Global Water Partnership
Central and Eastern Europe

Integrated Drought Management

Programme in Central and Eastern Europe

Activity 5.6

Upgrading of forecasting models for identification of crop yield losses caused by droughts (Output 3a)

January 20, 2015

Name of the milestone:	**Milestone 4:** Ukraine: Upgrading of forecasting models for identification of crop yield losses caused by droughts (for one crop)
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1. Introduction

Grain production is the most profitable economic sector of Ukraine. However, in years of catastrophic droughts (2003, 2007) annual losses in grain production exceeded €3 billion. Probability of droughts at the territory of the country varies from 10 to 70%. Until recently, droughts were almost never observed only in three Western oblasts (Lvivska, Zakarpatska, Ivano-Frankivska). However, in recent decades, even these Western oblasts experienced drought of different intensity, associated with raising air temperatures and minor increases of annual precipitation quantity.
At such conditions, advance assessment of potential crop yield losses or lost profits becomes even more relevant. Assessment of main grain crops (i.e. winter wheat and spring barley) yields reduction with application of the existing model demonstrated satisfactory results, but the model needs to be upgraded taking into account climate change.

2. National drought indicators and classification

After analysis of information value of indicators, opportunities to collect relevant data swiftly, simplicity of their calculation and simultaneous reflection of both atmosphere and soil droughts, the following indicators were selected:

1) Selyaninov's hydrothermal coefficient (HTC);
2) Shashko's humidity coefficient (Md);
3) Protserov's humility supply coefficient (V,%);
4) the number of days with relative air humidity ≤30% (No);
5) the number of days with maximal air temperature > 30 ° C (NT);
6) accessible soil moisture content in soil layer 0-20 cm under winter, early spring and late spring crops (W0-20);
7) accessible soil moisture content in soil layer 0-50 cm under winter, early spring and late spring crops (W0-50);
8) accessible soil moisture content in soil layer 0-100 cm under winter, early spring and late spring crops (W0-100).
9) SPI is used since 2014.

The above indicators are estimated based on standard observation data of hydrometeorological stations (precipitation, air temperatures, relative ambient air humidity and accessible soil moisture contents).
Drought monitoring is maintained in an operational mode with 10-days stepping.
Droughts are classified by intensity as: severe, heavy, medium, weak, none.

Thresholds values of indicators for different drought categories are shown in the Table below:

Drought assessment indicators	Drought intensity categories				
	severe	heavy	medium	weak	none
HTC	<0.5	0,5-0,6	0.7-0.9	1.0-1.2	>1.3
Md	0-0.09	0.10-0.19	0.20-0.30	0.31-0.40	0.41-3.0
V, %	0-40	41-50	51-60	61-70	71-100
No	8-11	6-7	3-5	1-2	0
NT	8-11	6-7	3-5	1-2	0
W0-20, mm	0-5	6-10	11-15	16-20	21-70
W0-50, mm	0-15	16-25	26-35	36-45	46-140
W0-100, mm	0-25	26-40	41-60	61-80	81-280

The droughts warning system incudes info releases via different mass media outlets, 10-days agro-meteorological bulletins, as well as weather forecasts, special operational information releases for different users - from farmers to the Government.

3. Assessment of droughts' impacts on winter wheat crop yield with application of "Automatic Drought Assessment in Ukraine" model

Drought indices allow to get a number of important parameters of the drought phenomenon. However, these indices do not always meet users' demands in quantified assessment of crop losses. Only a comprehensive use of multiple indices for generation of a final joint integrated estimation would provide a satisfactory assessment of potential crop losses. Such functionality is provided by the "Automatic Drought Assessment in Ukraine" model. The model allows providing oblast-level averages for drought-induced reduction of crop yields of winter wheat and spring barley.

3.1. A brief description of the model

In order to assess crop yield losses adequately, it is important to account period of drought's starting in relation to vegetation phases of specific crops. In the model, drought conditions are assessed in relation to 10-days periods of winter wheat vegetation. Every 10 days, the drought's beginning and development process is monitored from the start to the end of the vegetation period. The 10-days period, when a drought of any intensity was firstly identified, is assumed to be the drought start period. In the model, a drought start is identified by Bova's aridity coefficient, incorporating key factors that have impacts on crops vegetation:

$$K_B^j = \frac{10(W^o + \sum\Theta)}{\sum t}$$

here: K_B - Bova's aridity coefficient;
Wo - soil moisture content in 1 m soil layer by the beginning of vegetation;

$\Sigma\Theta$ - quantity of precipitation from the beginning of vegetation to the moment of the drought start;

Σt - the sum of temperatures over 0 °C in the above period of time.

$K_B \leq 1.5$ is assumed to indicate the drought start.

Further assessments define the drought development process (aggravation, decline, status quo, cessation).
Crop yield losses are estimated by a combination of two methods: the ones proposed by M.S. Kulik and the second – by E.O. Tsuberbiller. The methods were adapted for each agro-climate zone of Ukraine and assess moisture contents in top soil layer, precipitation quantity and deficit of air humidity. Crop yield losses are estimated by the following set of equations:

$$C_{\text{посух.}} = \begin{cases} n_1 \quad \text{при} \quad W_{\text{орн.}} < W_{crit1} \quad \text{і} \quad d_{\text{п}} > d_{crit1} \\ n_2 \quad \text{при} \quad W_{\text{орн.}} < W_{crit2} \quad \text{і} \quad r < r_{crit1} \quad \text{та} \quad d_{\text{п}} > d_{crit2} \\ n_3 \quad \text{при} \quad W_{\text{орн.}} < W_{crit2} \quad \text{і} \quad r < r_{crit1} \quad \text{та} \quad d_{\text{п}} > d_{crit2} \end{cases},$$

here: $C_{\text{посух}} = C_{drought}$ - assessments of crop yield formation conditions

$W_{орн} = W_{tops.}$ - accessible moisture content in the top soil layer;
W_{crit1}, W_{crit2} - critical thresholds of accessible soil moisture content, characterising soil drought start;
d_n - air humidity deficit;
d_{crit1}, d_{crit2} - critical thresholds of air humidity deficit, characterising an air drought start;
r - total precipitation;
r_{crit1} - critical threshold of total precipitation, characterising a drought start.
The criteria were developed for different agro-climate zones of Ukraine: 1 – Marshals: Polissya, Zakarpattya and Prykarpattya, 2 - Forest-Steppe; 3 - Southern and Northern Steppes.

The following inputs are used for every 10-days period of vegetation (depending on a particular agro-climatic zone, the period of vegetation may consist of 10 to 13 ten-days periods):

- a code of the agro-climate zone (KRNZ) for drought assessment;
- a sequential number of the ten-days period (j) ;
- accessible soil moisture content in 0-20 cm soil layer (Wp0(j));
- accessible soil moisture content in 0-100 cm soil layer (Wm0(j));
- total precipitation in the ten-days period (os(j));
- the average air humidity deficit for the ten-days period (dww(j));
- assessment of drought impacts on crop yield reduction (CZ).
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Starting from the second 10-days vegetation period, estimates are made sequentially, in several steps, reflecting growing aridity. For these purposes, the following interrelations are accounted for: the ratio of moisture contents of the top soil layer and 1 m soil layer, total precipitation for a 10-day period and the average air humidity deficit for the 10-days period.

The interrelations are listed below:

1. First decade of vegetation:

If j = 1 and Wp0(j) < 20 and os(j) < 15 and KRNZ=1, then C3 = C3 – 0,025;

If j = 1 and Wp0(j) < 20 and Wm0(j) < 100 and KRNZ=2, then C3 = C3 – 0,025;

If j = 1 and Wp0(j) < 20 and Wm0(j) < 90 and KRNZ=3, then C3 = C3 – 0,025.

2. The second decade of vegetation:

2.1. If j = 2 and Wp0(j)< 20 and dww(j)>7,9 and KRNZ=1, then C3 = C3 – 0,025;

If j = 2 and Wp0(j) < 20 and dww(j) > 7,9 and KRNZ=2, then C3 = C3 – 0,025;

If j = 2 and Wp0(j) < 20 and dww(j) > 7,9 and KRNZ = 3, then C3 = C3 – 0,025;

2.2. If j = 2 and Wp0(j) < 20 and os(j) < 15 and dww(j) > 8,9 and KRNZ = 1,

then C3 = C3 – (0,5·0,025);

If j = 2 and Wp0(j) < 20 and os(j) < 10 and Wm0(j) < 100 and dww(j) > 9,9

and KRNZ = 2, then C3 = C3 – (0,5· 0,025) ;

If j = 2 and Wp0(j) < 20 and os(j) < 10 and Wm0(j) < 90 and dww(j) > 11,9

and KRNZ = 3, then C3 = C3 – (0,5·0,025);

2.3. If j = 2 and Wp0(j) < 15 and os(j) < 15 and KRNZ = 1, then

C3 = C3 – (0,025·0,5);

If j = 2 and Wp0(j) < 10 and Wm0(j)< 100 and KRNZ = 2, then C3 = C3 – (0,025·0,5);

If j = 2 and Wp0(j) < 10 and dww(j) = >7,9 and KRNZ = 3, then C3 = C3–(0,025·0,5);

2.4. If j = 2 and Wp0(j) < 15 and os(j) < 15 and dww(j) > 8,9 and KRNZ = 1,

then C3 = C3 – (0,5·0,025);

If j = 2 and Wp0(j) < 10 and os(j) < 10 and Wm 0(j) < 100 and dww(j) > 9,9

and KRNZ = 2, then C3 = C3 – (0,5·0,025);

If j = 2 and Wp0(j) < 10 and os(j) < 10 and Wm0(j) < 90 and dww(j) > 11,9

and KRNZ = 3, then C3 = C3 – (0,5·0,025).

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13. Thirteenth decade of vegetation:

13.1. If j = 13 and Wp0(j) < 15 and dww(j) > 7,9 and KRNZ = 1,

then C3 = C3 – 0,025;

If j = 13 and Wp0(j) < 10 and dww(j) > 7,9 and KRNZ = 2, then C3 = C3 – 0,025;

If j = 13 and Wp0(j) < 10 and dww(j) > 7,9 and KRNZ = 3, then C3 = C3 – 0,025;

13.2. If j = 13 and Wp0(j) < 15 and os(j) < 5 and dww(j) > 8,9 and KRNZ=1, then C3 = C3 – (0,025·0,5);

If j = 13 and Wp0(j) < 10 and os(j) < 5 and Wm0(j) < 30 and dww(j) > 9,9 and

KRNZ = 2, then C3 = C3 – (0,025·0,5);

If j = 13 and Wp0(j) < 10 and os(j) < 5 and Wm0(j) < 25 and dww(j) >11,9 and

KRNZ = 3, then C3 = C3 – (0,025·0,5);

13.3. If j = 13 and Wp0(j) < 15 and dww(j) > 10,9 and KRNZ = 1,

then C3 = C3 – (0,0125·0,5);

If j = 13 and Wp0(j) < 10 and dww(j) > 11,9 and KRNZ = 2,

then C3 = C3 – (0,0125·0,5);

If j = 13 and Wp0(j) < 10 and dww(j) > 12,9 and KRNZ = 3,

then C3 = C3 – (0,0125·0,5);

If j = 13 and Wp0(j) < 5 and KRNZ = 3, then C3 = C3 – (0,0125·0,5);

If C3 < 0,7 , then C3 = 0,7.

During vegetation, the most serious negative effects of droughts on crop yield of winter wheat are observed in the period of formation of plant reproductive organs (i.e. from May to June), that define the crop yield. At early phases of vegetation (in spring) drought impacts on crop yield are weaker due to higher soil moisture contents in spring. At later vegetation phases (flowering, milky ripeness and waxy maturity of grain) a crop yield more seriously depends

on heat than on water. As a result, in the latter period, drought impacts on crop yield become weaker, similarly to the early vegetation period.

3.2. Input data

The model has four groups of input data:

1) Oblast (region) description - φ - geographic latitude, KRN - region code (1 - Polissya, Zakarpattya and Prykarpattya, 2 - Forest-Steppe; 3 - Southern and Northern Steppes);
KRNZ - region code for drought assessment: 1 - Polissya, Zakarpatya and Prykarpatya, 2 - Forest-Steppe; 3 - Southern and Northern Steppes;

Y_{max} - maximal oblast (region) average crop yield for the period from 1986, dt/ha.
W_{min} - the minimal soil moisture content of 1 metre soil layer, mm.

***2*) Average multi-year agro-meteorological information (norms);**
2.1 Data on accessible moisture contents in 1 metre soil layer by the initial moment of estimation;
2.2. Phenological data - starting dates of main plant growth phases: spring renewal of vegetation of winter wheat and waxy maturity of grain. Based on the above information, the following parameters are calculated:
2.3. n - the number of estimated 10-days periods from renewal of vegetation of winter wheat to waxy maturity of grain;
nn - the number of days in every estimated 10-days period;
no - the number of days from January 1 to the spring renewal of vegetation of winter wheat;
N1 - the sequential number of the month of renewal of vegetation of winter wheat;
N2 - the number of the month of renewal of vegetation: 1- January, 2 - February, etc.;

2.4. Agro-meteorological and meteorological data for 10-days periods in the whole crop vegetation period:
Wp0mn - accessible soil moisture content in the top soil layer;
Wm0mn - accessible soil moisture content in 1 metre soil layer;
σWm0 - mean squared deviation of soil moisture contents in 1 metre soil layer;
tsmn - average air temperature in the 10-days period;
σts - mean squared deviation of the average air temperature in the 10-days period;
ss - average number of sunny hours in the 10-days period;
osmn - total precipitation in the 10-days period;
σos - mean squared deviation of total precipitation in the 10-days period;
pnor – norm of vegetative irrigation in the 10-days period;
dww - average air humidity deficit in the 10-days period;
hgr - average groundwater level in the 10-days period;
dv - the number of days in the estimated 10-days period;

3) Actual agro-meteorological data for a specific year
The information that is updated every 10 days in ongoing vegetation period. The information includes all data entries listed in section 2 (except mean squared deviations).

4) Model parameters.

This group incorporates the following parameters
4.1. T0 - biological zero temperature for a given crop (+5ºC in the case of winter wheat);
4.2. Σtveg - the sum of effective temperatures for the period of vegetation, °C;
4.3. WHB - the lowest moisture content in 1 metre soil layer, mm;

4.4. KRN - region code (1 - Polissya, Zakarpattya and Prykarpattya, 2 - Forest-Steppe; 3 - Southern and Northern Steppes);
4.5. KRNZ - region code for drought assessment: 1 - Polissya, Zakarpattya and Prykarpattya, 2 - Forest-Steppe; 3 - Southern and Northern Steppes;
4.6. Σtmax1 - the sum of effective temperatures for the period from renewal of vegetation to earing;
4.7. W(0) - accessible soil moisture content at the beginning of vegetation (the starting date of assessments), mm;
4.8. Уmax - maximal oblast-level average crop yield of winter wheat (spring barley) in the period from 1986, dt/ha.
Model parameters for winter wheat were identified for all oblasts/regions of Ukraine.

3.3. Modelling results

Modelling results are produced in table format in the following sequence.
First, the input information is repeatedly listed (for control purposes). Then, two tables with estimates are produced for each 10-days period of the vegetation period under analysis (tables R.1and R.2):

Table R.1
contains assessments of drought impacts on grain growth - crop yield reduction (%), evaporation deficit (mm), Bagrov meteorological crop yield index, Ped aridity index, leaves water deficit (%), Bova aridity index, plant water supply sufficiency (Iwstr, %), HTC (GTK), cumulative sum of plant water demand from the beginning of vegetation (sumpot, mm), cumulative sum of evaporation from the beginning of vegetation (seakxr, mm).

Table R.2 contains information on precipitation in the 10-days period (os, mm), evaporation (Epot, mm), total evaporation (Eakt, mm), soil moisture deficit for normal plant growth (defwl, mm), plant water demand (ptwl, mm), cumulative sum of plant water demand from the beginning of vegetation (sumpot, mm), as well as cumulative sum of evaporation from the beginning of vegetation (seakxr, mm).

4. Results of the upgrade

Analysis of modelling results suggests that the model adequately reflects impacts of droughts on crop yield of winter wheat according to the criterion applied - i.e. crop yield reduction.
In years with heavy and severe droughts in May - June periods, modelling results suggested substantial negative deviations of winter wheat crop yields from averages. Some crop yield reduction was expected also in the case of prolonged droughts of medium intensity.
Comparative analysis of the initial version of the model (see Table 1) and the upgraded one (see Table 2) suggests improvement of estimates' precision by 2-5%. As an illustration, estimates for Odeska oblast are shown - the oblast borders Moldova and the largest land areas under winter wheat in Ukraine are located there (over 500 thousand ha).

Tables 1 and 2 show the results of calculations of winter wheat yield losses by using model before (tabl..1) and after (tabl..2) upgrading. The actual yield in 2007 was 1.8 t / ha. The trend (if not drought happens) was proposed 2.7 t / ha. Model (1) estimated crop yield reduction on 27% and Model (2) estimated crop yield reduction on 30%, while the actual reduction reached 34%. Thus upgraded model improves the accuracy of prediction of crop losses.

Table 1 - Results of winter wheat crop yield reduction estimates (%) based on model for 2007

Input data
ODESSA sr 20

n= 10
10 79 21 3 46.85
wp0 - soil moisture content in 0-20 cm soil layer (mm)
21.0000 17.0000 12.0000 9.0000 6.0000 2.0000 0.0000 2.0000 1.0000 1.0000
wm0 - soil moisture content in 0-100 cm soil layer (mm)
96.0000 98.0000 80.0000 63.0000 46.0000 26.0000 7.0000 9.0000 5.0000 5.0000
wm0mn – normal soil moisture content in 0-100 cm soil layer (mm)
130.0000 125.0000 119.0000 114.0000 108.0000 94.0000 74.0000 63.0000 55.0000 45.0000
wsigm – sigma of soil moisture contents in 0-100 cm soil layer
26.8000 26.8000 26.8000 29.5000 29.5000 34.8000 34.8000 29.4000 29.4000 29.4000
ts – average air temperature in the 10-days period (°C)
7.3 9.6 9.4 11.9 13.2 18.9 23.6 22.3 23.9 22.7
tsmn – normal average air temperature for the 10-days period (°C)
4.2 6.5 8.9 11.3 13.8 15.7 17.1 18.4 19.5 20.6
tsigm - the sum of average air temperature in the 10-days period
1.9 1.6 1.6 1.6 1.6 1.6 1.6 1.4 1.4 1.4
ss – average number of solar radiation hours in the 10-days period
5.4 6.2 6.9 7.7 8.3 8.9 9.3 9.8 10.2 10.6
os – total precipitation in the 10-days period (mm):
1.0 6.0 1.0 8.0 5.0 1.0 2.0 8.0 7.0 31.0
osmn – normal precipitation in the 10-days period (mm)
9.0 10.0 11.0 11.0 14.0 15.0 15.0 19.0 20.0 20.0
ossigm - the cumulative sum of precipitation in the 10-days period (mm):
4.6 5.1 5.1 5.1 7.6 7.6 7.6 10.3 10.3 10.3
dv – actual number of days on 10-days periods
11 10 10 10 10 10 11 10 10 9

inf – the array of model parameters:
pnor – norm of vegetative irrigation, mm:
5.000 880.000 170.000 4.000 3.000 445.000 130.000 38.000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
dww – average air humidity deficit in the 10-days period (mm)
6.0000 4.0000 5.0000 7.0000 7.0000 13.0000 17.0000 15.0000 16.0000 12.0000
hgr – groundwater level (m)
10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000
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Table 1.1 - Estimated drought parameters

10-days periods	days	C3	dIsp	Bagr	Ped1	Woddef	Bova	HTC
1	11	0.0	7.2	1.31	1.04	1.6	18.31	0.00
2	21	0.0	8.9	0.57	2.33	2.4	7.66	0.00
3	31	0.0	9.8	0.83	1.15	2.2	5.18	0.00
4	41	0.0	11.7	0.63	1.90	3.0	3.52	0.59
5	51	0.0	17.1	0.89	0.46	3.2	2.65	0.61
6	61	5.0	24.1	0.08	3.77	5.9	1.84	0.05

7	72	10.0	34.8	0.03	8.14	9.9	1.35	0.04
8	82	17.5	35.9	0.26	5.56	13.9	1.14	0.27
9	92	22.5	42.1	0.41	5.42	25.9	0.97	0.38
10	101	27.5	37.0	0.79	3.20	36.9	0.92	1.01

C_3 – estimated drought-induced crop yield reduction **(%)**
dlsp – evaporation deficit (mm)
Bagr - Bagrov's meteorological index
less than 0.8-0.9 = worsening conditions, about 1 = norm, over 1 = favourable conditions
Ped1- Ped's aridity index
varies from -4 to +10, "+" range corresponds to arid conditions
Woddef – Antonenko's water deficit in leaves (%)
Bova – Bova's aridity index
HTC - Selyaninov's hydrothermal coefficient

Table 1.2 Estimated crops water demands

10-days periods	days	os	Epot	Eakt	defwlag	ptwl	sumpot	seakxr	Ped2
1	11	1	22.5	14.3	0.0	22.5	22.5	14.3	3.69
2	21	6	26.0	15.4	0.0	26.0	48.5	29.8	2.03
3	31	1	31.1	17.3	0.0	31.1	79.6	47.1	1.96
4	41	8	36.5	19.6	0.0	36.5	116.1	66.7	0.71
5	51	5	40.8	20.4	0.0	40.8	156.9	87.1	0.50
6	61	1	44.8	17.9	0.0	44.8	201.6	105.0	4.34
7	72	2	52.4	13.1	-3.4	52.4	254.0	118.1	6.71
8	82	8	50.5	10.4	-10.0	50.5	304.6	128.5	4.28
9	92	7	52.6	10.5	-22.1	52.6	357.1	139.0	4.76
10	101	31	48.9	9.80	-22.1	48.9	406.1	148.8	0.22

os - total precipitation in the 10-days period (mm)
Epot – evaporation in the 10-days period (mm)
Eakt – total evaporation in the 10-days period (mm)
defwlag – plants' water deficit in the 10-days period (mm)
ptwl – plants' water demand (mm)
sumpot – cumulative sum of plant water demand from the beginning of vegetation (mm)
seakxr - cumulative sum of evaporation from the beginning of vegetation (mm)
Ped2 – Ped's index based on temperature and precipitation

Table 2 - Results of winter wheat crop yield reduction estimates (%) based on model for 2007 after upgrading

Input data
ODESSA sr 20

n= 10
10 79 21 3 46.85
wp0 - soil moisture content in 0-20 cm soil layer (mm)
21.0000 17.0000 12.0000 9.0000 6.0000 2.0000 0.0000 2.0000 1.0000 1.0000
wm0 - soil moisture content in 0-100 cm soil layer (mm)

96.0000 98.0000 80.0000 63.0000 46.0000 26.0000 7.0000 9.0000 5.0000 5.0000

wm0mn – normal soil moisture content in 0-100 cm soil layer (mm)

133.0000 129.0000 126.0000 118.0000 106.0000 90.0000 81.0000 76.0000 71.0000 45.0000

wsigm – sigma of soil moisture contents in 0-100 cm soil layer

26.8000 26.8000 26.8000 29.5000 29.5000 34.8000 34.8000 29.4000 29.4000 29.4000

ts – average air temperature in the 10-days period (°C)

7.3 9.6 9.4 11.9 13.2 18.9 23.6 22.3 23.9 22.7

tsmn – normal average air temperature for the 10-days period (°C)

5.3 8.5 9.8 11.8 14.2 16.3 17.0 18.6 20.3 20.5

tsigm - the sigma of average air temperature in the 10-days period

1.9 1.6 1.6 1.6 1.6 1.6 1.6 1.4 1.4 1.4

ss – average number of solar radiation hours in the 10-days period

5.6 6.4 6.1 7.2 9.0 9.1 8.6 8.9 10.2 9.9

os – total precipitation in the 10-days period (mm):

1.0 6.0 1.0 8.0 5.0 1.0 2.0 8.0 7.0 31.0

osmn – normal precipitation in the 10-days period (mm)

13.0 9.0 12.0 11.0 9.0 11.0 23.0 21.0 17.0 21.6

ossigm - the sigma sum of precipitation in the 10-days period (mm):

4.6 5.1 5.1 5.1 7.6 7.6 7.6 10.3 10.3 10.3

dv – actual number of days on 10-days periods

11 10 10 10 10 10 11 10 10 9

inf – the array of model parameters:

pnor - normal vegetative irrigation, mm:

5.000 880.000 170.000 4.000 3.000 445.000 130.000 38.000

0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

dww – average air humidity deficit in the 10-days period (mm)

6.0000 4.0000 5.0000 7.0000 7.0000 13.0000 17.0000 15.0000 16.0000 12.0000

hgr – groundwater level (m)

10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000

Table 2.1 - Estimated drought parameters

10-days periods	days	C3	dIsp	Bagr	Ped1	Woddef	Bova	HTC
1	11	0.0	7.2	1.31	1.04	1.6	18.31	0.00
2	21	0.0	8.9	0.57	2.33	2.4	7.66	0.00
3	31	0.0	9.8	0.83	1.15	2.2	5.18	0.00
4	41	0.0	11.8	0.63	1.84	2.9	3.53	0.59
5	51	0.0	17.1	0.89	0.46	3.2	2.65	0.61
6	61	5.0	24.0	0.08	3.77	5.9	1.85	0.05
7	72	13.7	34.7	0.03	8.40	10.4	1.35	0.04
8	82	21.2	35.9	0.25	6.49	17.6	1.14	0.27
9	92	26.2	42.1	0.41	5.42	25.9	0.97	0.38
10	101	30.0	37.0	0.79	3.20	36.9	0.92	1.01

C_3 – estimated drought-induced crop yield reduction **(%)**

dIsp – evaporation deficit (mm)

Bagr - Bagrov's meteorological index

less than 0.8-0.9 = worsening conditions, about 1 = norm, over 1 = favourable conditions

Ped1- Ped's aridity index

varies from -4 to +10, "+" range corresponds to arid conditions
Woddef – Antonenko's water deficit in leaves (%)
Bova – Bova's aridity index
HTC - Selyaninov's hydrothermal coefficient

Table 2.2 Estimated crops water demands

10-days periods	days	os	Epot	Eakt	defwlag	ptwl	sumpot	seakxr	Ped2
1	11	17.0	22.5	15.2	0.0	22.5	22.5	15.2	0.18
2	21	5.0	26.8	17.8	0.0	26.8	49.2	33.1	1.47
3	31	10.0	28.3	18.5	0.0	28.3	77.5	51.6	0.14
4	41	7.0	34.6	22.8	0.0	34.6	112.1	74.4	0.78
5	51	8.0	43.5	26.4	0.0	43.5	155.6	100.8	-0.49
6	61	1.0	45.6	21.5	0.0	45.6	201.1	122.4	2.94
7	72	1.0	49.3	14.6	0.0	49.3	250.5	136.9	7.02
8	82	6.0	46.9	11.0	0.0	46.9	297.3	147.9	4.24
9	92	9.0	52.6	10.5	-6.5	52.6	349.9	158.5	3.35
10	101	20.6	46.3	9.3	-6.5	46.3	396.2	167.7	1.67

os - total precipitation in the 10-days period (mm)
Epot – evaporation in the 10-days period (mm)
Eakt – total evaporation in the 10-days period (mm)
defwlag – plants' water deficit in the 10-days period (mm)
ptwl – plants' water demand (mm)
sumpot – cumulative sum of plant water demand from the beginning of vegetation (mm)
seakxr - cumulative sum of evaporation from the beginning of vegetation (mm)
Ped2 – Ped's index based on temperature and precipitation

5. Conclusions

In connection with climate change, models of drought impacts on crop yields need adjustment and upgrade. In the course of preparing this report, we recalculated and incorporated new parameters into the model - temperature, precipitation, air humidity deficit, accessible soil moisture contents in different soil layers at 10-days increments. Observation data of 145 meteorological stations for the period from 1991 to 2014 were applied (agro-meteorological parameters). Application of the above parameters accounts for climate change trends and impacts of these changes on development and spatial distribution of droughts of different intensity, and their timing.
In the course of preparing this section of the report, the new agro-climate zoning was applied (Milestone 3) to clarify drought criteria for different agro-climate regions. Maximal crop yields of winter wheat were clarified (an important component of the model). The upgraded model was tested with application of actual data (% of crop yield reduction) at the level of administrative oblasts. The check of adequacy of actual and estimated crop yield reduction demonstrated satisfactory results.

Upgrade of the model for crop yield reduction caused by droughts would improve provision of agro-meteorological services to the agricultural sector of Ukraine in terms of ensuring food security of the country, decision-making on grain import and export, drought management, and would promote provision of high quality information to stakeholders.

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