE EDUCATIONAL DISCIPLINE
«IMPACT OF CLIMATE CHANGE ON THE SECTORS OF UKRAINE'S ECONOMY (WATER MANAGEMENT)»

for full-time and part-time students
specialty 103 "Earth Sciences"

Approved
at a meeting of the specialty support group
Protocol № _10_from "13th" _May_ 2024.

Odesa – 2024

Collection of methodological instructions for performing practical work on the educational discipline " Impact of climate change on the sectors of Ukraine's economy (water management)" for full-time and part-time students in the specialty 103 "Earth Sciences", educational program «Hydrology and integrated use of water resources» / Loboda N.S., Otchenash N.D., Rozvod M.R. Odesa: OSENU, 2024. 71 p.

CONTENTS

INTRODUCTION

The relevance of the proposed topic for practical classes in the discipline "Impact of Climate Change on the Sectors of Ukraine's Economy (Water Management)" is due to the necessity of providing water management institutions with methods and techniques for calculating and forecasting the state of water resources in Ukraine in the conditions of climate change and significant scales of water management activities.

The aim of the practical tasks is to master the methods of assessing natural and anthropogenically altered water resources developed at the Odesa State Environmental University (OSENU) based on the "climate-runoff" mathematical model. Meteorological data is used as input into the model. This allows it to be used for calculations of runoff from watersheds with insufficient hydrological observation data and for forecasts of runoff based on climate change scenarios. The model consists of two parts. The first part is designed to calculate the characteristics of natural (unaffected by water management activities) annual runoff based on meteorological data. The theoretical basis of the modeling is the equation of the water-thermal balance of a closed watershed. The second part of the "climate-runoff" model is dedicated to determining the household (transformed by water management activities) annual runoff. The theoretical basis of this part is the equation of the water management balance of the watershed, presented in probabilistic form.

After completing practical tasks in the discipline "Impact of Climate Change on the Sectors of Ukraine's Economy", students should acquire basic knowledge:

- methodological approaches to assessing the state of water resources based on meteorological data (without considering water management activities).
- methodological approaches to determining the state of water resources in the context of water management activities.
- methodological approaches to determining the state of water resources in the conditions of global warming (with and without water management transformations).
- ways to address water management challenges in the context of climate change based on the "climate-runoff" model.

As a result of completing the tasks from the provided collection of practical works, students should acquire basic skills:

- assessing changes in climatic factors affecting runoff formation under current and potential (scenario-based) climatic conditions.
- providing characteristics of the state of water resources based on meteorological data, including data from climate scenarios.
- calculating characteristics of natural and household (transformed by water management activities) runoff under changed climatic conditions.

- performing optimization of water management activities based on the results of simulation modeling for different climatic conditions and levels of water management activities.

During the practical tasks in the discipline "Impact of Climate Change on the Sectors of Ukraine's Economy", the student should perform the following works:

1) assessment of changes in climatic factors affecting river runoff formation in ukraine during the XX-XXI centuries.

2) climatic factors affecting runoff formation and their changes in the future according to climate change scenarios.

3) assessment of changes in heat reserves, moisture, and the aridity index βx in the present and future based on global warming scenarios.

4) determination of statistical parameters of the annual climatic runoff of rivers in ukraine using the "climate-runoff" model.

5) determination of statistical parameters of household (transformed by water management activities) annual river runoff in the presence of artificial reservoirs on watersheds using the "climate-runoff" model.

6) determination of statistical parameters of household annual river runoff in the presence of lands irrigated by local runoff using the "climate-runoff" model. assessment of the cumulative impact of artificial reservoirs and irrigation.

7) assessment of characteristics of annual runoff in the conditions of climate change (according to scenarios) and water management activities.

8) assessment of the impact of agroamelioration and urbanization in the conditions of climate change.

Current knowledge control is carried out based on the modular control system according to the syllabus of the discipline. The form of ongoing control includes oral questioning during the defense of completed practical work, or written answers to control questions in the MOODLE system.

PRACTICAL WORK No.1
ASSESSMENT OF CLIMATIC FACTORS' IMPACT ON RIVER FLOW FORMATION IN UKRAINE DURING THE 20TH - 21ST CENTURIES

Objective: Identify trends in the changes of the statistical structure of hydrometeorological fields during the period of climate change. In Ukraine, statistically significant changes in annual air temperatures began after 1988.

Theoretical Part

Since the 1960s, climate changes have been observed in many regions of the Earth, including Ukraine. Over the past decades, changes in annual air temperatures, annual precipitation sums, and annual river flow have been observed.

Air temperature is a key climatic factor that shapes the main components of the water balance of a watershed - evaporation from the land surface. Cold periods affecting freezing and thawing dates of rivers, accumulation of water reserves in snow before the start of spring snowmelt, depth of soil freezing, and more depend on air temperature. Additionally, air temperature influences the formation of water resource deficits due to anthropogenic influences, as irrigation norms, drainage of agricultural lands, crop yields, and more depend on its changes.

Precipitation is a characteristic of the territory's moisture. It forms water resources and thus determines the conditions for river flow formation. Therefore, studying changes in precipitation and air temperatures in the conditions of global warming is an important task for hydrologists.

The task of the practical work is to establish trends in the fluctuations of precipitation and air temperatures and identify positive and negative phases in their fluctuations.

Observation materials include air temperatures and averaged precipitation sums for the warm (April-November months) and cold (December-March months) periods of the year, as well as annual air temperatures and precipitation sums. The length of the observation series is given for the years 1946-2015.

The main calculation methods include the method of linear pair regression and the method of residual mass curves.

Theoretical part of the work.

Trend is often understood as the general direction of development of a random process. It is usually represented as a trajectory. The trajectory represented as a function of time is called a trend. The trend describes the averaged tendency of the process over a given period in time. Changes over time are the result of the influence of various factors. The existence of a trend in the changes of the studied characteristic over time and its statistical significance can be determined based on the construction and analysis of the pair regression equation.

For sample data, the equation of the conditional mathematical expectation (this equation is indeed the equation of linear pair regression) for dependent random variables X and Y is represented as follows:

$$\tilde{y}_i = \tilde{y}(x_i) = \hat{m}_{y/x} = ax_i + b, \tag{1.1}$$

where x_i – represents discrete values of the random variable X;

y_i – represents discrete values of the random variable Y;

$\tilde{y}_i$ – represents the values of the random variable Y, calculated using the regression equation;

a, b – the sought parameters of the equation.

The estimation of the parameter of the linear regression equation is usually expressed through the correlation coefficient $r_{x,y}$

$$a = r_{x,y}\frac{S_y}{S_x}, \tag{1.2}$$

where S_x – estimate of the standard deviation σ_x of the random variable X;

S_y – estimate of the standard deviation σ_y of the random variable Y.

The estimate of the correlation coefficient, which reflects the strength of the linear relationship between the dependent variables *X* and *Y, is* given by:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2(y_i-\bar{y})^2}}, \tag{1.3}$$

where $\bar{x}, \bar{y}$ – the mean of the sample of length *n*.

The root mean square approximation error *S* is calculated by the equation:

$$S = S_y\sqrt{1 - r_{xy}{}^2}. \tag{1.4}$$

S is not sufficiently informative, as the calculation error is primarily determined by the likelihood of determining the regression coefficients and correlation. To ensure the probability of the constructed regression model, it is necessary to test hypotheses regarding the statistical significance of the correlation coefficient and regression equation coefficients.

In a simplified approach, the equation of linear regression is considered statistically significant if the correlation coefficient *r*, which assesses the strength of the linear relationship, takes a value greater than twice the error of its determination.

$$r \geq 2\sigma_r, \tag{1.5}$$

where *r* – the correlation coefficient;

σ_r – standard deviation of the sample correlation coefficient.

$$\sigma_r = \frac{1-r^2}{\sqrt{n-1}}, \tag{1.6}$$

where *n* – length of the series.

The ordinates of the residual mass curves represent the cumulative deviations of the studied variables from their long-term mean. If the sum of positive deviations predominates, it indicates a positive phase of oscillations. Conversely, if the sum of negative deviations predominates, it signifies a negative phase in the oscillations.

To make the curves dimensionless, they are represented as dimensionless quantities called modular coefficients *k*. These coefficients are the ratios of the current value of the studied characteristic to its long-term mean. For example, calculations of modular coefficients for runoff involve characteristics such as the runoff module *q*, runoff rate *Q*, runoff volume *W*, depth of runoff *Y*.

$$k_i = \frac{q_i}{\overline{q}} = \frac{Q_i}{\overline{Q}} = \frac{W_i}{\overline{W}} = \frac{Y_i}{\overline{Y}}, \qquad (1.7)$$

where q, Q, W,Y – runoff module, runoff rate, runoff volume, depth of runoff, respectively;

$\overline{q}, \overline{Q}, \overline{W}, \overline{Y}$ – long-term mean values of the considered runoff characteristics, respectively.

The modular coefficients for air temperatures and precipitation are calculated using the formulas:

$$k_i = \frac{T_i}{\overline{T}}, \qquad (1.8)$$

$$k_i = \frac{X_i}{\overline{X}}, \qquad (1.9)$$

$\overline{T}, \overline{X}$ – average multi-year values of the considered meteorological characteristics, respectively.

The average multi-year value of the module coefficient is always equal to one. Therefore, the current ordinates of the residual mass curve at the end of the *t* year from the beginning of the curve construction are determined by the equation:

$$\sum_{i=1}^{t}(k_i - 1) = f(t), \qquad (1.10)$$

де k_i – module coefficient;

$f(t)$ – time function.

The property of the residual mass curve is that deviation of the average value of the quantity (modulus coefficient) for any time interval of length *m* from its average value (unity) is characterized by the tangent of the slope angle of the line connecting the starting and ending points of the interval to the horizontal line and is determined by the formula:

$$tg\alpha = (k_i - 1)_{avg} = \frac{l_k - l_n}{m} = \frac{\sum_{i=1}^{n}(k_i - 1) - \sum_{i=1}^{n-m}(k_i - 1)}{m} = \frac{\sum_{i=1}^{m}(k_i - 1)}{m}, \qquad (1.11)$$

де l_k, l_n – final and initial ordinates of the integral curve for the considered time period;

m – number of years in the considered time period.

The period of time for which the segment of the integral curve has an upward slope relative to the abscissa axis and a positive $(k_i - 1)_{avg}$ value (because positive deviations from the mean prevail) corresponds to the positive phase of oscillations. The period for which the connecting line and the corresponding segment slope downward, and $(k_i - 1)_{avg}$ has a negative value, corresponds to the negative phase. For one highlighted cycle consisting of one positive and one negative phase, the average value of the modulus coefficient $k_{\text{сер.}}$ equals 1, for a positive phase, it is greater than 1, and for a negative phase, it is less than 1. The sum $\sum_{i=1}^{m}(k_i - 1)$ equals zero for one or several cycles.

Residual mass curves are used to determine phases and complete cycles in the oscillations of hydrometeorological characteristics. Short-duration cycles (several years) are not considered.

Practical Part

Input Data: Air temperatures and precipitation totals for the warm (April-November) and cold (December-March) seasons, annual average data for air temperature and precipitation for the observation period 1946-2015 at the meteorological station, according to the variant provided by the instructor.

Example of Execution

Task:

1. Form a table of input data.

Table 1.1 – Input data for meteorological parameters at Ternopil Meteorological Station

Year	Temperature			Precipitation		
	Annual	Warm period (April-November)	Cold period (December-March)	Annual	Warm period (April-November)	Cold period (December-March)
1976	5,64	10,9		716	528	
1977	7,00	11,3	-1,14	653	537	129
1978	6,01	10,8	-3,42	707	566	97,6
1979	6,46	11,2	-4,14	548	381	208
1980	5,34	10,3	-4,11	839	646	151
1981	6,74	11,5	-2,47	735	533	208
1982	7,30	12,0	-3,32	450	358	114
1983	7,83	12,2	0,30	661	555	130
1984	6,57	11,4	-3,21	570	441	105

End of table 1.1

1985	5,44	11,3	-7,00	613	480	117
1986	6,67	12,1	-3,14	506	410	114
1987	5,36	11,3	-6,76	649	495	131
1988	6,75	11,1	-2,14	675	527	163
1989	8,50	12,0	1,05	493	439	73,5
1990	8,37	11,9	1,79	434	348	65,3
1991	7,02	11,7	-1,84	515	442	88,8
1992	7,52	12,1	-1,73	571	499	81,8
1993	6,74	10,8	-2,33	665	579	71,1
1994	8,21	12,6	0,03	476	333	121
1995	7,33	11,8	-0,48	534	390	164
1996	5,87	12,3	-7,08	495	382	101
1997	6,79	11,2	-2,72	589	480	88,7
1998	7,22	11,6	-0,77	730	627	152
1999	8,11	12,7	-2,13	578	434	109
2000	8,60	13,1	-1,02	544	377	183
2001	7,55	12,5	-0,42	798	631	182
2002	8,27	13,0	-0,80	456	363	94,0
2003	7,36	12,7	-5,21	538	442	95,7
2004	7,56	12,3	-2,02	595	472	123
2005	7,42	12,3	-2,36	583	393	153
2006	7,42	13,0	-4,23	603	476	167
2007	8,81	12,9	1,56	636	508	128
2008	8,70	12,8	-0,25	718	581	121
2009	8,28	13,4	-1,16	509	353	140
2010	7,55	13,4	-3,65	764	618	133
2011	8,10	12,9	-2,97	400	295	133
2012	7,76	14,0	-2,79	736	564	136
2013	8,09	13,4	-4,13	727	541	250
2014	8,58	12,9	0,15	582	469	98,5
2015	9,49	13,6	0,40	452	341	111

2. Build graphs of the chronological course of air temperatures and precipitation for the year, warm period (April to October), and cold period (November to March) based on observation data.

Examples of chronological graphs are shown in Figures 1.1 and 1.2. Regression lines are drawn on the graphs. It is clearly seen that the trend represented by the regression line in Figure 1.1 has a positive dynamic, indicating an increase in average annual air temperatures. In Figure 1.2, the trend has a negative dynamic, indicating a decrease in the amount of precipitation during the warm period (April to November).

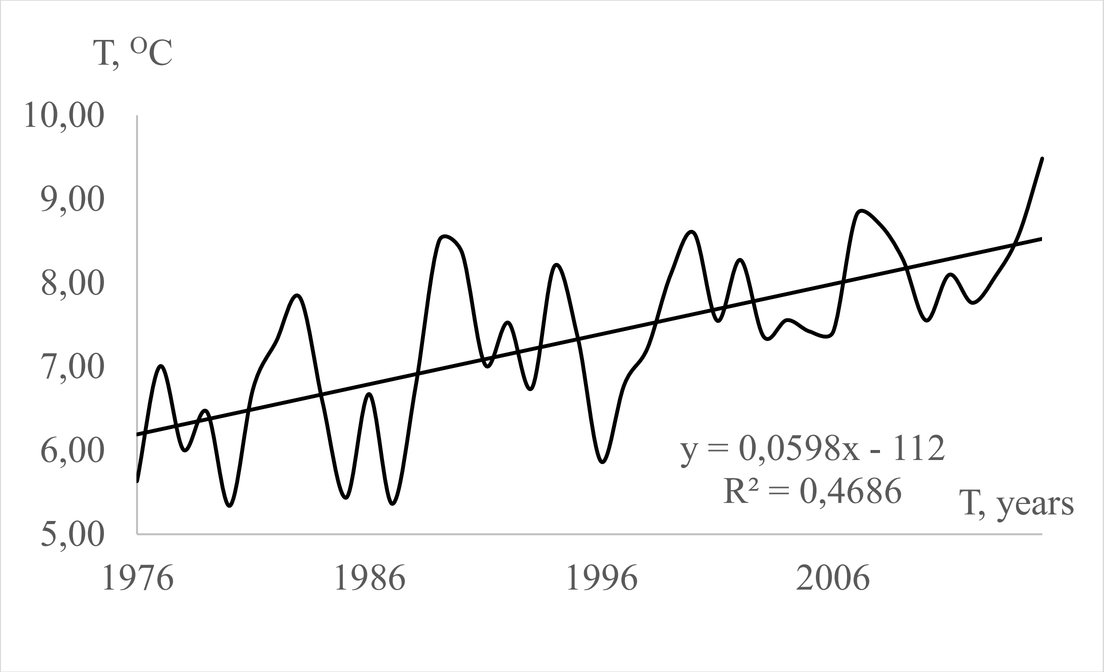

Figure 1.1 – Chronological Course of Average Annual Air Temperatures at the Ternopil Meteorological Station

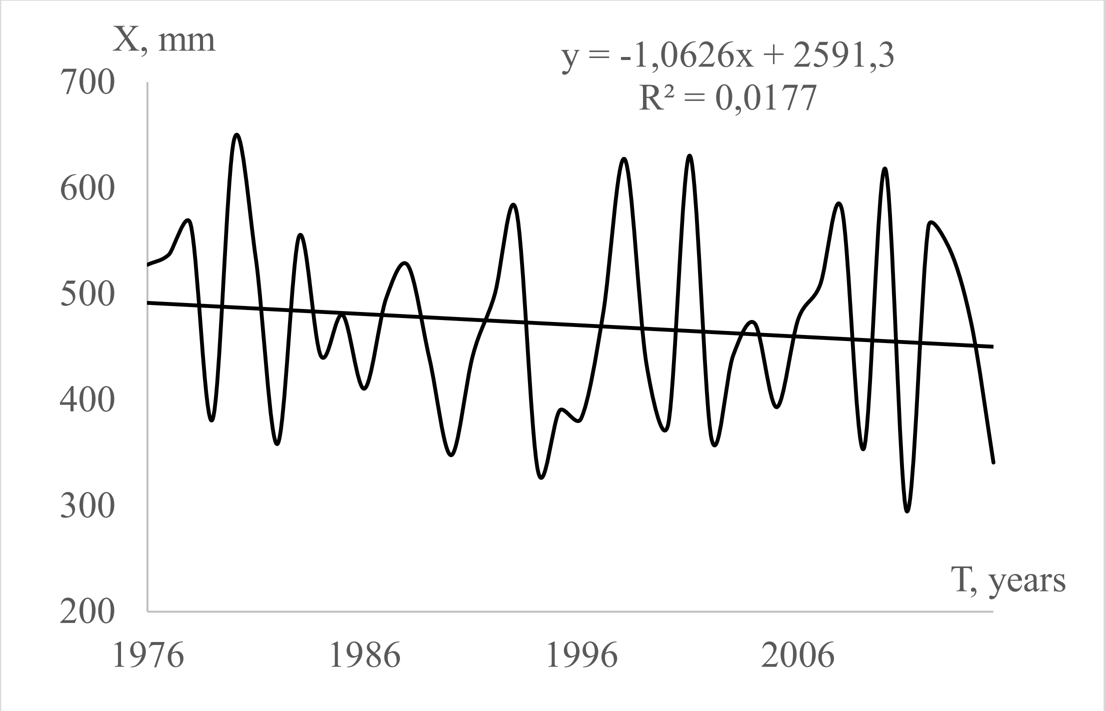

Figure 1.2 – Chronological Course of Precipitation during the Warm Period and Regression Equation at the Ternopil Meteorological Station

3. Determine the presence of trends using regression equations with Microsoft Excel. Obtain the regression equation, determine the correlation coefficient, and calculate its error.

Linear pair regression equations are considered statistically significant if the correlation coefficient *r* takes a value greater than twice its determination error:

- for the chronological course of average annual air temperatures (Fig. 1.1)

$$\sigma_r = \frac{1-0{,}4686}{\sqrt{39}} = 0{,}09 \qquad 0{,}68 \geq 0{,}18 \;\; (r \geq 2\sigma_r)$$

The correlation coefficient is statistically significant

- for the chronological course of precipitation during the warm period (Fig. 1.2)

$$\sigma_r = \frac{1-0{,}0177}{\sqrt{39}} = 0{,}16 \qquad 0{,}13 \leq 0{,}32 \;\; (r \geq 2\sigma_r)$$

The correlation coefficient is statistically insignificant

Therefore, it can be noted that there is an increase in average annual air temperatures at the Ternopil meteorological station against a backdrop of unchanged precipitation.

Construct graphs of residual mass curves for average annual air temperatures and annual precipitation sums.

To build the residual mass curves for average annual air temperatures, fill in Table 1.2 following the example. Create graphs of the mass curves and highlight positive and negative phases of oscillations (an illustration of the residual mass curves is provided in Figure 1.3).

Table 1.2 – The calculation of ordinates for the residual mass curves of annual air temperatures.

№ n/o	Years	Annual air temperatures T, ^{O}C	$k_i = X_i / X_{avg.}$	$k_i - 1$	$\Sigma(k_i - 1)$
1	1976	5,64	0,77	-0,23	-0,23
2	1977	7,00	0,95	-0,05	-0,28
3	1978	6,01	0,82	-0,18	-0,46
4	1979	6,46	0,88	-0,12	-0,58
5	1980	5,34	0,73	-0,27	-0,86
6	1981	6,74	0,92	-0,08	-0,94
7	1982	7,30	0,99	-0,01	-0,95

8	1983	7,83	1,06	0,06	-0,89
9	1984	6,57	0,89	-0,11	-0,99
10	1985	5,44	0,74	-0,26	-1,25

End of table 1.2

11	1986	6,67	0,91	-0,09	-1,35
12	1987	5,36	0,73	-0,27	-1,62
13	1988	6,75	0,92	-0,08	-1,70
14	1989	8,50	1,15	0,15	-1,55
15	1990	8,37	1,14	0,14	-1,41
16	1991	7,02	0,95	-0,05	-1,46
17	1992	7,52	1,02	0,02	-1,43
18	1993	6,74	0,92	-0,08	-1,52
19	1994	8,21	1,12	0,12	-1,40
20	1995	7,33	1,00	0,00	-1,41
21	1996	5,87	0,80	-0,20	-1,61
22	1997	6,79	0,92	-0,08	-1,69
23	1998	7,22	0,98	-0,02	-1,70
24	1999	8,11	1,10	0,10	-1,60
25	2000	8,60	1,17	0,17	-1,44
26	2001	7,55	1,03	0,03	-1,41
27	2002	8,27	1,12	0,12	-1,29
28	2003	7,36	1,00	0,00	-1,29
29	2004	7,56	1,03	0,03	-1,26
30	2005	7,42	1,01	0,01	-1,25
31	2006	7,42	1,01	0,01	-1,24
32	2007	8,81	1,20	0,20	-1,05
33	2008	8,70	1,18	0,18	-0,86
34	2009	8,28	1,12	0,12	-0,74
35	2010	7,55	1,03	0,03	-0,71
36	2011	8,10	1,10	0,10	-0,61
37	2012	7,76	1,05	0,05	-0,56
38	2013	8,09	1,10	0,10	-0,46
39	2014	8,58	1,17	0,17	-0,29
40	2015	9,49	1,29	0,29	-0,01
		$T_{avg.} = \Sigma T_i/40 = 7{,}36$			

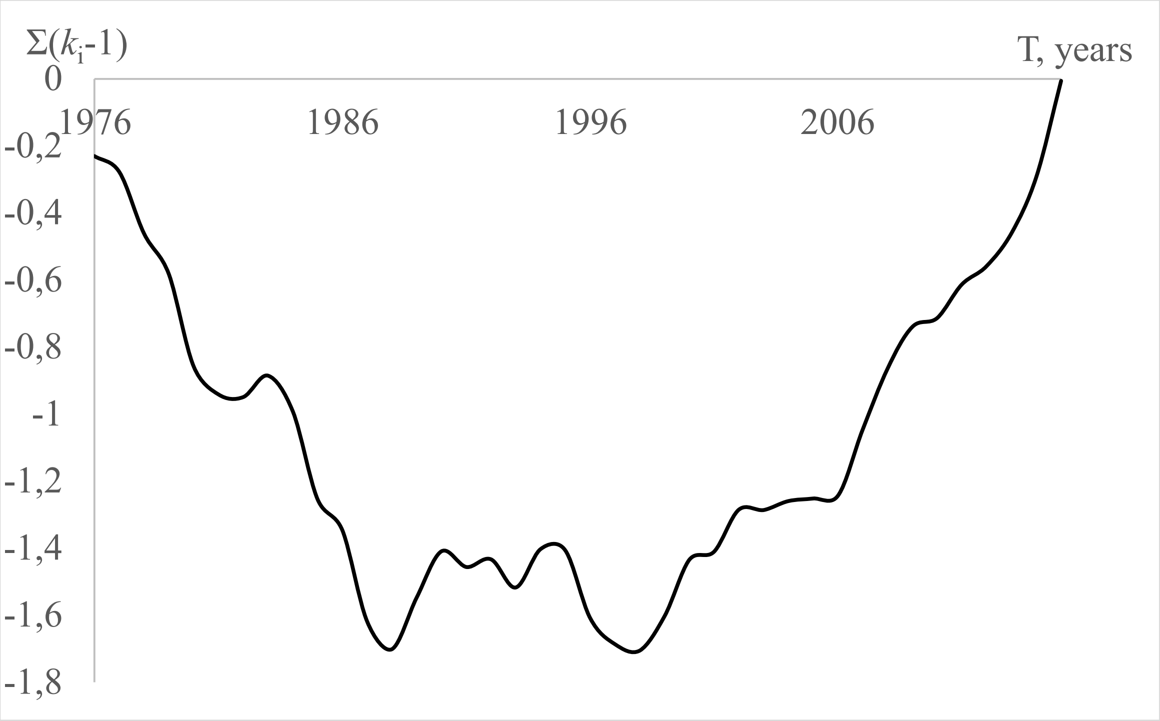

Figure 1.3 – Residual mass curves of average annual air temperatures

If we analyze the residual mass curve of average annual air temperatures, we can distinguish a negative phase (1976–1988) and a positive phase (1989–2015). The year 1989 marks the transition from the negative phase to the positive one. Specifically, 1989 is the year when significant changes in average annual air temperatures began on the plains of Ukraine.

5. Present the results and analyze the calculation outcomes based on your assignment.

Control Questions

1. Give the definition of tendency.
2. Give the definition of a trend.
3. How is the statistical significance of a trend detected, identified by the equation of linear paired regression?
4. How are positive and negative phases determined in the oscillations of meteorological characteristics?

PRACTICAL WORK No.2

CLIMATIC FACTORS OF RUNOFF FORMATION AND THEIR CHANGES IN THE FUTURE UNDER CLIMATE CHANGE SCENARIOS

The purpose of the work is to identify and analyze trends in the changes of climatic factors affecting runoff formation based on climate change scenarios.

Theoretical part

Climate change refers to statistically significant alterations in the climate system over an extended period. These changes can be induced by anthropogenic modifications to the composition of the atmosphere and land use.

The rise in global average air temperatures is primarily caused by increased concentrations of anthropogenic gases in the atmosphere. Alterations to the atmospheric composition affect Earth's radiation and energy balance, resulting in corresponding changes to the climate. Numerical descriptions of the climate system, including the atmosphere, hydrosphere, cryosphere, Earth's surface, and biosphere, are provided through climate models of various complexity levels. ***General circulation models*** (GCMs) offer comprehensive descriptions of the climate system from multiple perspectives.

A climate scenario is a plausible description of future climate developed to study the potential consequences of anthropogenic climate change.

Emission scenarios are plausible descriptions of future developments in emissions of substances that are potentially radioactively active (greenhouse gases, aerosols).

The increase in concentrations of greenhouse gases leads to an increase in the opacity of the atmosphere to infrared radiation. This situation disrupts the radiation balance. The disruption is compensated by an increase in temperature in the surface-troposphere system, which forms the greenhouse effect.

Emission scenarios include descriptions of demographics, socio-economic development, technological changes, and their interactions. These factors are expected to influence the concentration of gases in the atmosphere. Based on emission scenarios, scenarios of changes in concentrations of greenhouse gases in the atmosphere are developed. The obtained concentration scenarios are used as input data in climate models.

During calculations of hydro meteorological characteristics using scenarios, **the concept of projection** is used. Unlike a forecast, a projection includes assumptions, such as demographic development, so projections contain significant uncertainty.

To address the challenges of predicting the state of water resources in the context of climate change, it is necessary to develop models of runoff formation that use meteorological data as input: precipitation, temperatures, humidity deficits, wind speed, and others.

Such models are suitable for calculations and forecasts of changes in water resources based on global warming scenarios.

In 2000, the Intergovernmental Panel on Climate Change (IPCC) published the "Special Report on Emissions Scenarios" (SRES). These scenarios reflected various pathways of human development, taking into account demographic, economic, and technological factors, as well as the resulting emissions of greenhouse gases. The SRES scenarios were grouped into four storyline families (A1, A2, B1, and B2).

In 2013, with the Fifth Assessment Report (AR5) of the IPCC, a new approach to climate change forecasting was proposed. This approach focuses on projecting changes in the average concentrations of greenhouse gases, aerosols, and chemically active gases in Earth's atmosphere based on possible emissions. The conceptual basis of this approach lies in the understanding that human activities directly or indirectly influence Earth's energy balance. Changes in the energy balance lead to radiative forcing (RF). Positive RF leads to warming, while negative RF leads to cooling of the climate system. These scenarios are known as Representative Concentration Pathways (RCPs). The term "representative" implies that each RCP represents only one of many possible scenarios that would lead to specific characteristics of radiative forcing. The term "pathway" emphasizes that not only long-term concentration levels are considered but also their expected change over time to determine the ultimate outcome. In all RCP scenarios, the atmospheric concentration of CO_2 is projected to be higher than today's level due to increased total CO_2 emissions throughout the 21st century.

Practical part

Input data: average monthly and annual air temperatures and precipitation totals by months and years for the selected scenario (RCP4.5) (Table 2.1, Table 2.2).

To complete the task, you should follow the recommendations provided in task 1.

Execution example

The task:

1. Calculate the average precipitation sums for the warm (April-November months) and cold (December-March months) seasons for the scenario conditions from 2021 to 2050. Record the results in Table 2.3.
2. Build chronological graphs of precipitation sums over the years and for warm and cold periods. Construct linear regression equations describing the trends in meteorological characteristics and identify the statistical significance of these trends. Examples of graphs are shown in Figures 2.1 - 2.3.

Table 2.1 - Initial data of average precipitation sums in mm for Poltava per month from 2021 to 2050.

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	26,6	52,8	19,4	51,7	53,2	78,2	18,2	49,9	22,9	4,6	31,1	22,0
2022	24,3	29,2	34,9	63,2	10,8	60,9	8,8	16,6	41,3	69,5	52,8	56,5
2023	60,8	34,4	28,0	64,0	54,7	71,8	22,9	23,0	23,5	43,3	10,3	25,9
2024	22,1	0,8	45,4	27,5	7,9	33,2	1,1	2,9	30,8	18,6	12,7	73,1
2025	50,2	63,6	55,8	22,6	24,3	122,4	7,6	19,6	11,6	25,2	26,0	47,3
2026	40,5	28,1	18,6	14,5	28,6	15,9	0,0	4,9	39,4	64,1	10,7	25,7
2027	46,1	79,6	19,3	115,9	70,9	55,2	56,5	90,9	86,9	29,9	74,6	64,0
2028	48,8	63,7	28,9	81,6	60,8	33,1	57,6	2,1	47,9	36,4	33,4	62,5
2029	68,5	47,3	35,2	70,6	57,8	192,9	19,4	2,3	20,6	9,7	97,1	31,8
2030	60,1	33,0	74,2	55,9	70,5	75,0	78,5	12,0	46,2	30,8	59,4	84,8
2031	73,2	50,5	74,2	33,9	119,6	8,4	8,6	5,5	7,2	28,6	72,5	30,1
2032	31,3	10,6	79,5	31,3	37,4	14,0	20,5	52,4	28,9	73,3	12,3	48,3
2033	66,6	31,2	31,0	39,5	28,1	105,6	21,6	5,8	48,3	73,3	11,5	45,6
2034	22,4	75,4	23,1	10,1	20,7	37,4	68,1	27,3	26,3	48,4	95,8	62,7
2035	55,2	22,3	34,7	54,5	21,9	22,6	9,9	25,8	29,3	6,6	31,2	42,6
2036	20,5	34,0	65,7	39,7	38,4	77,1	7,6	8,6	34,8	33,7	59,2	11,2
2037	94,9	27,0	73,6	87,4	39,1	59,5	86,2	2,1	19,1	37,0	58,8	23,5
2038	22,9	21,3	32,9	44,6	49,6	26,5	100,7	7,6	49,6	14,7	63,5	28,1
2039	49,3	14,6	31,2	65,3	25,4	53,3	25,5	5,2	56,7	38,3	54,3	24,4
2040	47,6	90,9	30,9	7,3	45,1	25,1	1,8	0,5	21,3	16,5	66,4	9,8
2041	33,1	41,1	19,0	37,7	46,4	59,1	0,3	0,0	26,8	61,5	25,6	21,2
2042	15,5	37,5	64,0	46,6	10,1	27,9	20,7	93,6	10,4	22,9	33,2	20,9
2043	20,5	72,5	31,4	41,1	22,6	39,5	46,8	37,8	61,0	26,9	20,8	44,7
2044	37,8	61,5	36,3	8,1	72,3	3,4	0,6	21,0	17,2	29,3	35,7	37,2
2045	50,7	25,6	104,2	26,7	15,2	21,5	58,4	17,3	22,3	0,4	21,7	30,8
2046	64,3	65,5	17,4	38,0	35,7	22,0	0,0	24,7	3,4	69,7	18,2	43,0
2047	20,7	28,7	30,3	36,2	11,3	13,7	16,0	68,8	29,5	18,4	24,2	42,6
2048	32,1	35,3	35,9	62,3	45,7	24,9	3,4	1,9	63,1	49,8	21,0	28,0
2049	32,2	35,5	23,6	63,2	69,2	125,2	22,3	40,3	35,6	46,4	27,9	42,3
2050	44,4	32,1	4,9	40,9	26,7	35,5	1,0	27,9	40,5	36,8	0,4	9,0

Table 2.2 - Initial data of air temperature at the Poltava meteorological station from 2021 to 2050.

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	-2,9	-4,3	-1,6	7,6	15,4	18,3	21,9	22,1	19,0	8,0	5,7	-5,6
2022	-4,2	-10,8	-0,5	8,1	14,2	18,9	25,2	23,5	18,8	9,6	-0,7	2,7
2023	-0,4	-4,8	2,1	12,0	17,5	17,6	21,6	20,1	16,2	8,7	2,7	-6,7
2024	-6,5	-2,3	-0,1	11,7	16,8	19,2	28,3	23,4	16,6	11,8	2,9	-1,4
2025	-9,1	2,6	2,4	12,4	13,4	18,8	23,0	22,4	18,3	12,0	2,5	-3,5
2026	-4,9	-8,6	1,9	13,2	18,1	21,1	26,6	24,5	16,1	5,6	2,7	-1,0
2027	-3,5	-3,6	-2,9	6,6	17,4	18,8	21,0	19,9	16,7	1,5	1,0	-2,4
2028	-6,7	-5,6	-3,4	4,3	15,0	19,3	21,3	21,5	14,5	5,7	1,9	-3,2
2029	-5,6	-6,8	-5,9	6,9	13,9	18,9	21,3	21,2	18,3	11,0	2,4	-1,4
2030	0,1	-1,8	1,0	10,1	13,4	18,3	20,5	21,8	15,5	5,4	4,2	-3,2
2031	-2,2	-1,9	2,1	6,5	16,0	19,7	22,7	20,6	15,0	9,8	3,2	-0,6
2032	-4,7	-8,7	-5,2	10,1	17,9	18,8	20,2	21,1	15,7	7,5	1,3	-3,2
2033	-3,4	-4,3	-1,3	9,2	14,6	18,2	21,5	22,1	15,4	7,3	5,9	-0,7
2034	-3,6	-4,7	4,4	14,1	19,9	20,1	22,2	22,0	15,3	10,1	3,5	-8,6
2035	-4,7	-3,3	2,5	7,7	16,8	21,1	25,5	22,5	15,7	11,6	3,0	-1,4
2036	-6,5	-0,5	2,8	7,8	17,9	17,2	22,1	24,1	16,0	11,3	2,0	-5,1
2037	-6,1	-4,3	3,3	7,7	15,1	17,7	20,3	18,8	14,9	7,4	1,4	-1,1
2038	-1,5	0,2	-0,9	10,5	14,6	17,1	20,1	21,3	16,2	8,5	-0,6	0,7
2039	-6,2	-13,2	-4,6	11,4	15,7	19,1	23,2	21,6	15,5	7,3	5,7	1,7
2040	1,4	0,1	2,8	10,5	15,8	18,6	22,6	23,9	15,8	9,2	4,9	-1,7
2041	-6,1	-3,6	5,1	13,1	17,5	18,5	23,7	26,0	15,2	6,2	1,0	-3,9
2042	-1,0	2,2	-2,5	8,7	21,0	20,3	24,2	20,0	18,3	7,4	1,4	-1,3
2043	-4,3	-8,7	-1,0	8,0	18,4	20,4	23,1	23,0	16,4	6,8	2,0	0,0
2044	-0,7	2,0	1,2	12,9	15,2	21,7	27,7	25,3	15,9	8,5	-0,3	2,9
2045	1,4	-0,9	-0,1	7,4	14,9	19,0	21,6	23,2	15,8	8,9	2,6	1,3
2046	-0,4	0,6	2,6	10,4	16,4	20,9	29,0	23,6	14,9	9,8	6,1	-3,2
2047	-5,4	-2,6	4,3	13,2	18,1	20,1	22,1	19,8	15,5	8,0	0,2	-3,1
2048	-1,8	1,3	2,1	10,5	14,5	21,5	23,4	24,4	17,8	6,8	4,1	-3,4
2049	-4,6	-5,8	-1,5	8,3	15,6	18,5	20,4	21,6	16,0	8,6	1,9	-1,1
2050	-8,4	-10,4	-0,7	7,1	14,0	18,3	25,1	23,2	18,2	7,5	1,4	-1,2

Table 2.3 - Average precipitation totals for the warm (April-November) and cold (December-March) seasons under scenario conditions from 2021 to 2050.

№	Year	Annual	Warm period (April-November)	Cold period (December-March)
1	2021	431	310	121
2	2022	469	324	145
3	2023	463	314	149
4	2024	276	135	141
5	2025	476	259	217
6	2026	291	178	113
7	2027	790	581	209
8	2028	557	353	204
9	2029	653	470	183
10	2030	681	428	252
11	2031	512	284	228
12	2032	440	270	170
13	2033	508	334	174
14	2034	518	334	184
15	2035	357	202	155
16	2036	431	299	132
17	2037	608	389	219
18	2038	462	357	105
19	2039	443	324	120
20	2040	363	184	179
21	2041	372	257	114
22	2042	403	265	138
23	2043	466	297	169
24	2044	360	188	173
25	2045	395	183	211
26	2046	402	212	190
27	2047	340	218	122
28	2048	404	272	131
29	2049	564	430	134
30	2050	300	210	90,4

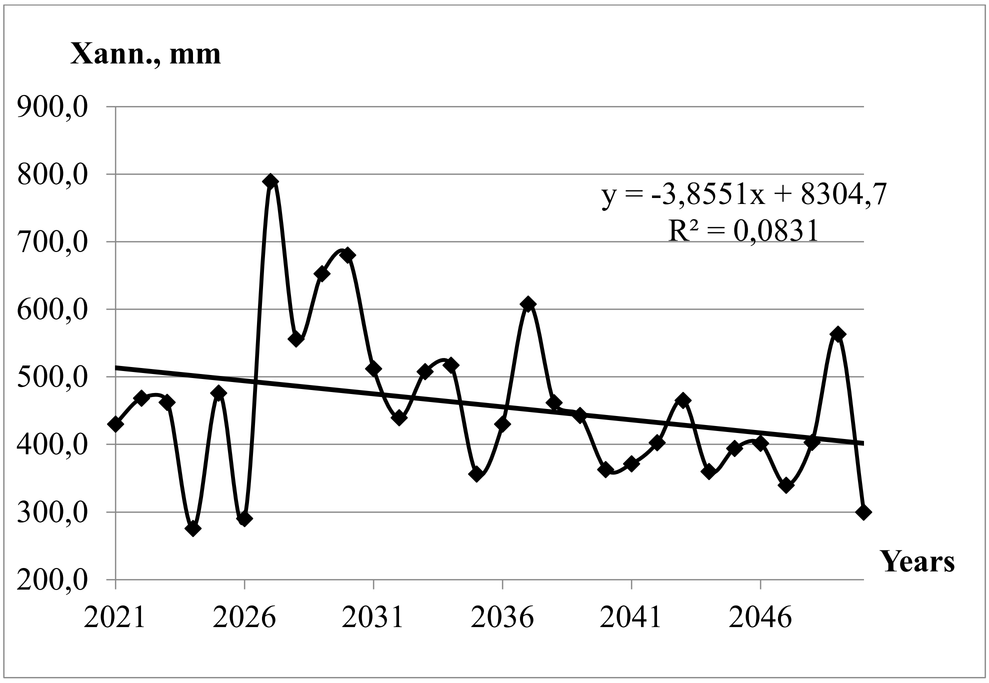

Figure 2.1 - Chronological trend of average annual precipitation at Poltava water gauge station (WGS)

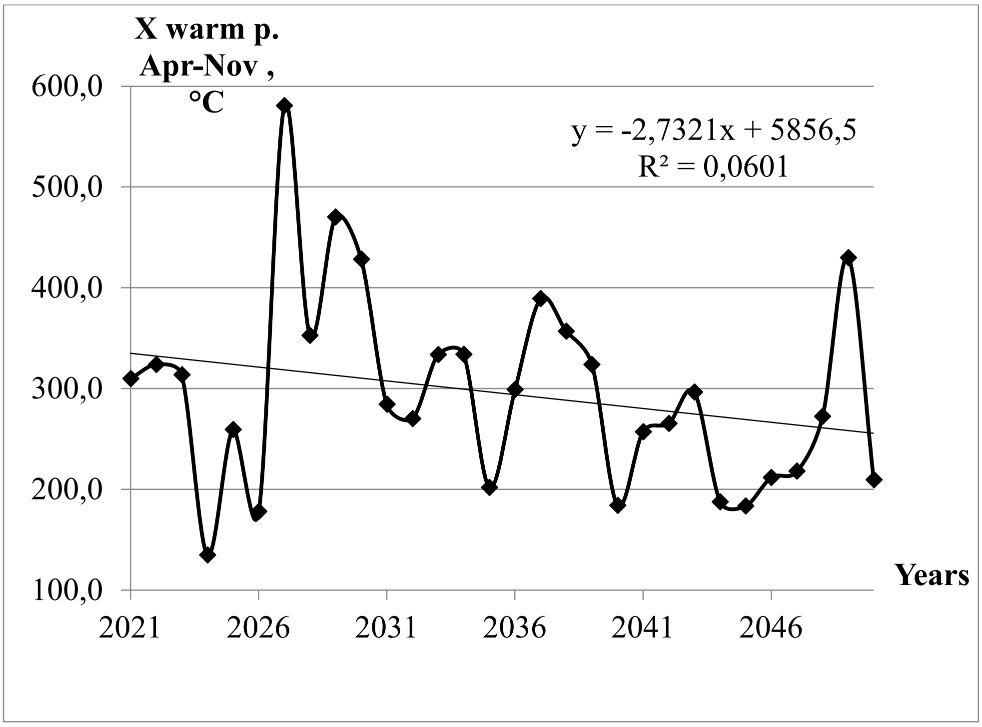

Figure 2.2 - Chronological trend of precipitation during the warm period at Poltava WSG

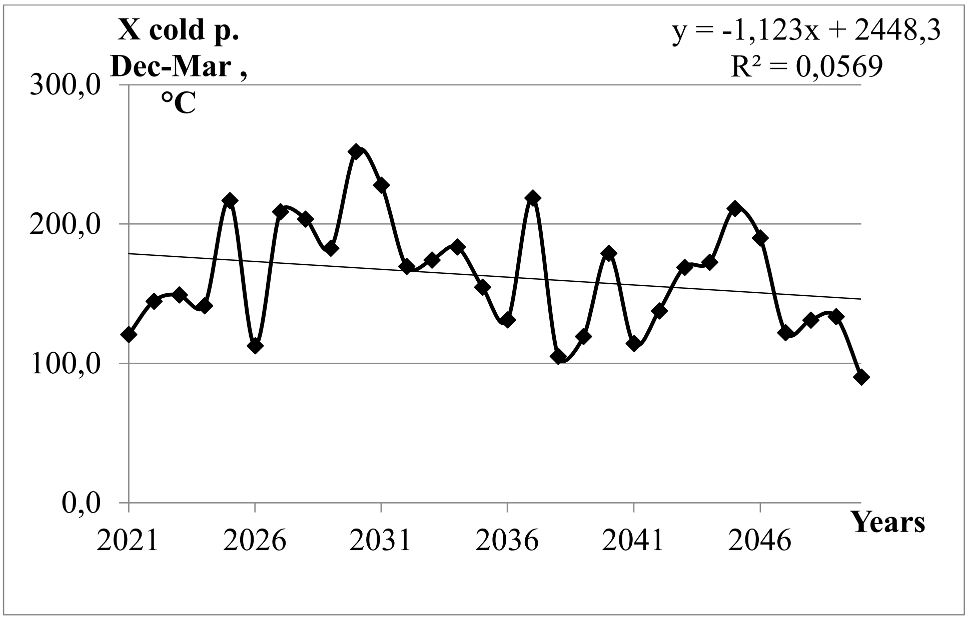

Figure 2.3 - Chronological trend of precipitation during the cold period at Poltava WSG

3. Calculate the ordinates of the residual mass curve of annual precipitation totals (Table 2.3) and plot the residual mass curve for annual precipitation totals (Figure 2.4).

Table 2.4 - Calculation of ordinates for the residual mass curve of annual precipitation totals

№	Years	Annual precipitation total X, mm	$k_i = X_i / X_{avg.}$	$k_i - 1$	$\Sigma(k_i - 1)$
1	2021	431	0,94	-0,06	-0,06
2	2022	469	1,02	0,02	-0,04
3	2023	463	1,01	0,01	-0,02
4	2024	276	0,60	-0,40	-0,42
5	2025	476	1,04	0,04	-0,38
6	2026	291	0,64	-0,36	-0,74
7	2027	790	1,73	0,73	-0,02
8	2028	557	1,22	0,22	0,20
9	2029	653	1,43	0,43	0,62
10	2030	681	1,49	0,49	1,11
11	2031	512	1,12	0,12	1,23
12	2032	440	0,96	-0,04	1,19
13	2033	508	1,11	0,11	1,30
14	2034	518	1,13	0,13	1,43
15	2035	357	0,78	-0,22	1,21
16	2036	431	0,94	-0,06	1,15

End of Table 2.4

17	2037	608	1,33	0,33	1,48
18	2038	462	1,01	0,01	1,49
19	2039	443	0,97	-0,03	1,46
20	2040	363	0,79	-0,21	1,25
21	2041	372	0,81	-0,19	1,06
22	2042	403	0,88	-0,12	0,94
23	2043	466	1,02	0,02	0,96
24	2044	360	0,79	-0,21	0,75
25	2045	395	0,86	-0,14	0,61
26	2046	402	0,88	-0,12	0,49
27	2047	340	0,74	-0,26	0,23
28	2048	404	0,88	-0,12	0,11
29	2049	564	1,23	0,23	0,34
30	2050	300	0,66	-0,34	0,00
		Xavg.=458			

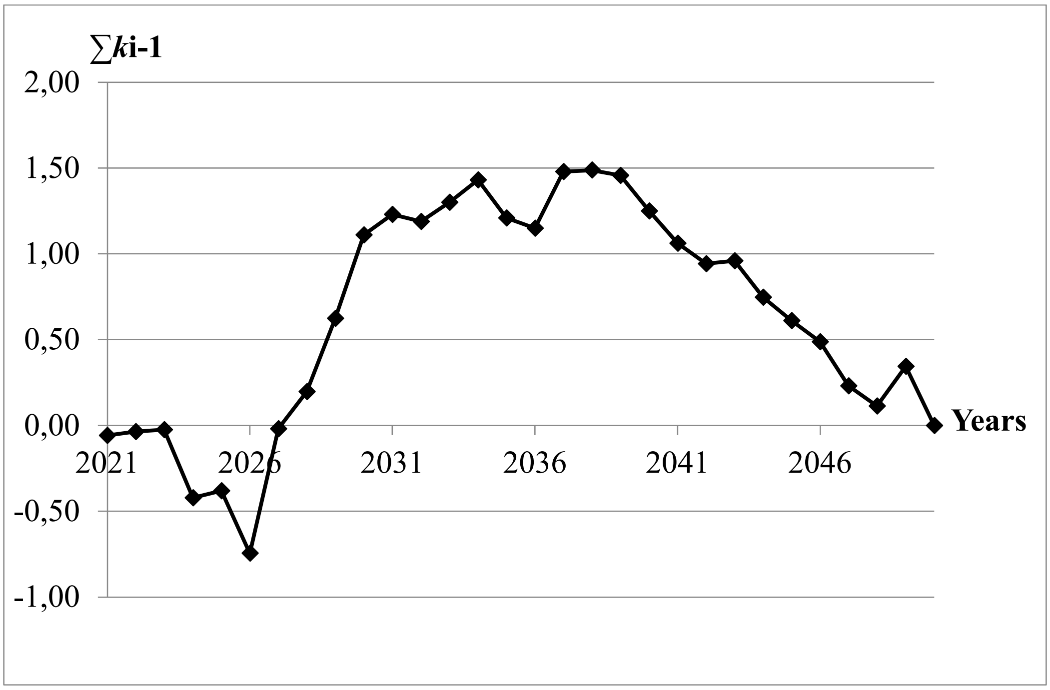

Figure 2.4 – Residual mass curve of annual precipitation totals for the Poltava meteorological station from 2021 to 2050.

4. Calculate the sums of air temperatures for the warm (April-November) and cold (December-March) periods of the year under the scenario conditions from 2021 to 2050. Record the results in Table 2.5.

Table 2.5 – Air temperature for the warm (April-November) and cold (December-March) periods of the year under scenario conditions from 2021 to 2050

№	Year	Annual	Warm period (April-November)	Cold period (December-March)
1	2021	8,6	118	-14,4
2	2022	8,7	118	-12,8
3	2023	8,9	116	-9,8
4	2024	10,0	131	-10,3
5	2025	9,6	123	-7,6
6	2026	9,6	128	-12,7
7	2027	7,5	103	-12,4
8	2028	7,1	104	-18,9
9	2029	7,9	114	-19,7
10	2030	8,8	109	-3,8
11	2031	9,2	113	-2,7
12	2032	7,6	113	-21,8
13	2033	8,7	114	-9,7
14	2034	9,6	127	-12,4
15	2035	9,7	124	-6,9
16	2036	9,1	119	-9,3
17	2037	7,9	103	-8,2
18	2038	8,8	108	-1,6
19	2039	8,1	120	-22,3
20	2040	10,3	121	2,6
21	2041	9,4	121	-8,5
22	2042	9,9	121	-2,6
23	2043	8,7	118	-14,0
24	2044	11,0	127	5,4
25	2045	9,6	113	1,7
26	2046	10,9	131	-0,5
27	2047	9,2	117	-6,8
28	2048	10,1	123	-1,8
29	2049	8,2	111	-13,1
30	2050	7,9	115	-20,6

5. Build chronological graphs of fluctuations in average annual air temperatures, as well as for the warm and cold periods. Construct linear regression equations describing trends in meteorological characteristics changes and identify the statistical significance of these trends. Examples of graphs are provided in Figures 2.5 - 2.7.

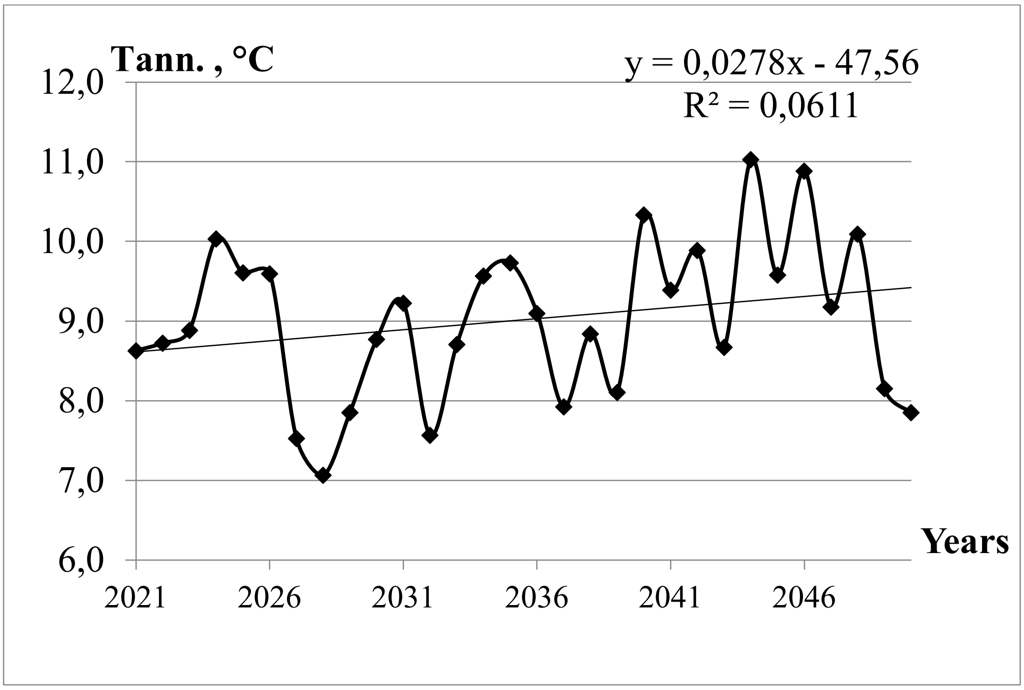

Figure 2.5 - Chronological trend of average annual air temperatures at the Poltava meteorological station

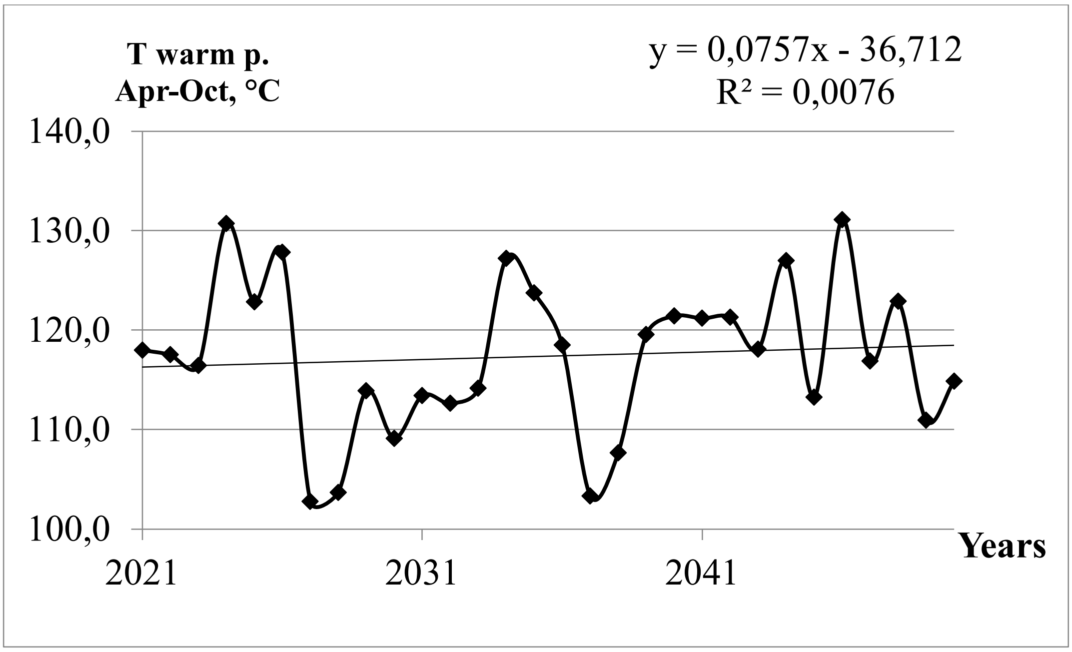

Figure 2.6 - Chronological trend of sum of air temperatures for the warm period at the Poltava meteorological station from 2021 to 2050

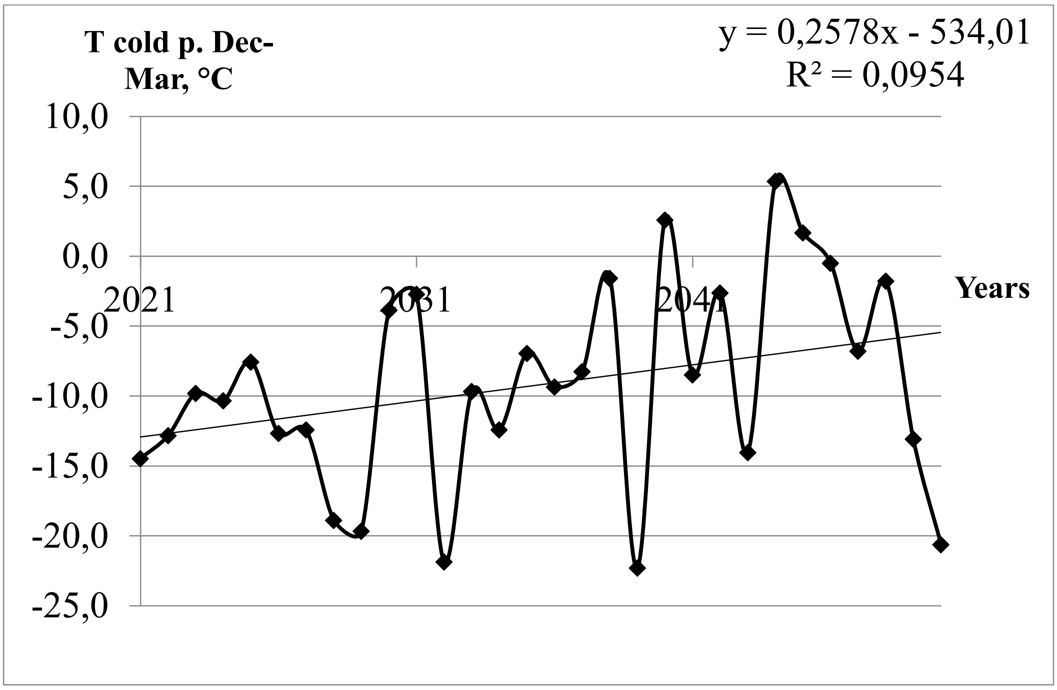

Figure 2.7 - Chronological trend of sum of air temperatures for the cold period at the Poltava meteorological station

6. Calculate the ordinates of the residual mass curve of annual air temperatures (Table 2.6) and plot the residual mass curve of average annual air temperatures (Figure 2.8).

Table 2.6 - Calculation of ordinates for the residual mass curve of annual air temperatures

№	Years	Annual air temperatures, T, ^{0}C	$k_i = X_i / X_{avg.}$	$k_i - 1$	$\Sigma(k_i - 1)$
1	2021	8,6	0,96	-0,04	-0,04
2	2022	8,7	0,97	-0,03	-0,08
3	2023	8,9	0,99	-0,01	-0,09
4	2024	10,0	1,11	0,11	0,02
5	2025	9,6	1,07	0,07	0,09
6	2026	9,6	1,06	0,06	0,15
7	2027	7,5	0,83	-0,17	-0,01
8	2028	7,1	0,78	-0,22	-0,23
9	2029	7,9	0,87	-0,13	-0,36
10	2030	8,8	0,97	-0,03	-0,39
11	2031	9,2	1,02	0,02	-0,36
12	2032	7,6	0,84	-0,16	-0,52
13	2033	8,7	0,97	-0,03	-0,56
14	2034	9,6	1,06	0,06	-0,50

End of Table 2.6

15	2035	9,7	1,08	0,08	-0,42
16	2036	9,1	1,01	0,01	-0,41
17	2037	7,9	0,88	-0,12	-0,53
18	2038	8,8	0,98	-0,02	-0,55
19	2039	8,1	0,90	-0,10	-0,65
20	2040	10,3	1,15	0,15	-0,50
21	2041	9,4	1,04	0,04	-0,46
22	2042	9,9	1,10	0,10	-0,37
23	2043	8,7	0,96	-0,04	-0,40
24	2044	11,0	1,22	0,22	-0,18
25	2045	9,6	1,06	0,06	-0,12
26	2046	10,9	1,21	0,21	0,09
27	2047	9,2	1,02	0,02	0,11
28	2048	10,1	1,12	0,12	0,22
29	2049	8,2	0,90	-0,10	0,13
30	2050	7,9	0,87	-0,13	0,00
		Tavg. = 9,0 ^{0}C			

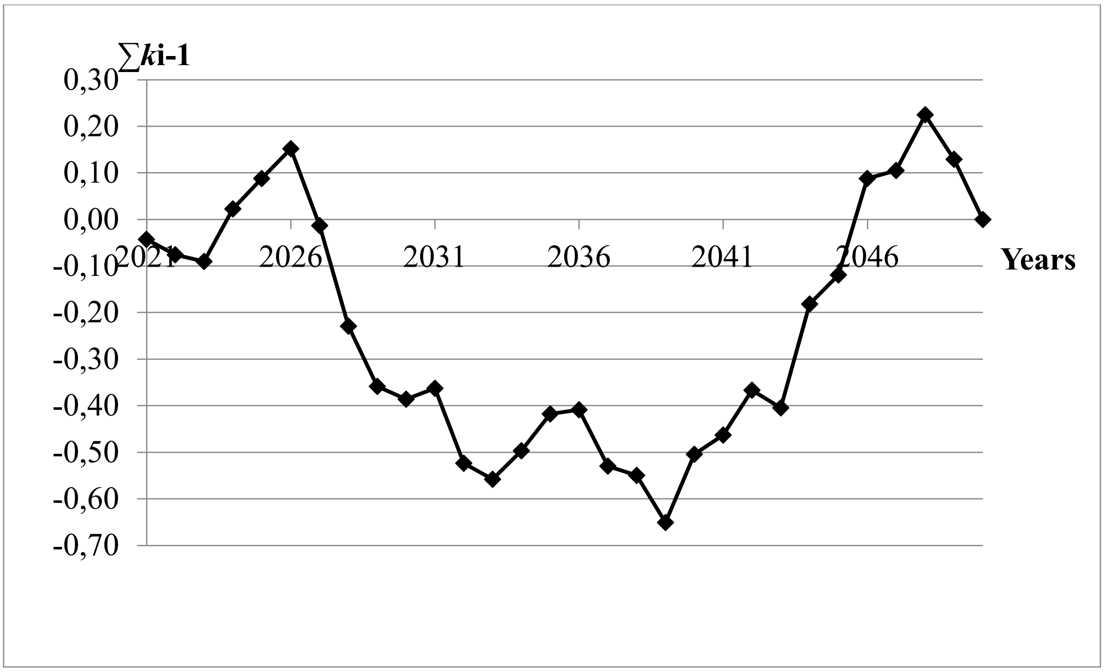

Figure 2.8 – Residual mass curve of average annual air temperatures

Conclusions:

The analysis of the chronological graphs depicting fluctuations in precipitation sums for the year, warm and cold periods (Figures 2.1-2.3) revealed tendencies towards a decrease in precipitation at the Poltava meteorological station during the period from 2021 to 2050. The obtained tendencies were described by linear regression equations, which were plotted on the graphs. Checking the statistical significance of the identified trends, based on the inequality r > 2бr or r < 2бr, showed that they are statistically insignificant, meaning they cannot be considered trends.

Statistically significant trends were not observed in the chronological graphs of average annual air temperatures and temperature sums for the warm and cold periods. However, in the trends of temperature sums for the cold period and for the year, the condition r > 2бr is satisfied, indicating that these should be considered as trends.

Analyzing the fluctuations in annual precipitation sums using residual mass curves allowed us to determine that a phase of low moisture begins around the year 2027 (Figure 2.4), while a warm phase in temperature fluctuations begins around the year 2039 (Figure 2.8). Therefore, by the end of the 2030s, unfavorable conditions for runoff formation may develop, as the decrease in moisture resources will be accompanied by an increase in heat resources.

Control questions

1. Provide the definition of a climate scenario.
2. Provide the definition of emission scenarios.
3. What trends in climate change are most unfavorable for runoff formation?
4. How is the statistical significance of the correlation coefficient determined?
5. Write down the equation for the water balance of a watershed.

PRACTICAL WORK No. 3

EVALUATION OF CHANGES IN HEAT YIELD, MOISTURE, AND DROUGHT INDEX B_X IN THE PRESENT AND FUTURE UNDER THE GLOBAL WARMING SCENARIO (RCP4.5 MODEL)

The aim of the work is to determine the heat, moisture, and drought index resources for the forecast period based on the "climate-runoff" model.

Theoretical part

One of the most common approaches to drought analysis is based on the use of specific indices/indicators that should reflect meteorological phenomena and conditions preceding the onset of agricultural or hydrological droughts. Among them are the Palmer Drought Severity Index, Standardized Precipitation Evapotranspiration Index (SPEI), the hydrothermal coefficient by G.T. Selyaninov (HTC), and the drought/moisture index (β_X) proposed in the "climate-runoff" model. Practically all existing drought indices are based on comparing available moisture reserves with potential evapotranspiration.

In the "climate-runoff" model, the characteristic of heat yields is represented by the maximum potential evaporation, which is calculated using air temperature data during the summer season according to the following formula:

$$\overline{E}_m = 13{,}3\sum_{V}^{IX}\overline{T_M} - 307, r = 0.94, \tag{3.1}$$

where $\sum_{V}^{IX}\overline{T_M}$ - sum of the norms of the average monthly air temperatures for the summer period (from May to September, inclusive).

The characteristic of moisture reserves over a multi-year period is the multi-year average annual sum of precipitation $\overline{X}$.

According to UNESCO recommendations, the degree of aridity (dryness) of a territory is determined by the following relationships:

$$\begin{gathered} X/PET < 0{,}03 \text{ – hyper arid zone;} \\ 0{,}03 < X/PET < 0{,}20 \text{ – arid zone;} \\ 0{,}20 < X/PET < 0{,}50 \text{ – semi-arid zone,} \end{gathered} \tag{3.2}$$

where X – annual mean precipitation; PET – potential evaporation.

An analogy can be drawn between the magnitude of PET and the maximum possible evaporation, or the thermal energy equivalent E_t, which is interpreted as the maximum possible evaporation from the land surface that would occur if all the climatic thermal energy resources were expended on the evaporation process.

According to the recommendations of V.S. Mezentsev, the degree of moisture (aridity) of the territory is determined by the value of β_X, which represents the relationship between moisture resources X and heat, as follows Et :

$$\beta_X = \frac{\overline{X}}{Et} \tag{3.3}$$

$$\begin{gathered}
\beta_X \geq 1{,}0 \text{ – oversaturated zone;} \\
0{,}8 \leq \beta_X < 1{,}0 \text{ – zone of sufficient saturation;} \\
0{,}5 \leq \beta_X < 0{,}8 \text{ – undersaturated zone;} \\
0{,}2 \leq \beta_X < 0{,}50 \text{ – semi-arid zone;} \\
0{,}03 \leq \beta_X < 0{,}20 \text{ – arid zone;} \\
\beta_X < 0{,}03 \text{ – hyper arid zone}
\end{gathered} \tag{3.4}$$

The assessment of changes is provided in the form of relative deviations δ (%) of characteristics between the past (baseline) and scenario periods. The relative deviations are calculated using the formula:

$$\delta = \frac{\overline{A}' - \overline{A}}{\overline{A}}, \tag{3.5}$$

where $\overline{A}'$ - average multi-year value of a parameter A, calculated based on the scenario data, mm; $\overline{A}$ - average multi-year value of a parameter A, calculated based on the data up to 1989 (before the onset of significant global warming influence).

Practical part

Input data: monthly average temperature and precipitation data for the observation period (up to 1989) and for the period 2021-2050 for the specified climate change scenario (the same variant as in activity 2).

Calculations example

Stages of task execution:

1. Form a table with the initial data of the multi-year average values of annual precipitation sums and air temperature sums for the summer season (see Table 3.1).
2. Determine the multi-year average value of annual precipitation sums and maximum possible evaporation for two periods: before 1989, from 1989 to 2021, and from 2021 to 2050.
3. Evaluate the aridity index for each of the periods considered.
4. Provide an assessment of changes in heat resources, moisture resources, and the β_X index for two periods.

Table 3.1 - Initial Data

№ n/o	Year	ΣT, ^{O}C	X, mm
1	1975	83,0	702
2	1976	70,6	716
3	1977	71,9	653
4	1978	68,2	707
5	1979	78,3	548
6	1980	68,9	839
7	1981	77,5	735
8	1982	80,6	450
9	1983	79,9	661
10	1984	73,3	570
11	1985	76,5	613
12	1986	78,4	506
13	1987	74,9	649
14	1988	79,0	675
15	1989	77,5	493
Average		**75,9**	**635**
1	1990	74,0	434
2	1991	76,8	515
3	1992	80,7	571
4	1993	74,7	665
5	1994	82,6	476
6	1995	80,4	534
7	1996	78,5	495
8	1997	78,2	589
9	1998	78,5	730
10	1999	83,5	578
11	2000	78,2	544
12	2001	80,3	798
13	2002	85,5	456
14	2003	85,8	538
15	2004	78,0	595
16	2005	80,9	583
17	2006	81,6	603
18	2007	87,1	636
19	2008	80,8	718
20	2009	83,9	509
21	2010	86,9	764
22	2011	85,3	400
23	2012	89,0	736

End of table 3.1

24	2013	83,1	727
25	2014	83,7	582
26	2015	89,0	452
Average		**81,8**	**586**
1	2021	82,7	357
2	2022	73,6	610
3	2023	71,9	601
4	2024	74	713
5	2025	73,9	634
6	2026	80,4	550
7	2027	75,7	676
8	2028	73,7	656
9	2029	77,2	580
10	2030	68,9	635
11	2031	71,5	707
12	2032	80,2	470
13	2033	71,6	786
14	2034	75,3	731
15	2035	76,5	554
16	2036	70,1	598
17	2037	75,6	574
18	2038	77,8	512
19	2039	76	805
20	2040	79,5	550
21	2041	75,9	709
22	2042	80,4	463
23	2043	75,7	743
24	2044	78	647
25	2045	77,4	584
26	2046	84,8	347
27	2047	75,7	535
28	2048	75,7	666
29	2049	73,7	596
30	2050	75,6	627
Average		**76,0**	**607**

1. Calculate the aridity index β_X for past years (before 1989 and after 1989) and according to the scenario (2021-2050).
   The calculation is performed using the formula:

$$\beta_X = \frac{\overline{X}}{E_t}$$

- For the period before 1989, we obtained: $\sum_{V}^{IX}\overline{T_M}$=75,9. The calculated value for the average multi-year maximum potential evaporation from (3.1) is 703 mm, while the average multi-year precipitation value is 635 mm.

$$\beta_{\text{X}} = \frac{635}{703} = 0{,}90$$

- For the period 1990-2015

$$\beta_{\text{X}} = \frac{586}{781} = 0{,}75$$

- For the period 2021-2050

$$\beta_{\text{X}} = \frac{607}{703} = 0{,}86$$

Results are recorded in table 3.2.

Table 3.2 - Changes in drought indicators according to scenario data compared to actual data before 1989.

Period	Drought/moisture indicator β_X	The established degree of moisture/drought of the territory	δ, %
Before 1989	0,90	zone of sufficient saturation	
1990-2015	0,75	undersaturated zone	-16,7
2021-2050	0,86	zone of sufficient saturation	-4,44

Conclusions:

It has been established that according to the observation data, after 1989, the investigated meteorological station transitioned into a zone of insufficient moisture.

It has been found that in the forecasted period according to the scenario data, there will also be a decrease in the β_X index, but according to the forecast, the investigated meteorological station will remain within the limits of the zone of sufficient moisture.

Results should be formatted and an analysis of the calculation results according to your variant should be provided.

Control questions

1. Provide the definition of the concept of "maximum potential evaporation."
2. How to calculate the maximum potential evaporation?
3. What is the β_X index?
4. How to determine the β_X index?

PRACTICAL WORK No. 4
DETERMINATION OF STATISTICAL PARAMETERS OF ANNUAL CLIMATE BALANCE AND NATURAL RIVER RUNOFF IN UKRAINE USING THE "CLIMATE-RUNOFF" MODEL.

The aim of the work is to determine the characteristics of water resources in the area using meteorological data.

Theoretical part

The relationship between runoff and climatic factors is described through the equation of the closed water balance of the watershed over a multi-year period.

$$\overline{Y} = \overline{X} - \overline{E} . \tag{4.1}$$

where $\overline{X}$, $\overline{E}$, $\overline{Y}$ – average multi-year layers (mm) of annual precipitation, evaporation from the land surface, and runoff, respectively.

Components of the water balance equation $\overline{X}$ and $\overline{E}$ are climate factors that contribute to the formation of annual runoff, which are distributed in space according to the laws of latitudinal or vertical zonality. Since the average annual runoff $\overline{Y}$depends on climatic factors, its spatial distribution is also determined by the latitude of the area for plain rivers or by altitude in mountainous regions.

Evaporation from the land surface depends on the thermal energy resources of the climate and the moisture content of the underlying surface. In turn, the thermal energy resources of the climate are determined by the influx of solar radiation, which governs the thermal regime of the near-surface layer of the air. Air temperatures are often used as the primary factor in calculating thermal energy resources and evaporation. In the northern hemisphere, evaporation from the land surface increases from north to south. If evaporation from the land surface is limited by thermal energy resources in the north, then in the south, this quantity is constrained by moisture resources. In the absence of moisture in the soil in arid (desert) and semi-arid (semi-desert) zones, evaporation from the land surface may decrease. In general, air temperatures and precipitation are considered the main climatic factors influencing runoff formation.

At the Odessa State Environmental University, under the guidance of Prof. Y.D. Gopchenko and Prof. N.S. Loboda, a model of annual runoff was developed. This model is based on the use of meteorological data and belongs to the "climate-runoff" type models. The mathematical model considers the climatic factors affecting runoff formation and the influence of the underlying surface, including water management activities. The model consists of two parts. The first part allows for the assessment of natural annual runoff based on meteorological data, while the second part assesses household (altered by water management activities) runoff. The first part of the model uses meteorological data as input, while the second part uses natural or unaltered annual runoff data along with quantitative indicators of water management alterations. The theoretical basis of the first part is the water-heat balance equation of the catchment, while the second part relies on the water management balance equation of the catchment, presented in a stochastic (probabilistic) form. The model considers a chain of sequences in runoff formation: "climate → climatic runoff → sub catchment surface → natural runoff → water management alterations → household runoff". Thus, the operation of the water management system is studied and modeled, which is subject to both external (climatic) and internal (water management) influences and responds to these influences in a certain way.

In the "climate-runoff" model, the primary evaporation from the land surface is calculated through the concept of maximum possible evaporation E_m. The value E_m is conceptually close to the notion of evaporation rate. (E_0). The latter has been defined by different authors as the upper limit of evaporation, but interpreted differently: "evaporation from a moist surface" (M.I. Budiko); "evaporation from a water surface under the same set of meteorological conditions as over land" (M.A. Bagrov); "evaporation for fields covered with vegetation, when the soil moisture is close to the minimum field capacity" (A.R. Konstantinov). V.S. Mezentsev represented the maximum possible evaporation as having an energy origin LE_m. Value E_m is part of the gross part of the heat balance of the land and the product LE_m is considered as the limiting energy resources that provide the process of evaporation from the land surface under certain climatic conditions

$$LE_m = R^+ + P^+ + (B_1 - B_2)\ , \tag{4.2}$$

where R^+- the positive (gross) part of the radiation balance; P^+- the positive component of turbulent heat exchange or heat incoming to the land area due to air movement, i.e., advective heat; $B_1 - B_2$ - change in heat storage in the active layer of the soil (heat exchange in the soil ΔB); L - latent heat of evaporation.; LE - heat expenditure on evaporation.

Value E_m got the name "heat energy equivalent" or "maximum possible evaporation," and it represents the amount of water that could evaporate from the land surface if all the climatic heat energy resources were used for evaporation LE_m

$$E_m = \frac{R^+ + P^+ + (B_1 - B_2)}{L}\ . \tag{4.3}$$

According to this formulation, the maximum possible evaporation is determined using data from actinometrical stations. In the mid-twentieth century, there were 19 such stations in Ukraine and Moldova. Professors Ye. D. Hoptchenko and N.S. Loboda derived regression equations based on calculations using data from these actinometrical stations, which show the relationship between the values E_m and air temperatures within the territory of Ukraine and Moldova. To determine the maximum possible evaporation based on air temperatures, the following equations are recommended

$$\overline{E}_m = 0{,}224\sum\overline{T}_{>10} + 226, r = 0.91; \tag{4.4}$$

$$\overline{E}_m = 0{,}209\sum\overline{T}_{>0} + 179, r = 0.87, \tag{4.5}$$

$$\overline{E}_m = 13{,}3\sum_{V}^{IX}\overline{T_M} - 307, r = 0.94, \tag{4.6}$$

where $\sum_{V}^{IX}\overline{T_M}$ - the sum of the average monthly air temperatures during the summer period (from May to September, inclusive); $\sum T_{>10}$ - the sum of air temperatures is greater than $10^\circ C$; $\sum T_{>0}$ - the sum of air temperatures is greater than $0^\circ C$. Most commonly, the equation is used for calculating the maximum possible evaporation (4.6).

The main equation used to determine the annual runoff for any calculation interval is the water-heat balance equation of the watershed, which for a multi-year period is represented as

$$\overline{Y} = \overline{X} - \overline{E}_m\left[1 + \left(\frac{\overline{X}}{\overline{E}_m}\right)^{-n}\right]^{-\frac{1}{n}}, \tag{4.7}$$

where $\overline{Y}, \overline{X}$, $\overline{E}_m$ – the average multi-year values (norms) of annual runoff, precipitation, and heat-energy equivalent, respectively; n – the parameter, which integrates the physiographic conditions of runoff formation, is taken to be equal to 3.

Average multi-year value of annual runoff $\overline{Y}$, calculated by (4.7), is determined by climatic factors - the annual precipitation norm $\overline{X}$ and the norm of maximum possible evaporation $\overline{E}_m$, which are subject to the law of geographical zoning and are represented in the form of isoline maps. The values of the runoff calculated using meteorological data using equation (4.7) are referred to as "climatic" runoff. The norm of climatic runoff is subsequently denoted as $\overline{Y}_C$.

Maps of isolines of average multi-year values (norms) of annual precipitation, maximum possible evaporation, and calculated climatic runoff according to equation (4.7) are constructed on a topographic basis of 1:500000 scale for the plains territory of Ukraine. When constructing maps of isopleths of the normal annual climatic runoff $\overline{Y}_C$ were determined using meteorological station data. On the map, these values were assigned to points corresponding to the geographical location of meteorological stations. When determining the norm of climatic runoff from the watershed using the constructed contour map, the sought-after value $\overline{Y}_C$ should be calculated as the weighted average over the partial areas of the watershed contained between the contour lines. Comparison of the norms of annual climatic runoff with actual data, carried out for river basins with established groundwater supply in various geographical zones of Ukraine, showed their correspondence to each other. The norm of annual climatic runoff is identical to the norm of zonal natural river runoff. Natural runoff is runoff under undisturbed hydrological conditions. The accuracy of determining the norm of annual climatic runoff based on the contour map constructed from meteorological data is ± 10 %.

For rivers with unstable groundwater supply (typically small and medium-sized rivers), there is a significant difference between natural runoff and zonal runoff. In such cases, the "climate-runoff" model involves the use of transition coefficients from the norms of annual climatic runoff, determined by contour maps, to the natural runoff. These coefficients describe the influence of factors of the underlying surface in the process of forming river runoff.

The territory of the Northwestern Black Sea region is located in a zone of insufficient moisture and is divided into areas of positive corrections to the norm of climatic runoff and areas of negative corrections. The boundary between them is the winter boundary with a stable snow cover, which is established in less than 50% of cases. The area of positive corrections is located above this boundary, and the area of negative corrections is below it. Empirical equations have been developed for calculating the transition coefficients from the norms of climatic runoff to the norms of natural runoff for rivers in the Northwestern Black Sea region in the area of positive corrections $K_{TR,1}$. These equations take into account the uneven distribution of rainfall and the distribution of snow cover across the watershed area.

$$k_{TR,1} = 2{,}4 - 0{,}7(lg(F + 1) - 1), \text{ where } F < 1000 \text{ km}^2; \quad (4.8)$$

$$K_{TR,1} = 1, \text{ where } F \geq 1000 \text{ km}^2, \quad (4.9)$$

where F – the watershed area, km^2.

In the region with negative adjustments to the norms of climatic runoff, surface retention losses play a significant role in shaping the river runoff. Transitional coefficients $K_{TR,2}$ from climatic to natural streamflow norms are determined depending on the average elevation of the watershed, which is an indirect characteristic of the flatness of the earth's surface and is related in a certain way to the slope of the surface.

$$K_{TR,2} = 1 - 0{,}003(280 - H_{AVG}), \text{ where } H_{AVG} < 280m, \quad (4.10)$$

$$K_{TR,2} = 1, \text{ where } H_{AVG} \geq 280m, \tag{4.11}$$

where H_{AVG} – the average elevation of the watershed.

The lower the elevation of the terrain, the gentler the slope of the surface and the greater the losses of meltwater and rainfall surface runoff due to retention in flat lowlands.

According to the "climate-runoff" model, the natural runoff norm $\bar{Y}_{NA}$ The natural runoff norm of the watershed is calculated as the product of the climate runoff norm, determined by the contour map or equation (4.7), and the transitional coefficient.

$$\bar{Y}_{AVG} = K_{TR} Y_K. \tag{4.12}$$

The coefficient of variation is determined by the following formula:

$$C_V = \frac{1{,}5}{\left(\frac{\bar{Y}_K}{10}\right)^{0{,}62}}, \tag{4.13}$$

where C_V – The coefficient of variation of the annual runoff, with a value of 1.5, corresponds to a climatic runoff norm of 10 mm (C_V=1,5 when $\bar{Y}_K$=10 mm). Between the coefficients of skewness and variation for the territory of the North-Western Black Sea region under the conditions of the past century, the following relationship was established.

$$C_S = 1{,}7 C_V, \tag{4.14}$$

where C_S – the coefficient of skewness

The coefficients of variation and skewness of natural runoff for small and medium rivers are determined by formulas (4.13) and (4.14).

Practical part

Input data: Map of isolines showing multi-year average values of annual climatic runoff, calculated using data up to 1989 (before the onset of global climate changes).

Watersheds of rivers according to the variants

Variant by number	River	Watershed area, F, km²	Average watershed elevation H_{AVG}
1	Cagul	605	120
2	Yalpugh	3180	150

3	Cohilnyk	3910	140
4	Khagider	894	80
5	Alcalia	653	70
6	Malyi Khuyalnyk	1540	110

Task stages:

1. Identify the watershed of the investigated river.
2. Find the weighted average of the annual climatic runoff from the map.
3. Determine the coefficient of the influence of the underlay surface using formulas (4.8) or (4.10).
4. Determine the multi-year average value of the natural river runoff according to (4.12).
5. Calculate the coefficients of variation and asymmetry using formulas (4.13) and (4.14).
6. Compile the table.

Table 4.1 - Statistical parameters of natural runoff from the watershed based on data up to 1989

River watershed (name)	$\overline{Y}_k$, mm	$K_{TR,2}$	$\overline{Y}_{NA}$, mm	C_V	Cs

Calculations example

For example, let's consider the Kuchurgan River.

1) From Appendix A, we will identify the watershed of this river.

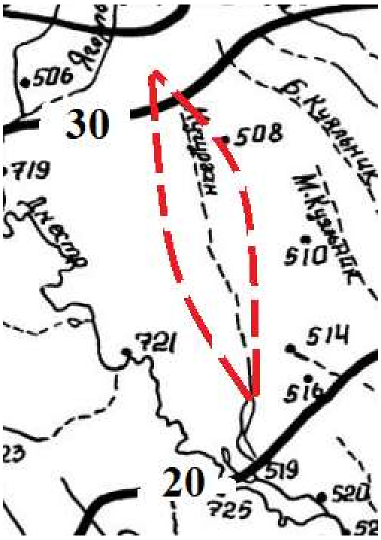

Fig. 4.1 – Fragment of Fig. A.1 (Addition A)

2) From Fig. 4.1, we find the value of the average multi-year annual climatic river runoff. It is determined that $\bar{Y}_k = 27$ mm.
3) The investigated watershed is in the zone of negative corrections. We calculate the transition coefficients from the norms of the annual climatic river runoff to the natural ones. For calculation, we use formula (4.10).

Given that the average watershed elevation is 122 meters, therefore

$$K_{TR,2} = 1 - 0,003\,(280 - H_{AVG})\text{, where } H_{AVG} < 280m,$$

$$K_{TR,2} = 1 - 0,003(280 - 122) = 0,526$$

4. We determine the average multi-year value of natural river runoff using formula (4.12).

$$\bar{Y}_{NA} = K_{TR}\bar{Y}_K = 0,526 \times 27 = 14,2 \text{ mm}$$

5. We calculate the coefficients of variation and skewness.

$$C_V = \frac{1,5}{\left(\frac{\bar{Y}_{NA}}{10}\right)^{0,62}} = \frac{1,5}{\left(\frac{14,2}{10}\right)^{0,62}} = 1,21$$

$$C_S = 1,7\,C_V = 1,7 \times 1,21 = 2,06$$

6. The results of the calculations are entered into Table 4.1.

Table 4.1 - Statistical parameters of natural runoff from the watershed based on data up to 1989

River watershed (name)	$\bar{Y}_k$, mm	$K_{TR,2}$	$\bar{Y}_{NA}$, mm	C_V	Cs
Cuchugur	27	0,526	14,2	1,21	2,06

7. According to the Foster's table of numbers. (F_P) (Appendix B, Table B.1) We determine the natural flow adequacy 5, 25, 50, 75 and 95%.

$$Y_P = \bar{Y}_{NA}(F_P Cv + 1)$$

The results are entered into Table 4.2.

Table 4.2 - Characteristics of natural annual runoff in years of varying water supply (based on data up to 1989).

Characteristics	$P=5\%$	$P=25\%$	$P=50\%$	$P=75\%$	$P=95\%$

(F_P)	2,01	0,38	-0,32	-0,70	-0,930
$(F_P Cv+1)$	3,43	1,46	0,61	0,15	-0,12
Y_P , mm	47,4	20,7	8,66	2,13	0

Present the results and analyze the calculations based on your personal variant.

Control questions

1. Write the equation of the water-energy balance for a closed watershed over a multi-year period.
2. What is meant by "climatic flow"?
3. What is "natural flow"?
4. How is the influence of the sub catchment area accounted for in the "climate-flow" model?
5. How is the transition from climatic flow norms to natural flow norms accomplished for small and medium watersheds?

PRACTICAL WORK No. 5

DETERMINATION OF STATISTICAL PARAMETERS OF DOMESTIC ANNUAL RIVER RUNOFF IN THE PRESENCE OF ARTIFICIAL RESERVOIRS ON THE WATERSHEDS USING THE "CLIMATE-RUNOFF" MODEL

The aim of the work is to determine the statistical parameters of annual runoff in the presence of artificial reservoirs (ponds and reservoirs) on the watershed, which increase water losses due to additional evaporation from the surface of artificial reservoirs.

Theoretical part

For the quantitative assessment of the ***additional evaporation impact from the water surface of artificial reservoirs*** on the annual runoff, the following functions of anthropogenic influence were used:

$$k'_{\bar{Y}} = e^{-\alpha_{\bar{Y}} f_B}; \qquad (5.1)$$

$$k'_{Cv} = e^{\alpha_{Cv} f_B}; \qquad (5.2)$$

$$k'_{Cs} = e^{\alpha_{Cs} f_B}; \qquad (5.3)$$

where $k'_{\bar{Y}}$, k'_{Cv}, k'_{Cs} – coefficients of the additional evaporation impact from the surface of artificial reservoirs on the statistical parameters of the annual household runoff; $\bar{Y}, C_V, C_S$; α_A – coefficients of anthropogenic influence on the investigated parameter A $(\bar{Y}, C_V, C_S)$; $\bar{Y}_K$ – long-term average value of climatic runoff; f_B – total area of artificial water bodies expressed as a percentage (%) of the total watershed area F.

Determination of coefficients α_A for flat territories is based on the following equations:

$$\alpha_{\bar{Y}} = 0{,}767\bar{Y}_{NA}^{(-0.49)}; \qquad (5.4)$$

$$\alpha_{C_V} = 0{,}247e^{(-0.0274\bar{Y}_{NA})}; \qquad (5.5)$$

$$\alpha_{C_S} = 0{,}179e^{(-0.0246\bar{Y}_{NA})}; \qquad (5.6)$$

where $\bar{Y}_{NA}$ – average long-term value of natural annual runoff (mm), which is determined through climatic runoff.

Statistical parameters of domestic annual runoff in the presence of artificial reservoirs on the watershed are determined as follows:

$$\bar{Y}_{DOM} = k'_{\bar{Y}}\hat{Y}_{NA}; \qquad (5.7)$$

$$Cvdom = k'_{Cv}Cv; \qquad (5.8)$$

$$Csdom = k'_{Cs}Cs, \qquad (5.9)$$

where $\bar{Y}_{DOM}, C_{vdom}, C_{Sdom}$ – statistical parameters of domestic (transformed by water management activities) runoff.

Practical part

Input data: statistical parameters of natural river runoff from practical work No. 4; ***surface area of artificial water bodies f_B for all variants, it is assumed to be equal to 1%.***

The task:

Calculate the domestic runoff of the river, its statistical parameters, and runoff characteristics in years of different water levels considering the loss of runoff due to additional evaporation from the water surface.

Calculations example

1. We calculate $\alpha_{\bar{Y}}$; α_{C_V}, α_{C_S}, using the data from practical work 4 regarding the average long-term value of natural runoff and the values f_B = 1%.

$$\alpha_{\bar{Y}} = 0{,}767\bar{Y}_{NA}^{(-0.49)} = 0{,}767\times 14{,}2^{(-0{,}49)} = 0{,}21$$

$$\alpha_{C_V} = 0{,}247e^{(-0.0274\bar{Y}_{NA})} = 0{,}247e^{(-0{,}0274\times 14{,}2)} = 0{,}17$$

$$\alpha_{C_S} = 0{,}179e^{(-0.0246\bar{Y}_{NA})} = 0{,}179e^{(-0{,}0246\times 14{,}2)} = 0{,}13$$

2. We calculate the coefficients of the additional evaporation impact from the surface of artificial reservoirs on the average long-term value of natural runoff, its coefficient of variation, and coefficient of skewness.

$$k'_{\bar{Y}} = e^{-\alpha_{\bar{Y}} f_B} = e^{-0{,}21\times 1} = 0{,}81$$

$$k'_{Cv} = e^{\alpha_{Cv} f_B} = e^{0{,}17\times 1} = 1{,}19$$

$$k'_{Cs} = e^{\alpha_{Cs} f_B} = e^{0{,}13\times 1} = 1{,}14$$

3. We calculate the statistical parameters of household annual runoff in the presence of artificial reservoirs on the watershed.

$$\bar{Y}_{DOM} = k'_{\bar{Y}}\hat{Y}_{NA} = 0{,}81\times 14{,}2 = 11{,}5 \text{ mm}$$

$$Cvdom = k'_{Cv}Cv = 1{,}19\times 1{,}21 = 1{,}41$$

$$Csdom = k'_{Cs}Cs = 1{,}14\times 2{,}06 = 2{,}35$$

4. We record the calculation results in Table 5.1.

Table 5.1 - Calculation results of the coefficients of additional evaporation impact from the surface of artificial reservoirs and statistical parameters of the annual domestic runoff when f_B =1,00 %

Coefficients α_A			Coefficients of anthropogenic impact			Statistical parameters of domestic runoff		
$\alpha_{\bar{Y}}$	α_{Cv}	α_{Cs}	$K^{/}_{Y}$	$K^{/}_{Cv}$	$K^{/}_{Cs}$	$\bar{Y}_{DOM} = k'_{\bar{Y}} \hat{Y}_{NA}$	$Cvdom = k'_{Cv} Cv$	$Csdom = k'_{Cs} Cs$
0,21	0,17	0,13	0,81	1,19	1,14	11,5	1,41	2,35

5. According to Foster's table (F_P) (Appendix B, table B.1) we determine the natural flow provision 5, 25, 50, 75 and 95%.

Table 5.2 - Characteristics of annual domestic runoff in years of different provision in the presence of artificial reservoirs on the catchment

Characteristics	$P=5\%$	$P=25\%$	$P=50\%$	$P=75\%$	$P=95\%$
(F_P)	2,01	0,31	-0,35	-0,68	-0,836
($F_P Cv+1$)	3,83	1,44	0,51	0,04	-0,18
Y_P , mm	44,0	16,6	5,87	0,46	0

6. Evaluate changes in annual runoff due to losses from additional evaporation from the water surface of artificial reservoirs.

$$\delta_{5\%} = \frac{\bar{Y}_{DOM} - \bar{Y}_{NA}}{\bar{Y}_{NA}} 100\%$$

Table 5.3 - Changes in characteristics of annual runoff with the presence of artificial reservoirs on the watershed.

Runoff characteristics	P=5%	P=25%	P=50%	P=75%	P=95%	Average multi-year value
$Y_{NA,P}$	47,4	20,7	8,66	2,13	0	14,2
$Y_{DOM\ ,P}$	44,0	16,6	5,87	0,46	0	11,5
Deviation, $\delta_{P\%}$	-7,17	-19,8	-32,2	-78,4	-	-19,0

Present the results and analyze the calculations based on your personal variant.

Control questions

1. How does additional evaporation from the surface of artificial reservoirs affect the average multi-year value of river flow?
2. How does additional evaporation from the surface of artificial reservoirs affect the coefficient of variation of river flow?
3. How is the relative area of the water surface of artificial reservoirs determined?
4. What is the flow called natural?
5. What is the flow called domestic?

PRACTICAL WORK 6

DETERMINATION OF STATISTICAL PARAMETERS OF ANTHROPOGENIC ANNUAL RUNOFF OF RIVERS UNDER CONDITIONS OF IRRIGATED LANDS (BASED ON LOCAL RUNOFF) USING THE "CLIMATE-STICK" MODEL. ASSESSMENT OF THE COMBINED IMPACT OF ARTIFICIAL RESERVOIRS AND IRRIGATION.

The aim of the study is to determine the statistical parameters of anthropogenic runoff (modified by water management activities) for catchment areas where irrigation occurs due to local runoff and additional evaporation from the surface of artificial reservoirs.

Theoretical part

The general form of multiple linear regression equations to determine the coefficients of anthropogenic influence when withdrawing water for irrigation through local drainage for the studied area is as follows:

$$K_{\bar{Y}} = 1{,}00 - a_{\bar{Y}} \lg(f_{3P} + 1) - b_{\bar{Y}} v_0 + m_{\bar{Y}} \eta \,; \qquad (6.1)$$

$$K_{C_V} = 1{,}00 + a_{C_V} \lg(f_{3P} + 1) + b_{C_V} v_0 - m_{C_V} \eta; \qquad (6.2)$$

$$K_{C_S} = 1{,}00 + a_{C_S} \lg(f_{3P} + 1) + b_{CS} v_0 - m_{CS} \eta, \qquad (6.3)$$

where $k_{\bar{Y}}, k_{C_V}, K_{C_S}$ – the coefficients of the influence of irrigation through local water resources on the average long-term runoff volume $\bar{Y}$ and on the coefficients of variation C_V and asymmetry C_S respectively;

f_{IR} – relative irrigated area in fractions*;*

a_A, b_A, m_A – coefficients of the multiple regression equations for various statistical parameters of runoff, denoted as A;

η – coefficient of effectiveness of the irrigation system.

v_0 – the dimensionless characteristic of the average soil moisture level throughout the entire growing season, at which the development of the corresponding agricultural crop is optimal.

The influence of irrigation due to local runoff is assessed by formulas (6.1-6.3), which for the average multi-year value of climatic runoff, 20 mm, take the form:

$$K_{\bar{Y}} = 1{,}00 - 16{,}0\, lg(f_{IR} + 1) - 0{,}820 v_0 + 0{,}645 \eta_{ir}; \qquad (6.4)$$

$$K_{C_V} = 1{,}00 + 23{,}5\,lg(f_{IR} + 1) + 3{,}0v_0 - 2{,}93\eta_{ir}; \tag{6.5}$$

$$K_{C_S} = 1{,}00 + 23{,}1\,lg(f_{IR} + 1) + 1{,}42v_0 - 1{,}45\eta_{ir}. \tag{6.6}$$

Statistical parameters of annual household runoff in the presence of irrigation in the catchment area are determined as follows:

$$\bar{Y}_{ANT} = k_{\bar{Y}}\hat{Y}_{NA}; \tag{6.7}$$

$$Cvant = k_{Cv}Cv; \tag{6.8}$$

$$Csant = k_{Cs}Cs, \tag{6.9}$$

where $\bar{Y}_{ANT}, C_{ANT}, C_{ANT}$ – statistical parameters of anthropogenic (transformed by water management activities) runoff.

For quantitatively assessing the impact of ***additional evaporation from artificial water bodies*** on the parameters of annual runoff, functions of anthropogenic influence of the following form are used:

$$k'_{\bar{Y}} = e^{-\alpha_{\bar{Y}} f_{WB}}; \tag{6.10}$$

$$k'_{Cv} = e^{\alpha_{Cv} f_{WB}}; \tag{6.11}$$

$$k'_{Cs} = e^{\alpha_{Cs} f_{WB}}, \tag{6.12}$$

where $k'_{\bar{Y}}$, k'_{Cv}, k'_{Cs} – the coefficients of the impact of additional evaporation from the surface of artificial water bodies on the statistical parameters of annual anthropogenic runoff

$\bar{Y}, C_V, C_S$; α_A – the coefficients of anthropogenic influence on the studied parameter A $(\bar{Y}, C_V, C_S)$;

$\bar{Y}_C$ – the average long-term value of climatic runoff;

f_{WB} – the total area of artificial water bodies expressed as a percentage (%) of the total watershed area F.

The determination of coefficients α_A for plain territories is based on the following equations

$$\alpha_{\bar{Y}} = 0{,}767\bar{Y}_{NA}^{(-0.49)}; \tag{6.13}$$

$$\alpha_{C_V} = 0{,}247e^{(-0.0274\bar{Y}_{NA})}; \tag{6.14}$$

$$\alpha_{C_S} = 0{,}179e^{(-0.0246\bar{Y}_{NA})}, \tag{6.15}$$

where $\bar{Y}_{NA}$ – the average multi-year value of natural annual runoff (mm), which is determined through climatic runoff.

The total coefficients of anthropogenic influence from additional evaporation from the surface of artificial reservoirs and losses due to irrigation are determined as follows:

$$K_{YСУМ} = (K_{\bar{Y}}' + K_{\bar{Y}} - 1)\;; \qquad (6.16)$$

$$K_{CV,СУМ_{ANT}} = (K_{C_V}' + K_{C_V} - 1)\;; \qquad (6.17)$$

$$K_{CS_{CYM}} = (K_{C_S}' + K_{C_S} - 1). \qquad (6.18)$$

The statistical parameters of anthropogenic runoff are calculated as follows

$$Y_{ANT} = Y_{NA}(K_{\bar{Y}}' + K_{\bar{Y}} - 1)\;; \qquad (6.19)$$

$$C_{V_{ANT}} = C_{V_{NA}}(K_{C_V}' + K_{C_V} - 1)\;; \qquad (6.20)$$

$$C_{S_{ANT}} = C_{S_{NA}}(K_{C_S}' + K_{C_S} - 1)\;, \qquad (6.21)$$

where $\bar{Y}_{ANT}, C_{ANT}, C_{ANT}$ – the statistical parameters of anthropogenic (transformed by water management activities) runoff.

Practical part

The initial data. The work employs information on the climatic and natural runoff of the river according to your variant (see task 4). For all calculation variants, the relative irrigation area is used, which is equal to f_{IR}=0,02, the efficiency coefficient of the irrigation system, which is equal to η =0,75 and the optimal soil moisture for forage and vegetable crops is equal to v_0 = 0,9.

Calculation examples

1. We calculate the parameters of anthropogenic runoff using the data from *practical work 4* on the average multi-year value of natural runoff and the value $f_{IR}=0{,}02$.

To do this, we need to determine the coefficients of the influence of irrigation on the average multi-year value of natural runoff (using formulas 6.4-6.6).

$$K_{\bar{Y}} = 1{,}00 - 16{,}0\,lg(f_{IR} + 1) - 0{,}820v_0 + 0{,}645\eta_{ir} =$$
$$=1{,}00-16{,}0lg(0{,}02+1)-0{,}820\times0{,}9+0{,}645\times0{,}75= 0{,}61$$

$$K_{C_V} = 1{,}00 + 23{,}5\,lg(f_{IR} + 1) + 3{,}0v_0 - 2{,}93\eta_{ir} =$$
$$= 1{,}00+23{,}5lg(0{,}02+1)+3\times0{,}9-2{,}93\times0{,}75 = 1{,}70$$

$$K_{C_S} = 1{,}00 + 23{,}1\,lg(f_{IR} + 1) + 1{,}42v_0 - 1{,}45\eta_{ir} =$$
$$= 1{,}00 + 23{,}1lg(0{,}02+1) + 1{,}42\times0{,}9 -1{,}45\times0{,}75 = 1{,}39$$

Given the known coefficients of irrigation influence, the parameters of anthropogenic runoff are determined using formulas 6.7-6.9.

$$\bar{Y}_{ANT} = k'_{\bar{Y}}\hat{Y}_{NA} = 0{,}61\times14{,}2 = 8{,}66 \text{ mm}$$

$$Cvant = k'_{Cv}Cv = 1{,}7\times1{,}21 = 2{,}06$$

$$Csant = k'_{Cs}Cs = 1{,}39\times2{,}06 = 2{,}86$$

We determine the runoff of different levels using the Pearson Type III probability distribution law for anthropogenic runoff.

The calculation results are entered into Tables 6.1 and 6.2.

Table 6.1 - Parameters of annual household runoff in the presence of irrigation on the watershed (f_{IR}=0,02, v_0=0,9, η =0,75)

Coefficients of anthropogenic influence			Parameters of anthropogenic runoff			Anthropogenic runoff magnitude in years of different supply, mm				
$K_{\overline{Y}}$	K_{C_V}	K_{C_S}	$\overline{Y}_{ANT}$, mm	C_V	C_S	$Y_{5\%}$	$Y_{25\%}$	$Y_{50\%}$	$Y_{75\%}$	$Y_{95\%}$
0,61	1,7	1,39	8,66	2,06	2,86	44,2	12,3	1,73	0	0

Table 6.2 - Characteristics of annual household runoff in years of different availability in the presence of irrigation on the watershed

Runoff characteristics	Supply, %				
	5	25	50	75	95
(F_P)	1,99	0,21	-0,39	-0,63	-0,693
$(F_P Cv+1)$	5,10	1,42	0,20	-0,30	-0,43
Y_P	44,2	12,3	1,73	0	0

2. An assessment is made of the change in annual runoff due to losses from irrigation on agricultural lands.

$$\delta_{5\%} = \frac{\bar{Y}_{ANT} - \bar{Y}_{NA}}{\bar{Y}_{NA}}100\%$$

The calculation results are shown in the Table 6.3.

Table 6.3 - Changes in characteristics of annual runoff with irrigation from local runoff

Runoff characteristics	Supply, %				
	5	25	50	75	95
$Y_{NA,P}$	47,4	20,7	8,66	2,13	0
$Y_{ANT,P}$	44,2	12,3	1,73	0	0
Deviation, $\delta_{P\%}$	-6,75	-40,6	-80	100	100

To account for the combined effect of two factors of water management activities (irrigation from local runoff and additional evaporation from artificial reservoirs, data taken from task 5), calculations are conducted using formulas 6.16–6.21.

The calculation results are entered into Table 6.4.

Table 6.4 – Total coefficients of anthropogenic influence from irrigation and artificial reservoirs, and statistical parameters of anthropogenic runoff

Total coefficients of anthropogenic influence			Parameters of anthropogenic runoff		
$K_{\bar{Y}}$	K_{C_V}	K_{C_S}	$\bar{Y}_{ANT}$, mm	C_V	C_S
0,81+0,61-1=0,42	1,19+1,70 -1=1,89	1,14+1,39-1=1,53	14,2*0,42=5,96	1,21*1,89=2,29	2,06*1,53=3,15

Table 6.5 – Characteristics of household annual runoff in years of different provision levels in the presence of irrigation from local runoff and additional evaporation from the surface of artificial reservoirs

Runoff characteristics	Supply, %				
	5	25	50	75	95
(F_P)	1,96	0,16	-0,41	-0,60	-0,635
$(F_P Cv+1)$	5,49	1,37	0,06	-0,37	-0,45
Y_P	32,7	8,17	0,36	0	0

Write down the results and perform an analysis of the calculation outcomes according to your variant.

Control questions

1. What does the index characterize ν_0 ?
2. What does the coefficient of useful action of the irrigation system represent η ?
3. How does irrigation through local runoff affect the average multi-year magnitude of river runoff?
4. How does irrigation through local runoff affect the coefficient of variation of river runoff?
5. Does the combined effect of additional evaporation from the water surface and irrigation enhance or mitigate the consequences of anthropogenic influence?

PRACTICAL WORK No. 7
ASSESSMENT OF ANNUAL RUNOFF CHARACTERISTICS UNDER CLIMATIC CHANGES AND WATER MANAGEMENT ACTIVITIES

The aim of the work is to acquire skills in determining the statistical parameters of natural and domestic (transformed by water management activities) annual runoff from the catchment area under conditions of climatic changes (according to climatic scenarios).

Theoretical part

As a rule, the outcome of calculations using the "climate-runoff" model consists of contour maps showing changes in climatic runoff for scenario-based climatic conditions. An example of such an approach is the map shown in Fig. 7.1. The forecasting period from 2021 to 2050 is considered for the climatic scenario RCP4.5. Each scenario includes 14 simulations from the EVRO-CORDEX project. Ensemble-averaged simulation data for scenarios were used in the runoff assessments.

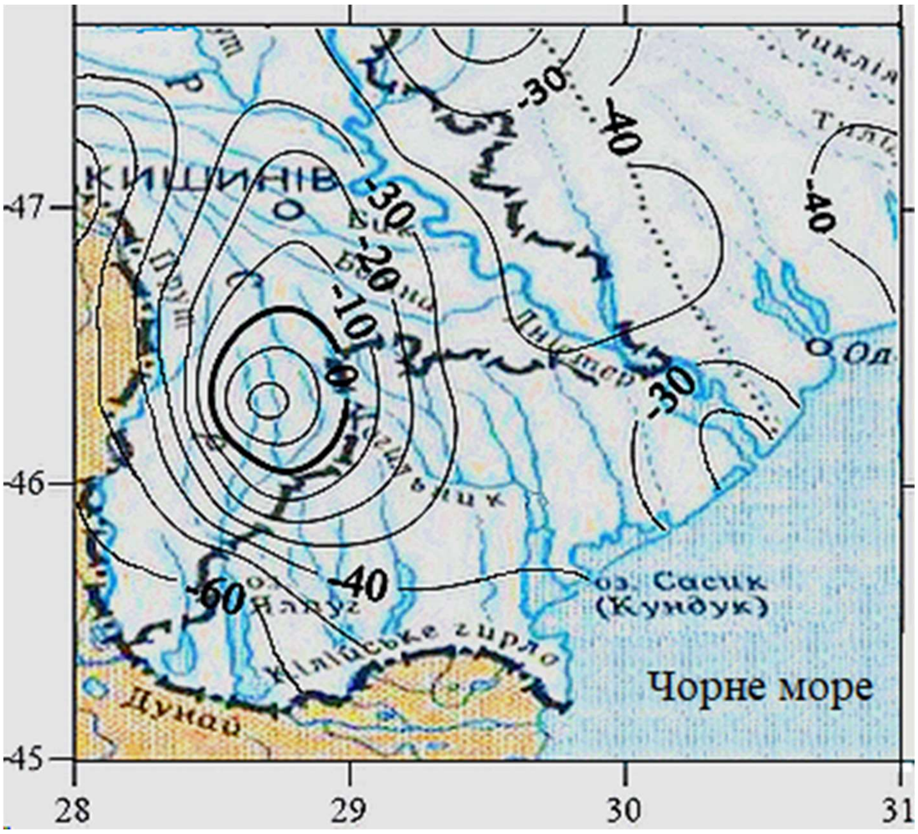

Figure 7.1 Changes in the spatial distribution of mean multi-year zonal annual runoff (ensemble-averaged trajectory model RCP4.5 with 14 simulations from the EVRO-CORDEX project) for the period 2021-2050 compared to the baseline data up to 1989.

Calculations of the mean multi-year natural (undisturbed by human activities) annual runoff of the rivers in the Northwest Black Sea region under scenario-based climatic conditions are conducted according to the following scheme.

In the first stage, the mean multi-year values of climatic (zonal) annual runoff from river basins are determined for the baseline period (up to 1989) using the contour map provided in Appendix A.

In the second stage, changes in climatic runoff are established for a specified river basin by considering its variations according to selected scenarios using constructed contour maps, an example of which is shown in Figure 7.1. Subsequently, the value of the annual climatic runoff corresponding to the new (scenario-based) climatic conditions is computed. The predicted relative change in annual climatic runoff is calculated using the following equation:

$$\delta = \frac{\bar{Y}_{SC} - \bar{Y}_{BAS}}{\bar{Y}_{BAS}}, \tag{7.1}$$

from which the scenario value come from like this

$$\bar{Y}_{SC} = \bar{Y}_{BAS}\delta + \bar{Y}_{BAS} = (1 \pm \delta)\ , \tag{7.2}$$

where $\bar{Y}_{SC}$ – the average multi-year value of annual runoff under scenario conditions;

$\bar{Y}_{BAS}$ – the baseline value of the average multi-year annual runoff (up to 1989).

If there is a decrease in water resources, then in formula (7.2) δ will be a minus sign.

The third stage involves using transition coefficients from climatic runoff to natural (unperturbed by water management activities) runoff. According to the "climate-runoff" model, the norm of natural annual runoff $\bar{Y}_{NA}$ for small or medium-sized catchments with unstable groundwater recharge is calculated as the product of the norm of climatic runoff, determined by the contour map, and the transitional coefficient.

$$\bar{Y}_{NA} = K\bar{Y}_{C}, \tag{7.3}$$

where $\bar{Y}_{NA}$– the average multi-year value of natural runoff.;

$\bar{Y}_{C}$ - the average multi-year value of climatic runoff;

K_{TRA} the transition coefficient from climatic runoff to natural runoff.

It is recommended to establish transition coefficients К_{TRA} depending on the average altitude of the watershed, which is an indirect characteristic of the Earth's surface flatness.

$$\text{К}_{TRA,2} = 1 - 0{,}003(280 - H_{AVG}), \text{ when } H_{AVG} < 280m, \tag{7.4}$$

$$К_{AVF,2} = 1, \text{ when } H_{AVG} \geq 280m, \quad (7.5)$$

where H_{AVG} – the average elevation of the watershed.

On the fourth stage, the coefficients of variation and asymmetry of the natural annual runoff are calculated using the equations.

$$C_V = \frac{1,5}{\left(\frac{\overline{Y}_{NA}}{10}\right)^{0,62}}, \quad (7.6)$$

where C_V – The coefficient of variation of the annual runoff is calculated as follows: the value 1,5 corresponds to the coefficient of variation associated with a climatic runoff norm equal to 10 mm (C_V =1,5 where $\overline{Y_c}$ =10mm).

The relationship between the coefficients of skewness and variation for the territory of the Northwestern Black Sea region is established as follows.

$$C_S = 1,7C_V, \quad (7.7)$$

where C_S – efficiency coefficients.

Initial data. The calculations utilize data on the multi-year average value of annual climatic runoff determined for the watershed according to the specified scenario (see task 4). For all scenarios, it is assumed that the reduction of the multi-year average value of annual climatic runoff for the period 2021-2050 will be 20%.

For all calculation variants, the relative irrigated area is used, which is equal to f_{IR}=0,02, the efficiency coefficient of the irrigation system, which is equal to η =0,75 and the optimal soil moisture for fodder and vegetable crops is v_0 = 0,9. The relative area of the water surface of artificial reservoirs is set equal to 1,00%.

Calculations example

1. Determination of the average multi-year value of climatic annual runoff based on the climate scenario data.
2. Yes, in the climatic conditions of the previous century (up to 1989) $\overline{Y}_C$=27 mm (the base value).

Given that a reduction of runoff by 20% is projected, the average multi-year runoff in the scenario conditions of climate runoff change would be equal to ***27*(1-0,20) = 28*0,8=21,6*** mm.

3. Determining the statistical parameters of natural (unaffected by water management activities) runoff is carried out according to equations (7.4-7.6). As a result of the calculations, we obtain a table in the following format.

Table 7.1 – Statistical Parameters of Natural Runoff from the Watershed based on Scenario Data for 2021-2050

Watershed (River Name)	$\overline{Y}_C$, mm	$K_{TRA,2}$	$\overline{Y}_{NA}$, mm	C_V	Cs
Kuchurgan	21,6	0,526	11,4	1,39	2,36

By using the Pearson III tables, we determine the values of natural runoff for different probabilities.

Table 7.2 - Characteristics of natural annual runoff for years of different probabilities for the scenario period 2021-2050.

Watershed characteristics	Availability, %				
	5	25	50	75	95
$(\varPhi_P)$	2,00	0,30	-0,35	-0,67	-0,834
$k_P = (\varPhi_P Cv + 1)$	3,78	1,42	0,51	0,07	-0,16
$Y_P = k_P \overline{Y}_{NA}$	43,1	16,2	5,81	0,80	0

4. Determination of coefficients of the additional evaporation impact from the water surface on the statistical parameters of the annual runoff is carried out according to the formulas

$$k'_{\bar{Y}} = e^{-\alpha_{\bar{Y}} f_{WR}}; \tag{7.8}$$

$$k'_{Cv} = e^{\alpha_{Cv} f_{WR}}; \tag{7.9}$$

$$k'_{Cs} = e^{\alpha_{Cs} f_{WR}}, \tag{7.10}$$

where $k'_{\bar{Y}}$, k'_{Cv}, k'_{Cs} – coefficients of the additional evaporation impact from the surface of artificial water bodies on the statistical parameters of the annual anthropogenic runoff $\overline{Y}, C_V, C_S$; α_A – coefficients of anthropogenic influence on the parameter A, which depend on the norm of climatic runoff $\overline{Y_C}$ as an integral indicator of watershed moisture; f_{WR}- the total area of artificial water reservoirs, expressed as a percentage (%) from the total area of watershed F.

Determination coefficients α_A for flat territories is based on the following equations

$$\alpha_{\bar{Y}} = 0{,}767\bar{Y}_{NA}^{(-0.49)} = 0{,}767\times 11{,}4^{(-0{,}49)} = 0{,}233$$

$$\alpha_{C_V} = 0{,}247e^{(-0.02\qquad \bar{\ }_{NA})} = 0{,}247\mathrm{e}^{(-0{,}0274\times 11{,}4)} = 0{,}181$$

$$\alpha_{C_S} = 0{,}179e^{(-0.0246\bar{Y}_{NA})} = 0{,}179\mathrm{e}^{(-0{,}0246\times 11{,}4)} = 0{,}135$$

The coefficients influencing the additional evaporation from the water surface on the statistical parameters of river runoff will be:

$$k'_{\bar{Y}} = e^{-0,233}=0,79$$

$$k'_{Cv} = e^{0,181}=1,20$$

$$k'_{Cs} = e^{0,135}=1,14$$

The calculation results are recorded in Table 7.3

Table 7.3 - Results of calculations of coefficients of anthropogenic influence

Coefficients α_A			Coefficients of additional evaporation impact from the water surface			Coefficients of irrigation influence		
$\alpha_{\bar{Y}}$	α_{Cv}	α_{Cs}	$K^{/}_{\bar{Y}}$	$K^{/}_{Cv}$	$K^{/}_{Cs}$	$K_{\bar{Y}}$	K_{Cv}	K_{Cs}
0,233	0,181	0,135	0,79	1,20	1,14	0,57	2,16	1,44

5. Determination of the coefficients of influence of irrigation due to local runoff is carried out according to the following formulas:

$$K_{\bar{Y}} = 1{,}00 - 17{,}0\lg(f_{IR}+1) - 0{,}900v_0 + 0{,}70\eta_{ir} =$$
$$=1{,}00-17{,}0\lg(0{,}02+1)-0{,}9\times0{,}9+0{,}7\times0{,}75=0{,}57$$

$$K_{C_V} = 1{,}00 + 23{,}7\lg(f_{IR}+1) + 3{,}5v_0 - 2{,}93\eta_{ir} =$$
$$=1{,}00+23{,}7\lg(0{,}02+1) + 3{,}5\times0{,}9 - 2{,}93\times0{,}75 = 2{,}16$$

$$K_{C_S} = 1{,}00 + 23{,}5\lg(f_{IR}+1) + 1{,}5v_0 - 1{,}48\eta_{ir} =$$
$$=1{,}00+23{,}5\lg(0{,}02+1)+1{,}5\times0{,}9 - 1{,}48\times0{,}75 = 1{,}44$$

6. Determination of the combined impact of water management transformations

$$K_{'Y,gr} = (K'_{\bar{Y}} + K_{\bar{Y}} - 1) = 0{,}79+0{,}57-1 = 0{,}36$$
$$K_{CV,gr} = (K'_{C_V} + K_{C_V} - 1) = 1{,}20+2{,}16-1 = 2{,}36$$
$$K_{CS_{gr}} = (K'_{C_S} + K_{C_S} - 1) = 1{,}14+1{,}44-1 = 1{,}58$$

Statistical parameters of household annual runoff in scenario climatic conditions in the presence of artificial reservoirs and irrigation are determined as follows:

$$\bar{Y}_{ANT} = k_{Y,GR}\hat{Y}_{NA} = 0{,}36\times11{,}4 = 4{,}10$$
$$Cvant = k_{Cv,GR}Cv = 2{,}36\times1{,}39 = 3{,}28$$
$$Csant = k_{CS,GR}Cs = 1{,}58\times2{,}36 = 3{,}73$$

The calculation results are recorded in Table 7.4

Table 7.4 – Combined coefficients of anthropogenic influence of irrigation and artificial reservoirs and statistical parameters of household runoff in scenario climatic conditions

Combined coefficients of anthropogenic influence			Parameters of household sewage		
$K_{\overline{Y}}$	K_{C_V}	K_{C_S}	$\overline{Y}_{ANT}$, mm	C_V	C_S
0,36	2,36	1,58	4,10	3,28	3,73

Table 7.5 – Characteristics of household annual runoff in years of varying supply with irrigation and artificial reservoirs for 2021-2050

Watershed characteristics	Availability, %				
	5	25	50	75	95
$(\varPhi_P)$	1,91	0,043	-0,42	-0,53	-0,537
$k_P = (\varPhi_P Cv + 1)$	7,26	1,14	-0,38	-0,74	-0,76
$Y_P = k\overline{Y}$	29,8	4,67	0	0	0

Table 7.6 – Changes in characteristics of household annual runoff of varying supply

Watershed characteristics	Availability, %				
	5	25	50	75	95
$Y_{NA,P}$, mm in the last century (pre-1989)	47,4	20,7	8,66	2,13	0
$Y_{NA,P}$, mm according to scenario	43,1	16,2	5,81	0,80	0
Reduction of natural runoff in the 21st century compared to baseline data (pre-1989), $\delta_{5\%} = \frac{\overline{Y}_{NA,SC} - \overline{Y}_{NA}}{\overline{Y}_{NA}} 100\%$	-9,07	-21,7	-32,9	-62,4	–100
$Y_{ANT,P}$ in the last century (pre-1989) *according to the data from the 6th task*	32,7	8,17	0,36	0	0
$Y_{NA,P}$ according to scenario (2021-2050)	29,8	4,67	0	0	0

End of table 7.6

The decrease in river flow in the 21st century compared to the baseline data (before 1989) taking into account the influence of climate change and water management transformations. $\delta_{\%} = \frac{\overline{Y}_{ANT,SC} - \overline{Y}_{NA}}{\overline{Y}_{NA}} 100\%$	-8,87	-42,8	100	–	–

Conclusions. In the scenario climatic conditions of the 21st century, the average multi-year natural flow of the Kuchugur River will be 11.4 mm, while due to the influence of water management activities, this value will be 4.10 mm. Therefore, the reduction due to anthropogenic influence will be minus 64.0%. If in the natural conditions of the past century the river dried up only in very low-water years, then in the scenario conditions, it will dry up even in average water years.

Control questions

1. What is referred to as "climatic" flow?
2. What is referred to as natural flow?
3. What are the anthropogenic impact functions developed for?
4. What types of water management activities can the "climate-runoff" model take into account when calculating domestic flow?
5. How is the cumulative impact of anthropogenic factors on river flow determined when applying the "climate- runoff " model?

PRACTICAL WORK No.8
ASSESSMENT OF THE IMPACT OF LAND RECLAMATION AND URBANIZATION UNDER CLIMATE CHANGE CONDITIONS

The aim of the work is to acquire skills in assessing the consequences of the impact of agroforestry and urbanization on water resources.

Theoretical part

The coefficient of the anthropogenic impact function of agro melioration on the average multi-year annual flow is established as follows:

$$\Psi_{at} = \frac{\bar{Y}_{ANT}}{\bar{Y}_{NA}} = 1\text{-}10^{-2}\Delta_{at}, \tag{8.1}$$

Ψ_{at} – The coefficient of the impact of agroforestry melioration;
$\bar{Y}_{ANT}$ – The average long-term value of domestic runoff, which was formed under the influence of agroforestry melioration;
$\bar{Y}_{NA}$ – The average long-term value of natural (unaffected by water management activities) annual runoff.
Δ_{at} – The reduction in the natural runoff rate (%) is determined according to Table 8.1 depending on the watershed's degree of land reclamation.

Table 8.1 - Reduction of the natural runoff rate due to the degree of land reclamation

Degree of land reclamation, %	60-70	25-50	5-15
Reduction of natural runoff, Δ_{at}, %	6,1	5,4	3,9

Urbanized area is a locality, part (section), or region of the territory with all its components (settlements, civilian population, industry, socio-cultural facilities, and transportation routes). The impact of urbanization on runoff formation is manifested through its increase due to significant impermeable surfaces. Assuming no additional atmospheric precipitation over the urbanized area, groundwater recharge, and absence of runoff transfer from other basins, the change in the average long-term value of river runoff is recommended to be assessed by the following formula

$$\Delta Y_{uk} = \bar{Y}_{NA}\Psi_{\eta}f_{uk}, \tag{8.2}$$

where ΔY_{uk} – changes in annual runoff due to urbanization;
Ψ_{η} – coefficient depending on the share of impermeable areas in the total watershed area;

f_{uk} – The share of urbanized area.

Parameters f_{uk} are found in the chart 8.2

Table 8.2 - Values of the anthropogenic influence function Ψ_η

fur	0	0,05	0,10	0,30	0,50
ψ_η	1,00	1,15	1,30	1,8	2,30

The coefficient of anthropogenic influence, which reflects the consequences of urbanization in forming runoff from catchments, was determined by the formula

$$k_{ur} = \frac{\bar{Y}_{NA} + \Delta\bar{Y}_{ur}}{\bar{Y}_{NA}}, \tag{8.3}$$

from which

$$k_{ur} = 1 + \psi_n f_{ur}, \tag{8.4}$$

where ψ_n – The coefficient dependent on the share of impermeable areas;

f_{ur} – The share of area occupied by urbanized territory.

The total coefficient of anthropogenic influence of agroland reclamation and urbanization is determined by the formula

$$Y_{ANT} = Y_{NA}\{[\psi_{at} + k_{ur} - 1]\} \tag{8.4}$$

Table 8.3 - Assessment of the impact of agroforestry and urbanization on the average long-term flow of the river under conditions of the past century (before 1989)

Y_{NA}, mm (according to the data from task 4)	flr	Δat	Ψat	fur	ψ_n	k_{ur}	k_{GR}	Y_{ANT}	Runoff changes

Table 8.4 - Assessment of the impact of agroforestry and urbanization on the average long-term flow of the river in scenario climatic conditions (2021-2050)

Y_{NA} , mm (according to the data from task 7)	flr	Δat	Ψat	fur	ψ_n	k_{ur}	k_{GR}	Y_{ANT}	Runoff changes

Practical part

Input data. For all scenarios, data on land cultivation and the relative area of urbanized territories are used, as well as data on natural flow in the conditions of the past century (see work 4) and climatic scenarios (see work 7). According to the developments of Moldovan scientists, incorporated into the regulatory document prepared in collaboration with scientists from OSENU, coefficients of influence on flow from agroforestry and urbanization were determined.

Calculations example

For example, cultivation intensity of 25-50% and the relative area of urbanized territories equal to 0.05 are used, along with data on natural flow in conditions of the past century (see work 4) and climatic scenarios (see work 7).

1. We calculate the coefficient of the influence of land reclamation for the entire observation period (formula 8.1):

$$\Psi at = 1 - 5.4 * 0.01 = 0.946$$

2. We determine the coefficient of anthropogenic influence, which reflects the consequences of urbanization in forming runoff (formula 8.4):

$$kur = 1 + 1.15 * 0.05 = 1.06$$

3. We find the total coefficient of anthropogenic influence and the household runoff of the river (formula 8.5):

For the base period, we obtain:

$$Y\text{ant} = 14.2 * (0{,}946 + 1{,}06 - 1) = 14{,}3 \text{ mm}$$

For the forecast period based on scenario data (2021-2050):

$$Y\text{ant} = 4{,}1 * (0{,}946 + 1{,}06 - 1) = 4{,}12 \text{ mm}$$

4. The calculation results are entered into Tables 8.5 and 8.6.

Conclusions. The outcome of the practical work led to the understanding of the minor influence of agroland reclamation and urbanization on the multi-year flow of the river compared to the impact of irrigation on the watershed or the presence of artificial reservoirs.

Table 8.5 - Assessment of the impact of agroland reclamation and urbanization on the average multi-year flow of the river in the conditions of the past century (until 1989)

Y_{NA}, mm (according to the data from task 4)	f_{lr}, %	Δ_{at}	ψ_{at}	f_{ur}	ψ_n	k_{ur}	Y_{ANT}	Runoff changes
14,2	25-50	5.4	0,946	0,05	1,15	1,06	14,3	0,70%

Table 8.6 - Assessment of the impact of agroland reclamation and urbanization on the average multi-year flow of the river under scenario climatic conditions (2021-2050)

Y_{NA}, mm (according to the data from task 7)	f_{lr}, %	Δ_{at}	ψ_{at}	f_{ur}	ψ_n	k_{ur}	Y_{ANT}	Runoff changes
4,10	25-50	5.4	0,946	0,05	1,15	1,06	4,12	0,49%

Control questions

1. Provide a definition of "urbanized area"?
2. What factor does the coefficient of agro-land reclamation depend on?
3. What factor does the coefficient of urbanization depend on?
4. How does the area of deforestation affect river flow?
5. How does the area of urbanization affect river flow?

REFERENCES

1. Гопченко Є.Д., Лобода Н.С., Овчарук В.А. Гідрологічні розрахунки: підручник. Одеса: ТЕС, 2014. 484 с.
2. Лобода Н.С., Гопченко Є.Д. Стохастичні моделі у гідрологічних розрахунках: навчальний посібник. Одеса: Екологія, 2006. 200 с.
3. Лобода Н.С. Вплив кліматичних змін на галузі економіки України (водне господарство): конспект лекцій (електронний варіант). Одеса, 2015. 62 с.

Additional

4. Гопченко Е.Д., Лобода Н.С. Водные ресурсы северо-западного Причерноморья (в естественных и нарушенных хозяйственной деятельностью условиях). Київ: КНТ. 2005. 188 с.
5. Водні ресурси та гідроекологічний стан Тилігульського лиману: Колективна монографія / Під ред. Ю.С. Тучковенко, Н.С. Лободи. Одеса: ТЕС, 2014. 276 с.
6. Водний режим та гідроекологічні характеристики Куяльницького лиману / За ред. Лободи Н.С., Гопченка Є.Д. Одеса, ТЕС, 2016. 332 с.
7. Лобода Н.С. Расчеты и обобщения характеристик годового стока рек Украины в условиях антропогенного влияния: Монография. Одесса: Экология, 2005. 208 с.
8. Лобода Н.С. Оцінка стану водних ресурсів України в умовах змін регіонального клімату та їх вплив на економіку України (розділ колективної монографії під ред.. Степаненко С.М., Польового А.М.) // Оцінка впливу кліматичних змін на галузі економіки України. Одеса.: Екологія, 2011. С.566-605.
9. Лобода Н.С. Моделювання впливу змін клімату на характеристики стоку річок України (розділ 8) // Колективна монографія: Кліматичні зміни та їх вплив на сфери економіки України / За ред. С.М. Степаненка, А.М. Польового. Одеса: “ТЕС”, 2015. С.451-482.
10. Прогноз змін водних ресурсів України за сценаріями змін клімату (RCP4.5, RCP8.5) та оцінка ризиків для водного господарства // Кліматичні ризики функціонування галузей економіки України в умовах зміни клімату: колективна монографія / за ред. С.М. Степаненка, А.М. Польового; Одеський державний екологічний університет. Одеса: ТЕС, 2018. – 498-521 с.
11. Loboda N. Impact of Climate Change on Water Resources of North-Western Black Sea Region / N. Loboda, Y. Bozhok // International Journal of Research In Earth and Enviornmental Sciences. – 2015. - Vol 02. – No. 9. – P. 1-6.
12. Loboda N. S., Gryb O. M. (2017).Hydroecological Problems of the Kuyalnyk Liman and Ways of Their Solution. Hydrobiological Journal, 53(6), C.87-95. http://www.dl.begellhouse. com/journals/38cb2223012b73f2, 0631386b38d70fec, 26684a4766c364cb.html

13. Nataliia Loboda, Yuliia Bozhok. Applicatin of the Climate-runoff model to the assessment of the Danube River basin water resources in the XXI century according to the climate scenarios (A1B) // Electronic book with full papers from XXVIII Conference of the Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management. November 6-8, Kyiv, Ukraine, 2019 – P.100-109
14. Melnic V. S., Loboda N. S. (2020)Trends in monthly, seasonal and annual fluctuations in flood peaks for upper Dniester River. Meteorology, Hydrology and Water Management. 2020. Vol. 8, Iss. 2. pp. 28-36 DOI: https://doi.org/10.26491/mhwm/126705
15. Tuchkovenko Y., Khokhlov V. , Loboda N. (2023) Climate change impact on the freshwater balance of quasi-closed lagoons in the North-Western Black Sea coast // Journal of Water and Climate Change, 2023, Vol 14 No 7, 2416-2431. doi: 10.2166/wcc.2023.109 Scopus https://iwaponline.com/jwcc/article/doi/10.2166/wcc.2023.109/95706/Climate-change-impact-on-the-freshwater-balance-of (http://eprints.library.odeku.edu.ua/id/eprint/12333/)

ADDITION

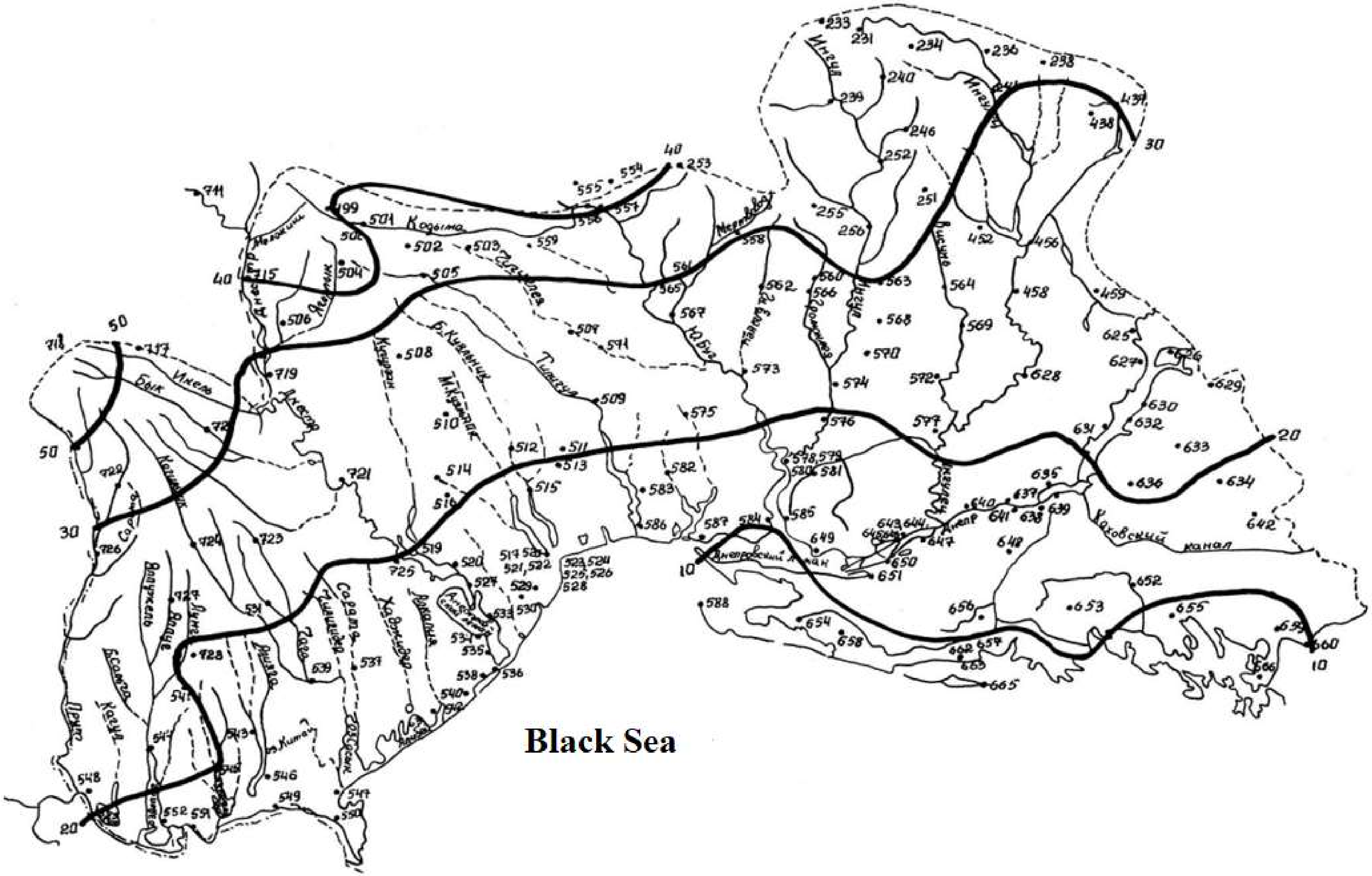

Fig A.1 – Average long-term value of annual climatic runoff, basic characteristic (until 1989)

Table A.1 – Normalized deviations from the mean value of the ordinates of the Pearson distribution of type III $\frac{x_{p\%}-\bar{x}}{\sigma}=\frac{k_{p\%}-1}{C_V}=\hat{O}(P,C_S)$ (binomial distribution curve)

C_S	*P%*											
	0,01	0,1	1,0	3,0	5,0	10	20	25	30	40	50	60
-4,0	0,500	0,500	0,500	0,500	0,500	0,500	0,500	0,49	0,49	0,46	0,41	0,31
-3,8	0,527	0,527	0,526	0,526	0,526	0,526	0,520	0,52	0,51	0,48	0,42	0,30
-3,6	0,556	0,556	0,556	0,556	0,556	0,555	0,550	0,54	0,54	0,49	0,42	0,28
-3,4	0,588	0,588	0,588	0,588	0,587	0,586	0,580	0,57	0,55	0,50	0,41	0,27
-3,2	0,625	0,625	0,625	0,625	0,625	0,621	0,610	0,59	0,57	0,51	0,41	0,25
-3,0	0,667	0,667	0,666	0,666	0,665	0,661	0,640	0,62	0,59	0,51	0,40	0,22
-2,8	0,715	0,715	0,715	0,714	0,711	0,703	0,670	0,64	0,60	0,51	0,39	0,20
-2,6	0,770	0,770	0,770	0,766	0,764	0,746	0,700	0,66	0,61	0,51	0,37	0,17
-2,4	0,835	0,833	0,830	0,826	0,820	0,792	0,720	0,67	0,62	0,51	0,35	0,17
-2,2	0,914	0,910	0,905	0,895	0,882	0,842	0,750	0,69	0,64	0,50	0,33	0,12
-2,0	1,01	1,00	0,990	0,970	0,950	0,900	0,780	0,71	0,64	0,49	0,31	0,09
-1,8	1,11	1,11	1,09	1,06	1,02	0,940	0,800	0,72	0,64	0,48	0,28	0,05
-1,6	1,26	1,24	1,20	1,14	1,10	0,990	0,810	0,73	0,64	0,46	0,25	0,02
-1,4	1,41	1,39	1,32	1,23	1,17	1,04	0,830	0,73	0,64	0,44	0,22	-0,02
-1,2	1,68	1,58	1,45	1,33	1,24	1,08	0,840	0,74	0,63	0,42	0,19	-0,05
-1,0	1,92	1,79	1,59	1,42	1,32	1,13	0,850	0,73	0,62	0,39	0,16	-0,09
-0,8	2,23	2,02	1,74	1,52	1,38	1,17	0,860	0,73	0,60	0,37	0,13	-0,12
-0,6	2,57	2,27	1,88	1,01	1,45	1,20	0,850	0,72	0,59	0,34	0,10	-0,16
-0,4	2,98	2,54	2,03	1,70	1,52	1,23	0,850	0,71	0,57	0,31	0,07	-0,19
-0,2	3,37	2,81	2,18	1,79	1,58	1,26	0,850	0,69	0,55	0,28	0,03	-0,22
0,0	3,72	3,09	2,33	1,88	1,64	1,28	0,840	0,67	0,52	0,25	0,00	-0,25
0,2	4,16	3,38	2,47	1,96	1,70	1,30	0,83	0,65	0,50	0,22	-0,03	-0,28
0,4	4,61	3,66	2,61	2,04	1,75	1,32	0,82	0,63	0,47	0,19	-0,07	-0,31
0,6	5,05	3,96	2,75	2,12	1,80	1,33	0,83	0,61	0,44	0,16	-0,10	-0,34
0,8	5,50	4,24	2,89	2,18	1,84	1,34	0,78	0,58	0,41	0,12	-0,13	-0,37
1,0	5,96	4,53	3,03	2,25	1,88	1,34	0,76	0,55	0,38	0,09	-0,16	-0,39

Continuation of the table A.1

C_S	P%											
	0,01	0,1	1,0	3,0	5,0	10	20	25	30	40	50	60
1,2	6,41	4,81	3,15	2,31	1,92	1,34	0,73	0,52	0,35	0,05	-0,19	-0,42
1,4	6,87	5,09	3,27	2,37	1,95	1,34	0,71	0,49	0,31	0,02	-0,22	-0,44
1,6	7,31	5,37	3,39	2,42	1,97	1,33	0,68	0,46	0,28	-0,02	-0,25	-0,46
1,8	7,76	5,64	3,50	2,46	1,99	1,32	0,64	0,42	0,24	-0,05	-0,28	-0,48
2,0	8,21	5,91	3,60	2,51	2,00	1,30	0,61	0,39	0,20	-0,08	-0,31	-0,49
2,2	8,63	6,14	3,68	2,54	2,02	1,27	0,57	0,35	0,16	-0,12	-0,33	-0,50
2,4	9,00	6,37	3,78	2,60	2,00	1,25	0,52	0,29	0,12	-0,14	-0,35	-0,51
2,6	9,39	6,54	3,86	2,63	2,00	1,21	0,48	0,25	0,085	-0,17	-0,37	-0,51
2,8	9,77	6,86	3,96	2,65	2,00	1,18	0,44	0,22	0,057	-0,20	-0,39	-0,51
3,0	10,16	7,10	4,05	2,66	1,97	1,13	0,39	0,19	0,027	-0,22	-0,40	-0,51
3,2	10,55	7,35	4,11	2,66	1,96	1,09	0,35	0,15	-0,006	-0,25	-0,41	-0,51
3,4	10,9	7,54	4,18	2,66	1,94	1,06	0,31	0,11	-0,036	-0,27	-0,41	-0,50
3,6	11,3	7,72	4,24	2,66	1,93	1,03	0,28	0,064	-0,072	-0,28	-0,42	-0,49
3,8	11,67	7,97	4,29	2,65	1,90	1,00	0,24	0,032	-0,095	-0,30	-0,42	-0,48
4,0	12,02	8,17	4,34	2,65	1,90	0,96	0,21	0,010	-0,120	-0,31	-0,41	-0,46
4,2	12,40	8,38	4,39	2,64	1,88	0,93	0,19	-0,10	-0,13	-0,31	-0,41	-0,45
4,4	12,76	8,60	4,42	2,63	1,86	0,91	0,15	-0,032	-0,15	-0,32	-0,40	-0,44
4,6	13,12	8,76	4,46	2,62	1,84	0,87	0,13	-0,052	-0,17	-0,32	-0,40	-0,42
4,8	13,51	8,96	4,50	2,60	1,81	0,82	0,10	-0,075	-0,19	-0,32	-0,39	-0,41
5,0	13,87	9,12	4,54	2,60	1,78	0,78	0,068	-0,099	-0,20	-0,33	-0,38	-0,40
5,2	14,25	9,27	4,59	2,60	1,74	0,73	0,035	-0,120	-0,21	-0,33	-0,37	-0,38
5,4	14,60	9,42	4,62	2,60	1,70	0,67	0,02	-0,100	-0,21	-0,33	-0,37	-0,37
5,6	14,95	9,59	4,65	2,60	1,67	0,62	0,0	-0,120	-0,21	-0,30	-0,36	-0,36
5,8	15,32	9,70	4,70	2,60	1,64	0,57	-0,02	-0,140	-0,21	-0,30	-0,35	-0,35
6,0	15,67	9,84	4,70	2,60	1,60	0,51	-0,05	-0,150	-0,21	-0,30	-0,34	-0,34
6,2	16,04	9,95	4,71	2,60	1,56	0,47	-0,05	-0,150	-0,21	-0,30	-0,34	-0,34
6,4	16,40	10,05	4,71	2,60	1,52	0,42	-0,05	-0,150	-0,21	-0,30	-0,33	-0,39

Continuation of the table A.1

C_S	$P\%$								$\Phi_{5\%} - \Phi_{95\%}$	$S = \frac{x_{5\%} - x_{95\%} - 2_{50\%}}{x_{5\%} - x_{95\%}}$
	70	75	80	90	95	97	99	99,9		
-4,0	-0,120	-0,010	-0,21	-0,96	-1,90	-2,65	-4,34	-8,17	2,40	-0,93
-3,8	-0,095	-0,032	-0,24	-1,00	-1,90	-2,65	-4,29	-7,97	2,426	-0,91
-3,6	-0,072	-0,064	-0,28	-1,03	-1,93	-2,66	-4,24	-7,72	2,486	-0,89
-3,4	-0,036	-0,11	-0,31	-1,06	-1,945	-2,66	-4,18	-7,54	2,527	-0,86
-3,2	-0,006	-0,15	-0,35	-1,09	-1,96	-2,66	-4,11	-7,35	2,58	-0,83
-3,0	-0,027	-0,19	-0,39	-1,13	-1,97	-2,66	-4,05	-7,10	2,64	-0,80
-2,8	-0,057	-0,22	-0,44	-1,18	-2,00	-2,65	-3,86	-6,86	2,71	-0,76
-2,6	-0,085	-0,25	-0,48	-1,21	-2,00	-2,63	-3,86	-6,54	2,76	-0,71
-2,4	-0,12	-0,29	-0,52	-1,25	-2,00	-2,60	-3,78	-6,37	2,82	-0,67
-2,2	-0,16	-0,35	-0,57	-1,27	-2,02	-2,54	-3,68	-6,14	2,90	-0,62
-2,0	-0,20	-0,39	-0,61	-1,30	-2,00	-2,51	-3,60	-5,91	2,92	-0,57
-1,8	-0,24	-0,42	-0,64	-1,32	-1,99	-2,46	-3,50	-5,64	3,01	-0,51
-1,6	-0,28	-0,46	-0,68	-1,33	-1,97	-2,42	-3,39	-5,37	3,07	-0,45
-1,4	-0,31	-0,49	-0,71	-1,34	-1,95	-2,37	-3,27	-5,09	3,12	-0,39
-1,2	-0,35	-0,52	-0,73	-1,34	-1,92	-2,31	-3,15	-4,81	3,16	-0,34
-1,0	-0,38	-0,55	-0,76	-1,34	-1,88	-2,25	-3,02	-4,53	3,20	-0,27
-0,8	-0,41	-0,58	-0,79	-1,34	-1,84	-2,18	-2,89	-4,24	3,22	-0,22
-0,6	-0,44	-0,61	-0,80	-1,33	-1,80	-2,12	-2,75	-3,96	3,25	-0,17
-0,4	-0,47	-0,63	-0,82	-1,32	-1,75	-2,04	-2,61	-3,66	3,27	-0,11
-0,2	-0,50	-0,65	-0,83	-1,30	-1,70	-1,96	-2,47	-3,38	3,28	-0,05
0,0	-0,52	-0,67	-0,84	-1,28	-1,64	-1,88	-2,33	-3,09	3,28	0,00
0,2	-0,55	-0,69	-0,85	-1,26	-1,58	-1,79	-2,18	-2,81	3,28	0,06
0,4	-0,57	-0,71	-0,85	-1,23	-1,52	-1,70	-2,03	-2,54	3,27	0,11
0,6	-0,59	-0,72	-0,85	-1,20	-1,45	-1,61	-1,88	-2,27	3,25	0,17

End the table A.1

C_S	$P\%$								$\Phi_{5\%} - \Phi_{95\%}$	$S = \frac{x_{5\%} - x_{95\%} - 2_{50\%}}{x_{5\%} - x_{95\%}}$
	70	75	80	90	95	97	99	99,9		
0,8	-0,60	-0,73	-0,86	-1,17	-1,38	-1,52	-1,74	-2,02	3,22	0,22
1,0	-0,62	-0,73	-0,85	-1,13	-1,32	-1,42	-1,59	-1,79	3,20	0,28
1,2	-0,63	-0,74	-0,84	-1,08	-1,24	-1,33	-1,45	-1,58	3,16	0,34
1,4	-0,64	-0,73	-0,83	-1,04	-1,17	-1,23	-1,32	-1,39	3,12	0,39
1,6	-0,64	-0,73	-0,81	-0,99	-1,10	-1,14	-1,20	-1,24	3,07	0,45
1,8	-0,64	-0,72	-0,80	-0,94	-1,02	-1,06	-1,09	-1,11	3,01	0,51
2,0	-0,64	-0,71	-0,78	-0,90	-0,95	-0,97	-0,99	-1,00	2,95	0,57
2,2	-0,64	-0,69	-0,75	-0,842	-0,882	-0,895	-0,905	-0,910	2,89	0,62
2,4	-0,62	-0,67	-0,72	-0,792	-0,820	-0,826	-0,830	-0,833	2,82	0,67
2,6	-0,61	-0,66	-0,70	-0,746	-0,764	-0,766	-0,770	-0,770	2,76	0,72
2,8	-0,60	-0,64	-0,67	-0,703	-0,711	-0,714	-0,715	-0,715	2,71	0,76
3,0	-0,59	-0,62	-0,64	-0,661	-0,665	-0,666	-0,666	-0,667	2,64	0,80
3,2	-0,57	-0,59	-0,61	-0,621	-0,625	-0,625	-0,625	-0,625	2,59	0,83
3,4	-0,55	-0,57	-0,58	-0,586	-0,587	-0,588	-0,588	-0,588	2,53	0,86
3,6	-0,54	-0,54	-0,55	-0,555	-0,556	-0,556	-0,556	-0,556	2,48	0,89
3,8	-0,51	-0,52	-0,52	-0,526	-0,526	-0,526	-0,526	-0,527	2,43	0,91
4,0	-0,49	-0,49	-0,50	-0,5000	-0,500	-0,500	-0,500	-0,500	2,40	0,92
4,2	-0,47	-0,473	-0,475	-0,476	-0,476	-0,476	-0,477	-0,477	2,36	0,94
4,4	-0,451	-0,454	-0,455	-0,455	-0,455	-0,455	-0,455	-0,455	2,32	0,95
4,6	-0,432	-0,434	-0,435	-0,435	-0,435	-0,435	-0,435	-0,435	2,28	0,97
4,8	-0,416	-0,416	-0,416	-0,416	-0,416	-0,416	-0,417	-0,417	2,23	0,98
5,0	-0,399	-0,400	-0,400	-0,400	-0,400	-0,400	-0,400	-0,400	2,18	0,98
5,2	-0,384	-0,385	-0,385	-0,385	-0,385	-0,385	-0,385	-0,385	2,12	0,98
5,4	-0,37	-0,37	-0,37	-0,37	-0,37	-0,37	-0,37	-0,37	2,07	1,00