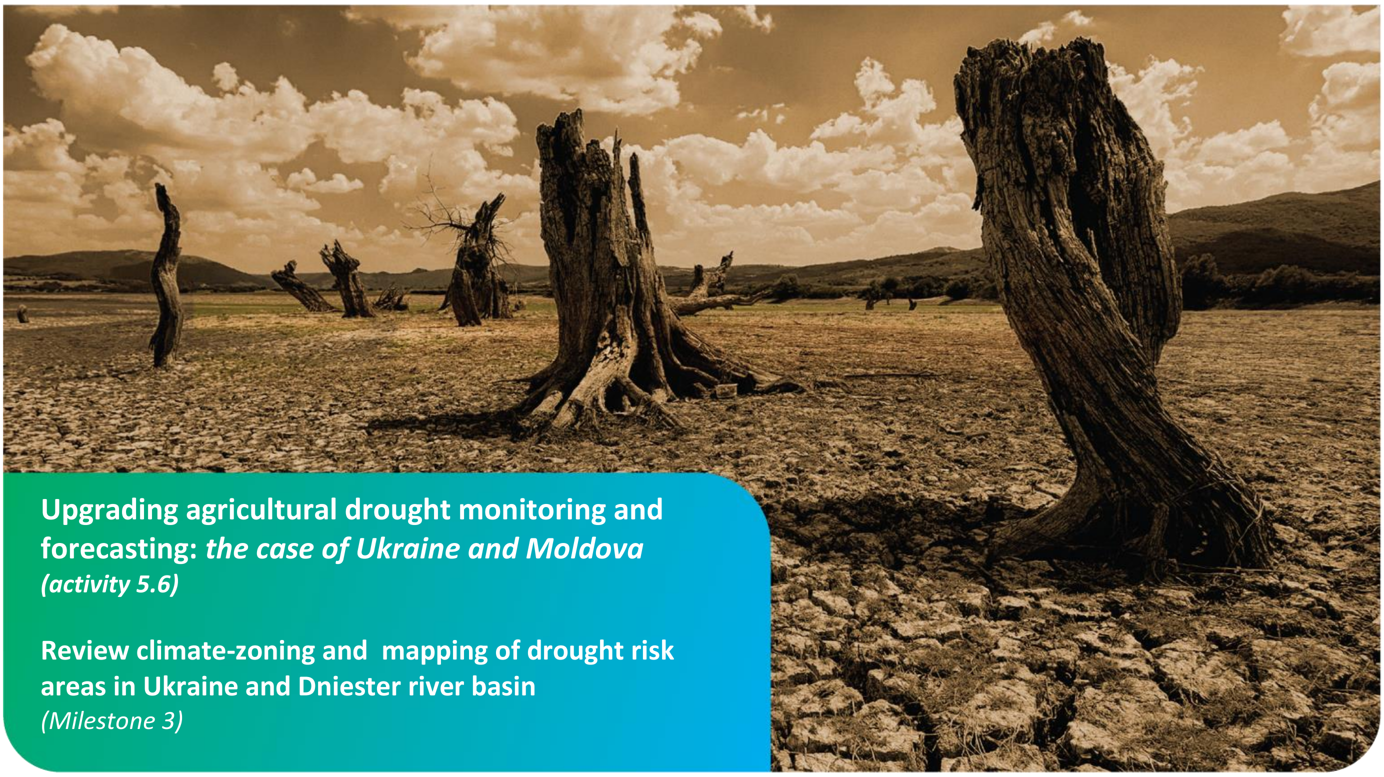
Integrated Drought Management

Programme in Central and Eastern Europe



Upgrading agricultural drought monitoring and forecasting: ***the case of Ukraine and Moldova***
(activity 5.6)

Review climate-zoning and mapping of drought risk areas in Ukraine and Dniester river basin
(Milestone 3)

Name of the milestone:	Report on Step 3: Review climate-zoning and mapping of drought risk areas in Ukraine and Dniester river basin
WP:	5
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Table of contents	1. Review of the existing approach to climate zoning accounting for climate change 2. Review of the agroclimate zoning of the territory of Ukraine with application of Selyaninov's hydrothermal coefficients (HTCs) 3. Zoning of the territory of Ukraine in terms of soil humidity change trends (HTC based) 4. Comparison of indices (HTC and SPI)

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Contents

1. Introduction

Agroclimate zoning defines spatial distribution of main climate-related resources - air temperature and moisture. So far, optimal allocation of agricultural crops at the territory of Ukraine relied on the agroclimate zoning that was based on climate observations in the period from 1956 to 1985. The hydrothermal coefficient (HTC) was used as the key area humidity parameter for the zoning purposes. *See a detailed description in the REPORT on MILESTONE 1 to WP5. Activity 5.6 (October 2013).*

Now, the latter zoning is outdated as it does not account for climate and humidity changes of the recent decades. Inadequate use of altered thermal and water resources of land areas results in additional losses incurred by both farmers and the state. In this connection, an updated agroclimate zoning - i.e. the one based on actual contemporary information on climate resources and application of new indices for evaluation of droughts (as presented in this Report) - would facilitate a more efficient distribution of agricultural crops at the territory of Ukraine.

2. Review of the existing approach to climate zoning accounting for climate change

2.1 Methodologies and study objects

An analysis of climate change trends in Ukraine (in terms of air temperature and precipitation) was presented in REPORT on MILESTONE 1 to WP5 Activity 5.6 (October 2013). The Report noted that the contemporary climate of Ukraine is characterised by a spatially asymmetric warming, particularly manifested in winter and summer months. Since early 20th century, the annual average air temperature in Ukraine increased by more than 0.8 °C. At the same time, annual average precipitation figures did not decrease, moreover in some districts these figures were observed to increase. However, as analysis of temporal precipitation distribution patterns reveals, the annual precipitation increase was due to higher precipitation in two months only - September and October.

Precipitation intensity is a direct indicator of soil moisture sufficiency for agricultural crops. Moreover, it is precipitation in specific periods of time is of particular importance - i.e. precipitation in periods of active vegetation and precipitation in cold seasons, that defines soil moisture storage capacity at spring.

We analysed aggregate precipitation data in cold seasons (November to March), in spring-summer seasons (April to August) and in autumn months (September to October). We reviewed 2 long-term periods - 1991 to 2013 (contemporary climate) and 1961 to 1990 (the standard climate period).

The analysis results revealed that at the major part of the country's territory, aggregate precipitation in cold periods decreased comparatively to the standard climate period. Precipitation in spring-summer periods was also observed to decrease. Definite increases of precipitation were observed only in Zakarpatska, Volynska, Lvivska and Rivnenska oblasts. However, at the same time, annual precipitation figures remained largely unchanged and even increased in some regions. In particular, in the period from 1961 to 1990, annual average precipitation in Ukraine reached 590 mm, while in the period from 1991 to 2013 the relevant figure reached 601 mm. Data analysis suggests that the precipitation increase may be attributed to higher precipitation in autumn seasons (September to October).

Table 1.1 end Table 1.2 contains precipitation data for different agroclimate zones and oblasts of the country in different periods.

Table 1.1 - Aggregate precipitation in cold periods (November to March -ΣR_{11-3})
and in spring-summer periods (April to August - $\sum R_{4-8}$,)

	$\sum R_{11-3}$, mm			$\sum R_{4-8}$, mm		
Agroclimate zones, oblasts	1961-1990	1991-2013	Δ	1961-1990	1991-2013	Δ
STEPPE						
AR Crimea	184	179	-5	186	198	12
Dnipropetrovska	196	199	3	243	244	1
Donetska	227	232	5	252	241	-11
Zaporizska	208	204	-4	215	225	10

Kirovogradska	187	176	-11	281	272	-9
Luganska	216	205	-11	244	244	0
Mykolaivska	182	166	-16	243	225	-18
Odeska	183	164	-19	240	229	-11
Khersonska	164	166	2	192	193	1
FOREST STEPPE						
Vinnitska	186	180	-6	359	345	-14
Kyivska	197	190	-7	320	313	-7
Poltavska	221	204	-17	274	261	-13
Sumska	213	199	-14	310	280	-30
Ternopilska	191	187	-4	380	362	-18
Kharkivska	221	205	-16	265	256	-9
Khmelnitska	195	183	-12	382	366	-16
Cherkaska	201	190	-11	301	288	-13
Chernivetska	173	164	-9	404	375	-29
MARSHY						
Volynska	182	193	11	319	349	30
Zhytomyrska	202	200	-2	357	335	-22
Ivano-Frankivska	180	182	2	476	457	-19
Lvivska	203	206	3	398	402	4
Rivnenska	174	179	5	337	350	13
Chernigivska	220	214	-6	327	302	-25
Zakarpatska	324	346	22	411	390	-21

Table 1.2 - Aggregate precipitation in September to October periods (ΣR_{9-10})
and annual precipitation data $\sum R_{1-12}$,)

	ΣR_{9-10}, mm			R_{1-12}, mm		
Agroclimate zones, oblasts	1961-1990	1991-2013	Δ	1961-1990	1991-2013	Δ
STEPPE						
AR Crimea	63	74	11	433	452	19
Dnipropetrovska	68	83	15	507	532	25
Donetska	64	90	26	543	568	25
Zaporizska	59	76	17	494	512	18
Kirovogradska	68	98	30	537	551	14
Luganska	66	91	25	524	543	19
Mykolaivska	61	79	18	486	474	-12
Odeska	67	84	17	490	479	-11
Khersonska	60	68	8	416	430	14
FOREST-STEPPE						
Vinnitska	78	98	20	623	619	-4
Kyivska	76	100	24	593	605	12
Poltavska	78	110	32	574	578	4
Sumska	84	105	21	607	583	-24
Ternopilska	89	109	20	659	651	-8
Khersonska	79	102	23	566	566	0
Khmelnitska	83	106	23	661	648	-13
Cherkaska	72	104	32	576	585	9
Chernivetska	83	98	15	660	635	-25

MARSHY						
Volynska	95	105	10	596	646	50
Zhytomyrska	89	100	11	648	636	-12
Ivano-Frankivska	104	129	25	759	765	6
Lvivska	102	125	23	704	731	27
Rivnenska	92	105	13	603	632	29
Chernigivska	86	108	22	632	629	-3
Zakarpatska	117	157	40	852	891	39

The REPORT on MILESTONE 2 to WP5. Activity 5.6 (January 2014) provides results of analysis of long-term time series (50 years) of observations of moisture contents in 0-20 cm and 0-100 cm soil layers under agricultural crops. The study results were generalised for different agroclimate zones of Ukraine and for Ukrainian meteorological stations located close to the Dniester basin. The Report demonstrated a slight positive trend in soil moisture data series for the upper 1 m soil layer.

The most common approach to agroclimate zoning and analysis of area aridity changes relies on application of specialised indices. On the one hand, such indices reflect thermal and humidity resources, while on the other hand they correlate with parameters that reflect development of agricultural or hydrological droughts (soil moisture content, run-off). The indices can be estimated based on available data of standard hydrometeorological observations.
In Ukraine, Selyaninov's hydrothermal coefficients (HTCs) are used for zoning and assessment of area aridity. HTC is an integral indicator of area hydrothermal regime, accounting for temperature and humidity. HTC is applied as an indicator of soil moisture sufficiency or as an indicator of favourable conditions for cultivation of agricultural crops.

Selyaninov's hydrothermal coefficients reflect area specifics of hydrothermal regime, the coefficients can be easily calculated based on available raw meteorological data. HTC is calculated as the ratio of the aggregate precipitation in a given period of time (or for the whole vegetation period) to 0.1 of the sum of air temperatures for the same period of time. The denominator is a rough approximation of evaporation.

The coefficient is not used for assessment of humidity conditions in seasons with average daily air temperatures under +10 ºC.
In addition to HTC, a number of other soil humidity indicators are also applied. The most commonly used one is estimated as the percentage ratio of aggregate precipitation to the climate norm. Aggregate precipitation under 50% of the climate norm means a very heavy drought, 50-70% mean a heavy drought, while 71-80% mean a moderate drought.

2.2 Review of the agroclimate zoning of the territory of Ukraine with application of Selyaninov's hydrothermal coefficients (HTCs)

Now, all necessary preconditions are available in Ukraine to update the agroclimate zoning, to enhance monitoring capacity and to forecast droughts. To this end, as the first step, we developed a new agroclimate zoning map for the period of active vegetation of all agricultural crops (May to September) - HTC 5-9, and for the period from May to June (HTC 5-6) - the decisive period for eventual crop yield of main grain crops (wheat, barley and corn).

We used precipitation observation data of 180 meteorological stations and calculated sums of active air temperatures over +10° for the same meteorological stations. The evaluations covered the period from 1961 to 2013.

Table 1.3 Relative climate aridity was assessed by the following criteria

HTCs	*Aridity*
<0.7	very arid
0.71-1	moderately arid
1.01-1.2	slightly humid
1.21-1.8	sufficiently humid
> 1.81	humid

The new HTC-based zoning of the territory of Ukraine for the active vegetation period (May - September) is shown at Fig. 1. The mapping was based on point observations' data with further interpolation in the network's nodes. The maps were produced with application of inverse distance weighting methodology (IDW).

According to the new zoning, humid areas (HTC 5-9> 1.8) include:
the whole territory of Ivano-Frankivska oblast, the Southern part of Lvivska oblast, almost all territory of Zakarpatska oblast and the Western part of Chernivetska oblast.

Sufficiently humid areas (HTC 5-9 = 1.21-1.80) include: the Southern part of Sumska oblast, Northern and Western districts of Kyivska oblast, Western districts of Cherkaska oblast, Northern districts of Lvivska oblast, as well as almost all territories of Volynska, Rivnenska, Ternopilska, Khmelnitska, Vinnitska and Zhytomyrska oblasts.

Slightly humid areas (HTC 5-9= 1.01-1.20) include: Northern districts of Kharkivska oblast, Southern districts of Sumska and Chernigivska oblasts, Eastern districts of Kyivska and Cherkaska oblasts, a major part of Poltavska oblast, the whole Kirovogradska oblast (except its southernmost area), southernmost areas of Odeska and Mykolaivska oblasts.

Moderately arid areas (HTC 5-9 = 0.71-1.00) include the rest of the territory of Ukraine, except Southern districts of Khersonska oblast, westernmost districts of Zaporizska oblast and North-western districts of Crimea, that belong to the group of very arid areas (HTC 5-9 <0.7).

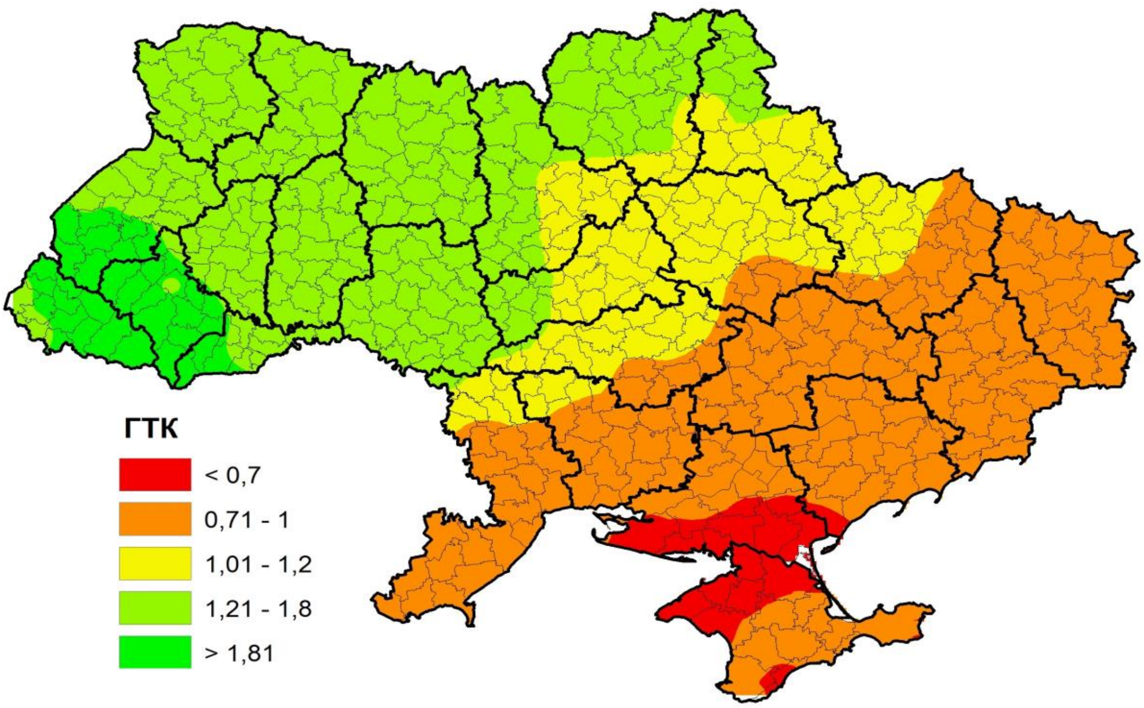


Fig.1. Spatial HTC (ГТК) distribution for May to September periods (1961-2013)

Agroclimate zoning for May to June periods is shown at Fig.2

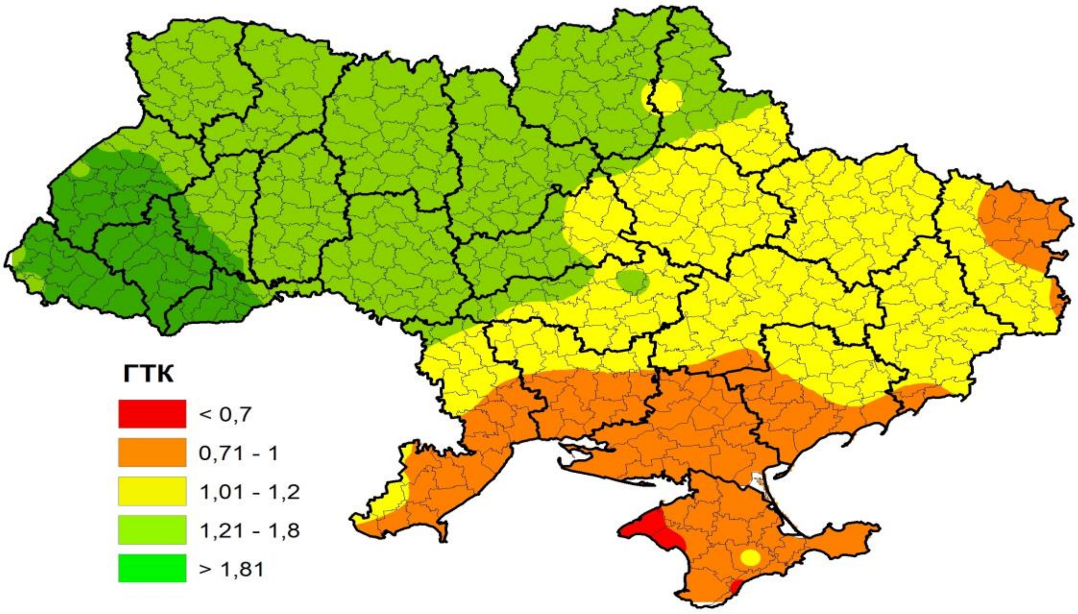
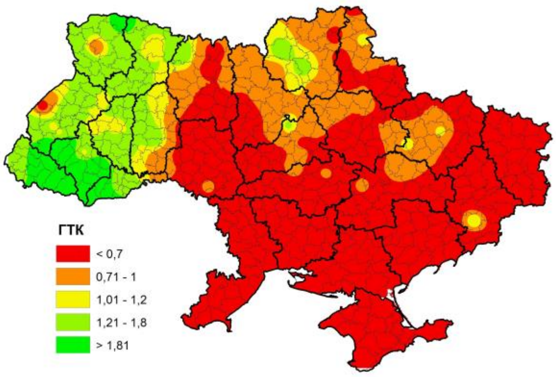


Fig.2 Spatial HTC (ГТК) distribution for May to June periods (1961-2013)

As Fig.1 and Fig. 2 demonstrate, the major part of Ukraine is ether slightly humid or arid.The highest aridity is observed in the South-eastern part of the country. However, in some years droughts may be observed in any part of Ukraine. In 21st century, the most severe droughts in Ukraine were observed in 2003 and 2007 - the droughts covered the major part of the country's territory. Fig.3 and Fig. 4 demonstrate HTC distribution patterns in May 2003 and in May 2007.



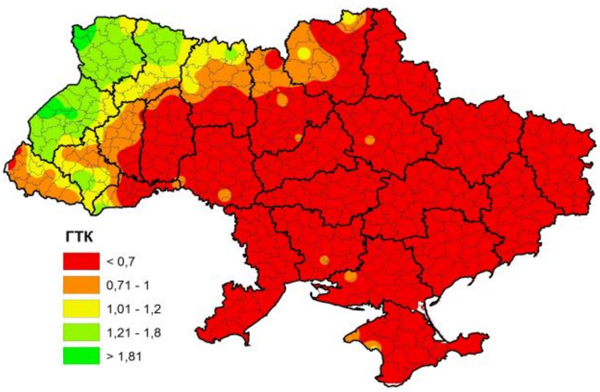


Fig. 3. May 2007 Fig. 4. May 2003

In 2003, air temperatures were extremely high - average monthly air temperatures exceeded the norm by 3-5º and reached 18.5-20.5ºC at the whole territory. At that time, the highest average monthly air temperatures for the whole period of meteorological observations were registered. The majority of meteorological stations registered temperatures that reached or even exceeded absolute air temperature maximums (+33, +35 ºC). At the background of such air temperatures, in May, almost no effective precipitation was observed (similarly to the situation in April). The period of time without effective precipitation was extremely long - 56-60 days in two months. Such long rainless periods at so large territories had not been ever observed in Ukraine in such seasons.

Since early May, an air drought affected the overwhelming majority of the country's regions, except some districts in Western Ukraine. By the end of May, the air drought was accompanied by soil drought (reduction of soil moisture content to critically low level for vegetation) and covered more than 75% of the country's territory. Such conditions resulted in almost complete loss of grain crops at more than a half of planted areas.

A similar drought development scenario was observed in 2007, when more than a half of all grain crops were lost.

In 2003 and 2007, crop yields of main grain crops (winter wheat, barley and corn) were lowest since 1991. Table 1.4 shows adverse consequences of droughts for crop yields of main grain crops in Ukraine in comparison to high-yield years in the period from 1991 to 2013.

Table 1.4

Winter wheat				Barley				Corn			
Year	Yield	Year	Yield	Year	Yield	Year	Yield	Year	Yield	Year	Yield
1993	38.0	1999	23.0	1993	32,0	2010	18,3	2011	64,4	2003	30
2008	37.0	2007	20.2.	2008	30.0	2007	17.3	2013	64.1	1992	25.1
2013	34.1	2000	20.0	1992	29.1	1996	16.0	2009	50.0	1998	25
2011	33.9	2003	14.2	2004	28.2	2003	10.2	2008	49.1	1999	25

2.3 Zoning of the territory of Ukraine in terms of soil humidity change trends (HTC based)

Changes of climate humidity in different regions of Ukraine were analysed with application of hydrothermal coefficients. For the study purposes, we estimated HTCs for May to September periods (HTC 5-9) for 2 long-term observation intervals (1961-1990 and 1991-2013) and compared them. The results were subdivided into 3 categories:

- A slightly positive trend to some climate humidity increase;
- A slightly negative trend to some climate humidity decrease;
- Almost unchanged conditions.

Fig. 5 shows zoning of the territory of Ukraine in terms of HTC 5-9 changes.

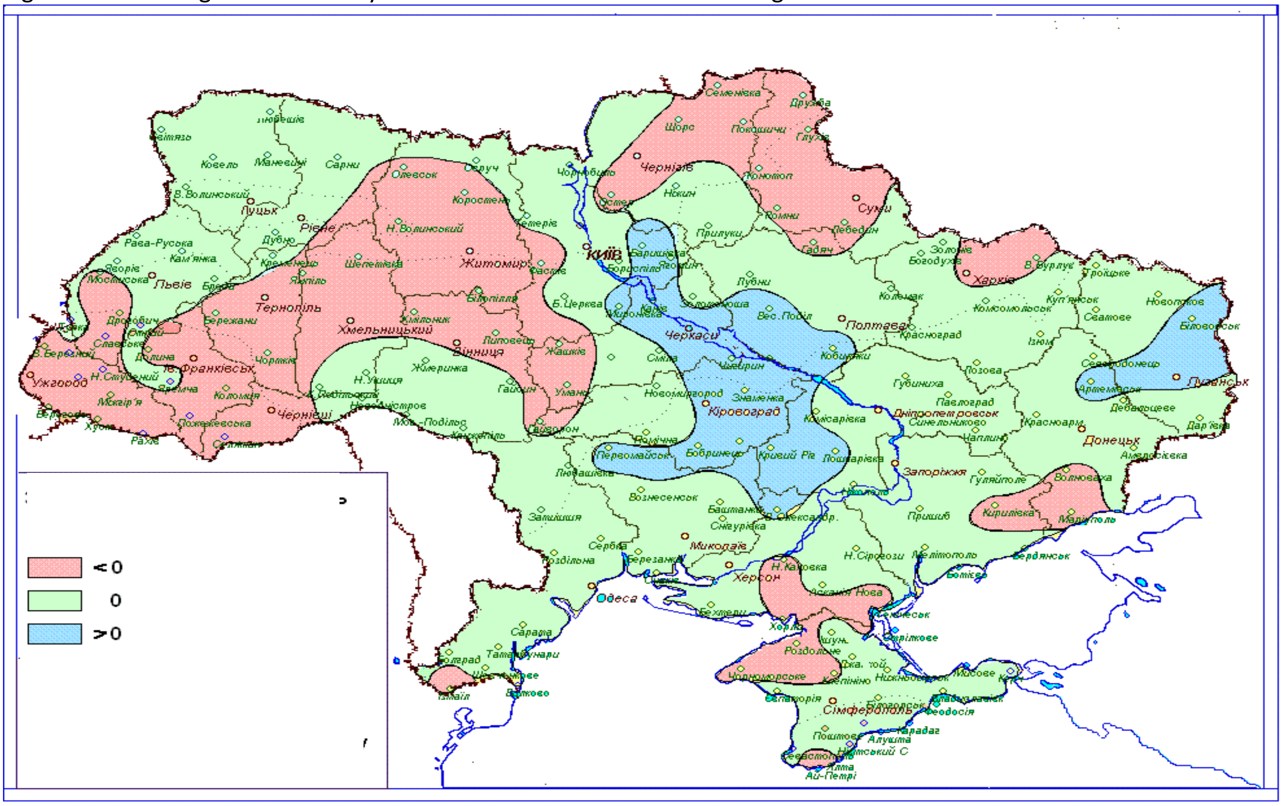


Fig. 5. HTC 5-9 changes in 1961-1990 and 1991-2013.

According to the above categories, the territory of Ukraine may be subdivided into three sectors:

1) ecreasing aridity in recent decades in comparison to the standard climate period - observed in some districts of Luganska, Cherkaska, Kirovogradska and Poltavska oblasts.

2) Increasing aridity was observed in Northern, North-eastern and Western oblasts of Ukraine (including some districts of the Dniester basin), as well as in Southern districts of Khersonska oblasts and in North-western districts of Crimea.

3) At the rest of the territory, soil humidity indicators remained almost unchanged.

The above analysis results are supported by some expert assessments that suggest higher aridity in active vegetation periods in some districts that were earlier categorised as sufficiently humid areas. These changes are attributed to sustained air temperature increases both in cold seasons and in other seasons, particularly in July and August.

3. Comparison of indices (HTC and SPI)

In Ukraine, drought monitoring relies on methodologies and assessments based on data of terrestrial meteorological observations. The methods are based on experience of development of physically substantiated indicators for characterisation of droughts, on modern scientific knowledge, technologies, software and ITs.

In early XXI century, standardised precipitation index (SPI) became the most commonly applied aridity index (McKee et al., 1993), the index relies on precipitation data only. However, a single universal ideal climate aridity indicator does not exist, so the most adequate assessment of area humidity may be made with application of several indicators.

The WMO recommended all national hydrometeorological services to apply standardised precipitation indices (SPI) for characterisation of meteorological droughts in addition to other indices these services already applied. SPI has some advantages, as a rather reliable precipitation data base has been already developed, indices do not depend on geographic location of a territory and SPI is calculated with temporal normalisation.

Earlier, SPI has not been used by the Ukrainian Hydrometeorological Service. In the framework of the current research study (comparative analysis of drought indices), applicability of SPI for drought assessments in Ukraine was studied in detail for the first time. So, our participation in the GWP project provided an impetus to study and introduction of SPI into operation of hydrometeorological services of Ukraine.

On the base of long-term observations of 180 meteorological stations (since 1961 to the contemporary time), SPIs were estimated for different periods of time (from 1 to 24 months). The relevant software was downloaded from: http:// drought.unl.edu/ Monitoring Tools/ Downloadable SPIProgram.aspx.

Now, these indices are estimated automatically, in parallel with other aridity indices that were traditionally applied in Ukraine.

In terms of SPI, a drought is defined as a period of time, when SPI values are continuously negative and reach (-1) or less. A continuously negative SPI at the level of less than (-1) corresponds to a drought, SPI under (-1.5) corresponds to a serious drought, while SPI under (-2) corresponds to a heavy drought.

Fig. 6 and 7 show SPI-based maps. SPI values were estimated based on operational data of Ukrainian meteorological stations for different time intervals.

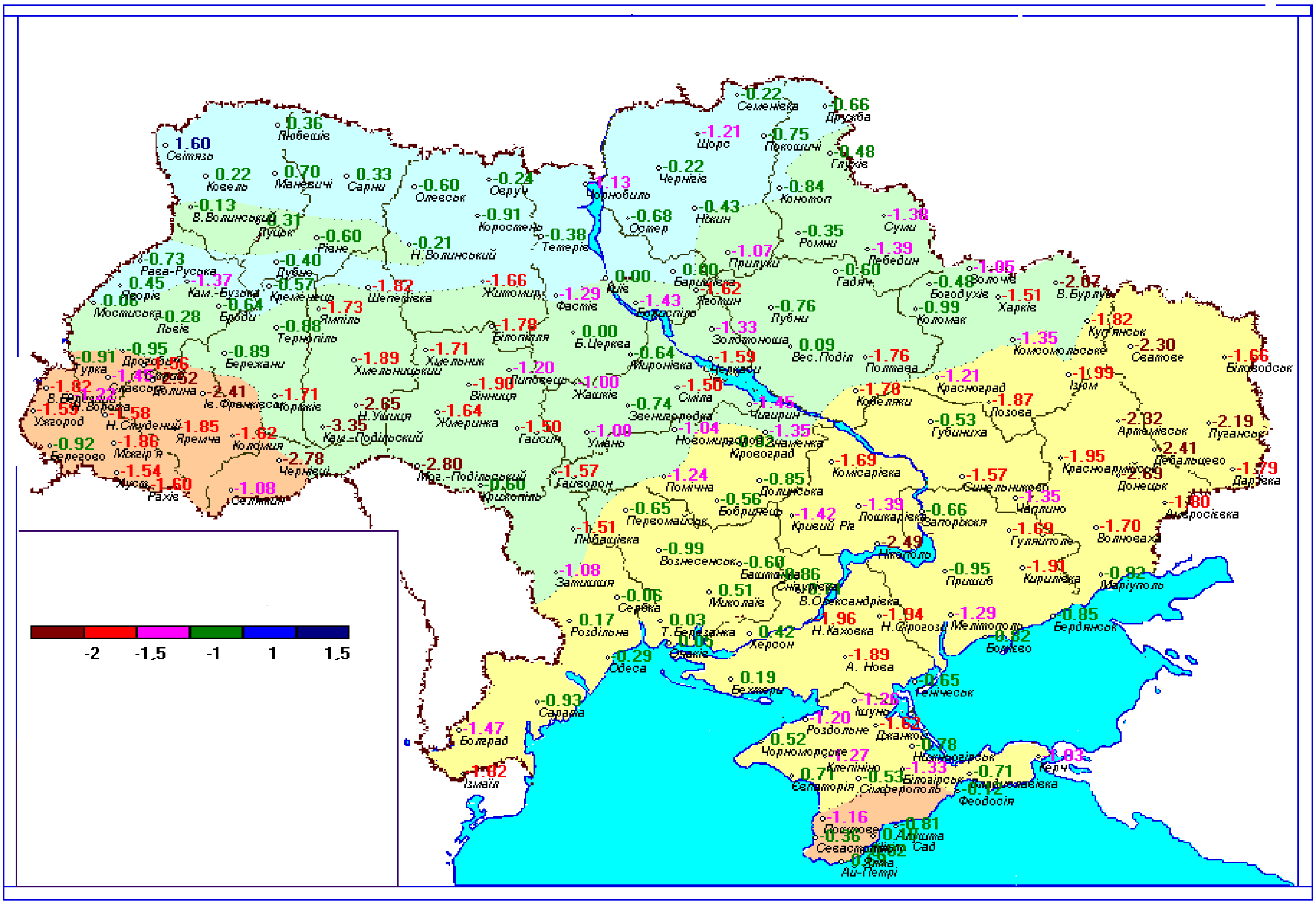


Fig. 6 3-months SPIs for March - May, 2003

Fig. 8 and 9 show monthly SPIs for May 2003 and May 2007 (see HTC values for the same periods in Section 1). The maps were produced by interpolation of point data of meteorological stations in nods of the network.

A comparative analysis of SPI and HTC values for years and months of the most severe droughts in Ukraine demonstrates that these indices are different in their sensitivity. For example, in May 2007 and in May 2003, SPI does not demonstrate severe drought at the major part of the national territory, while HTC provides a more adequate reflection of conditions on that time. It is clear, that in that particular case SPI reflects a precipitation deficit but fails to account for the thermal stress observed. On the other hand, HTC accounts for excessive heat.

However, comparative analysis of SPI, HTC, Ped's Droght Index, Ivanov's humidity Index and other indicators suggests that SPI does not contradict to traditional indices that have been applied earlier. SPI is an efficient tool for early warning on droughts in cold seasons, as aridity in cold seasons in Ukraine was traditionally assessed by precipitation only (% to norm). Standardised precipitation indices are generally calculated for temporal intervals from 1 to 24 months. The latter temporal scale is also of relevance for Ukraine as well. In Southern oblasts of Ukraine (in particular in Khersonska oblast) precipitation deficit periods exceeded a year in some cases (Fig. 10) .

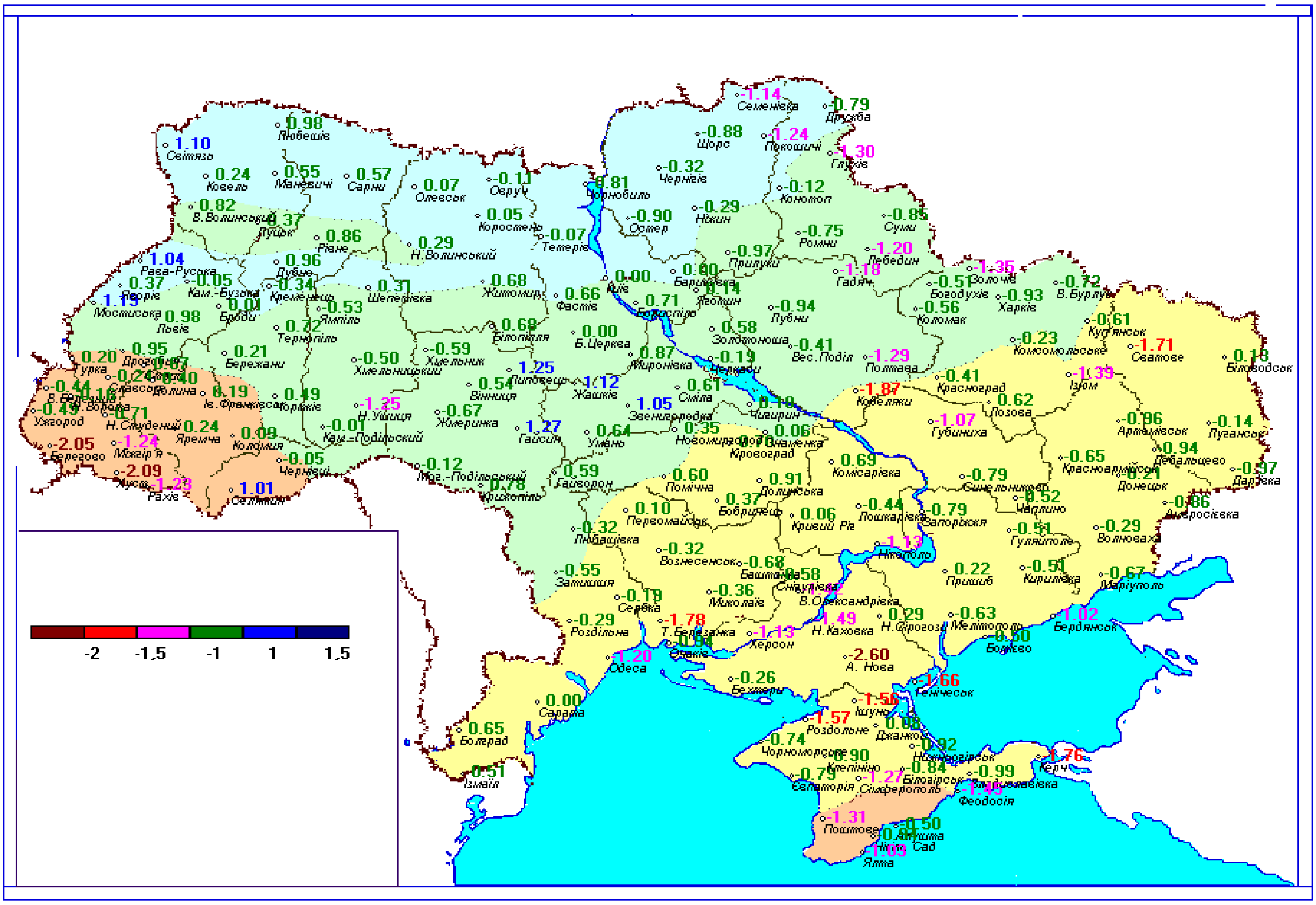


Fig. 7   6-months SPIs for December 2013 - May 2014

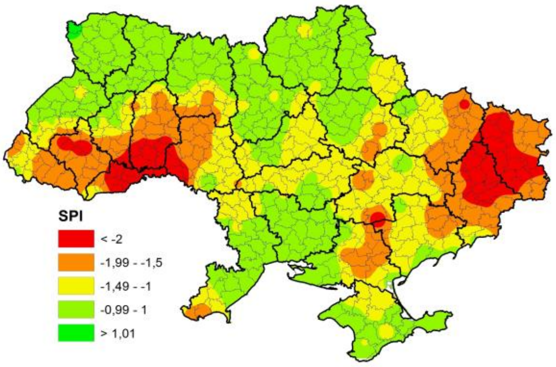


Fig. 8.   May 2003

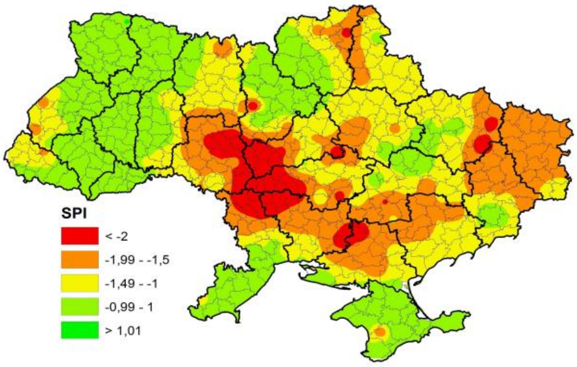


Fig. 9.   May 2007

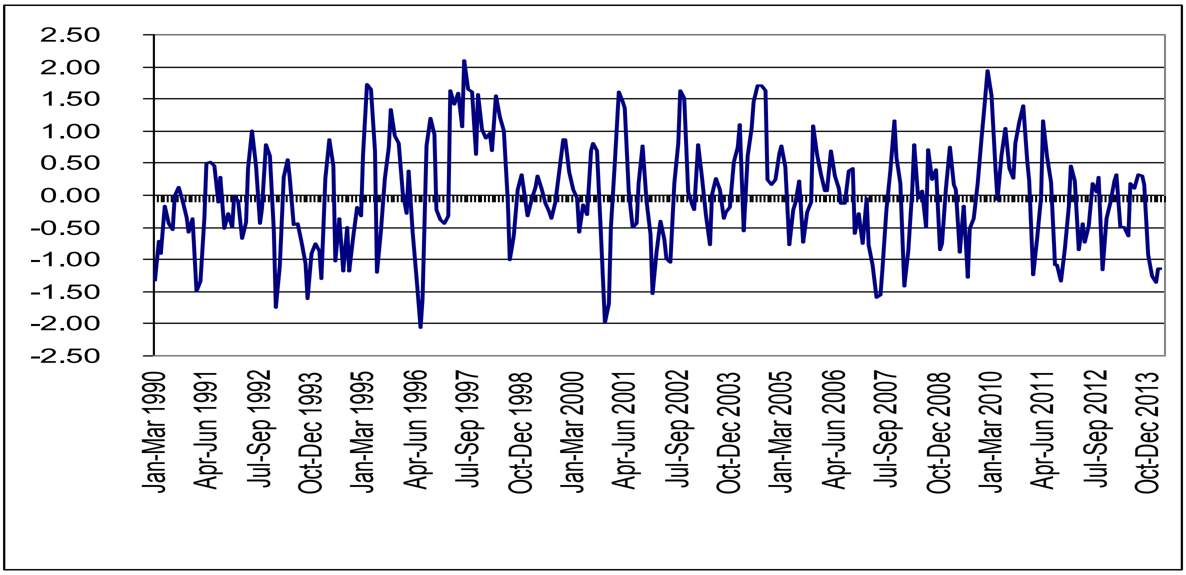


Fig. 10. 3-months SPI in Khersonska oblast

4. Conclusions

In the course of this research study, contemporary agroclimate zoning maps of Ukraine were produced with application of Inverse distance weighting (IDW) methodology. The source data for the mapping - i.e. HTC indices for the active vegetation periods (May to September periods) were estimated for the period from 1961 to 2013.

The new agroclimate zoning supported expert assessments that droughts in Ukraine started to cover the sufficiently humid zone, extending to new territories. Areas of humid agroclimate zone (Marshes) and unstable humidity zone (Forest - Steppe) are decreasing, while areas of arid zone (Steppe) are increasing. All these changes are occurring at the background of growing thermal resources of the territory and slightly increasing annual precipitation (or slightly decreasing precipitation in some regions).

The new agroclimate zoning presented may be applied by the Ministry of Agricultural Policy and the Agency of Water Resources in the course of decision-making on the following matters:
- reconstruction and expansion of irrigation networks;
- assessment and forecasting necessary water resources for irrigation;
- optimisation of operations of water reservoirs;
- introduction and promotion of moisture retaining soil handling technologies;
- planning crop rotation;
- development of measures for adaptation and mitigation of adverse consequences of climate change;
- introduction of new agricultural crops;
- insurance of drought-related risks for agricultural crops;
- recommendations for farmers on appropriateness of planting specific agricultural crops,
- recommendations for farmers on seedtimes in specific argometeorological conditions.
- maximal utilisation of growing thermal resources.

A comparative analysis of HTC and SPI indices suggested that application of SPI for characterisation of meteorological droughts - in addition to drought indices that are already applied by the Ukrainian meteorological service - is an efficient option, particularly in terms of humidity assessment in cold seasons. SPI allows to provide a fairly reliable estimate of territories under drought risks in Ukraine, it allows to provide early warnings on droughts, and to assess drought intensity. Besides that, it may be rather easily calculated.
Incorporation of SPI into the system of indices for drought monitoring in Ukraine would allow to enhance opportunities for provision of information on drought development risks to information users in a clear visual format, easily understandable by the general public.

In the course of mapping the agroclimate zoning of the Dniester basin, jointly with Moldavian project participants, we processed and provided hydrometeorological information for the period from 1980 to 2013, including monthly precipitation, average monthly air temperatures, aggregate active temperatures, numbers of dry days, maximal and minimal air temperatures for 9 Ukrainian meteorological stations located nearby the Dniester basin.

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