Development of Ukraine Territory Flooding Processes; Its Parameters and the Influence on the Environmental Safety Level

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Summary. Shows the present state of development of flooding processes of Ukraine territory. Given filtration stages in the flooding the process of and methods of their calculation. The method of filtration resistance for calculating of the filtering in flooding process is analyzed. Shows the dependence between the development of flooding process and intensifying processes of landslides on Ukraine territory.

Key words: environmental safety, flooding process, groundwater level, method of filtration resistance, process of landslide.

INTRODUCTION

Spread areas of flooding is one of the major environmental problems on the territory of modern Ukraine, in connection with which there is a need to study the causes of its origin and determine the level of environmental safety with regard to the factors that cause it.

Essential factors of the regional flooding development are:

- increase of rainfall in the last decade as a result of global climate change,

- almost total underregulation of the river network on plain areas with groundwater level`s skids from 1,5-4 m to 8-10 m and a substantial reduction in the volume of water unsaturated rocks above soil water-bearing horizon, which increased the rainfall influence on the above-lying rocks water saturation,

- forming of zones of an increase technogenic feed of subsoil waters within the limits of the irrigatory systems etc.

THE CURRENT STATE OF UKRAINE`S TERRITORY FLOODING PROCESS

From data of Government geological service the general area of flooding for 20 last the on territory of Ukraine grew twice. General data about the number of the impounded settlements and flooding areas in the Ukraine`s administrative regions are listed in Table 1.

Depending on the main source of flooding and the complex of influential factors, the flooded areas of Ukraine`s territory are divided into three types:

- flooding in natural conditions, according to the source natural – precipitation (thawed snow, flood and rainwater), when balance of groundwater is not broken. This type pertains Polissya (Volyn, Zhytomyr, Rivne areas and the northern part of Kyivarea), as well as the northern part of Lviv and Ternopil areas,

- naturally-technogenic flooding when groundwater balance slightly disturbed or disrupted due to increase their power, which is associated with a decrease in the natural

Table 1. The flooding areas in the administrative regions Ukraine

№	Administrative area	Area of flooding, ths. km^2			The ratio indicators, 1982 to 2013
		1980	2010	2013	
1	Vinnytsia	0,3	0,005	0,005	2,96
2	Volyn	-	9,14	9,14	-
3	Dnipropetrovsk	1,04	7,29	7,29	7,0
4	Donetsk	0,35	0,23	1,66	8,67
5	Zhytomyr	-	0,04	0,04	-
6	Zakarpattia	-	0,001	0,001	-
7	Zaporizhia	0,73	0,01	0,01	4,37
8	Ivano-Frankivsk	-	-	-	-
9	Kiev	0,21	0,02	0,021	-
10	Kirovohrad	0,01	0,057	0,057	4,2
11	Luhansk	0,48	0,02	0,035	0,34
12	Lviv	0,15	0,25	0,261	1,43
13	Mykolaiv	0,74	17,03	17,03	17,5
14	Odessa	1,37	20,6	20,6	9,9
15	Poltava	0,81	0,15	8,5	10,4
16	Rivne	-	11,7	11,7	-
17	Sumy	0,4	0,07	0,07	1,8
18	Ternopil	-	-	-	-
19	Kharkiv	0,77	3,0	3,0	3,9
20	Kherson	0,62	11,3	11,3	16,85
21	Khmelnytskyi	0,01	0,06	0,06	-
22	Cherkasy	0,35	0,06	0,06	0,22
23	Chernivtsi	0,26	-	4,1	16,0
24	Chernihiv	0,03	0,15	0,15	5,0

territory drainage. This type occurs in the Central and southern regions of Ukraine in Dnipropetrovsk, Zaporizhya, Kharkiv, Lugansk, Donetsk and to the North of Odessa, Nikolaev and Kherson areas,

- technogenic flooding with violation of groundwater balance under the influence of economic activity, when man-made sources of flooding are dominating (irrigation systems, canals, reservoirs, ponds, in settlements – water supply and sewerage network). Plot of technogenic underflooding exist on the almost all Ukraine`s territory. The most impounded areas are: Kherson, Odesa, Mykolayiv, Dnipropetrovsk, Zaporizhia, Poltava, Kharkiv and Donetsk areas. This type of flooding is one of the most dangerous, since even in years with a low rainfall, the situation does not change.

STAGES OF FILTRATION IN THE FLOODING PROCESS

The forecast of raising of the ground waters when flooding and a water loss estimate on filtering from natural and artificial reservoirs on agricultural areas, requires study the main filtration stages with taking into account of the area hydrogeological conditions.

The first filtration stage is characterized by conditions of the aeration zone water saturation and achievement by a filtrational flow of ground waters level. Conditions of the such schemes existence provides an estimated water level on a surface, which is set in a fairly short time period and some time remains variable.

The first stage of filtration is characterized by the following parameters:

- time of the homogeneous soil saturation to the ground waters surface:

$$t = \frac{\mu}{k}(h_в + H_к)\varphi(\alpha), \qquad (1)$$

where: the function $\varphi(\alpha)$ is defined by the equation:

$$\varphi(\alpha) = \frac{h_0}{h_в + H_к} - \ln\left(1 + \frac{h_0}{h_в + H_к}\right), \qquad (2)$$

where: k i μ – the coefficient of soil filtration and the coefficient of soil insufficient saturation, H_c – t he overall height of capillary water rise in the soil, $H_к$ – the height of capillary soil vacuum, $h_в$ – the height of the soil surface flooding:

$$H_к \approx (0{,}5 - 0{,}7)H_c. \qquad (3)$$

The time of soil saturation by water depends on the its type (height of aeration zone in the soil) and the water level on the flooded areas.

In the absence of the outflow on the flooded areas, the time of soil saturation by water in general is pretty short.

In the outflow presence on the borders of the filtration area, groundwater motions stabilization can ensue in the lower soil layer, and groundwater level lifting to the bottom border of an upper saturated soil layer may not ensue.

In the outflow absence and in condition of infiltration stable mode presence the at the free soil surface, which may be defined by the equation:

$$\varepsilon = k_1 \frac{h_в + h_{01}}{h_{01}}. \qquad (4)$$

The next filtration stage after saturation of soil aeration zone is observed for a long term of the time and is characterized by the continuing drainage structures functioning or natural outflow from territory.

The estimated scheme of the given stage is presented as the completely flooded territory, within which is located a systematic drain.

Filtration flow for such drain is calculated by the equation:

$$q = \frac{k_1(h_в - h_g)}{\Delta L}, \qquad (5)$$

where: ΔL - filtration resistance of the drain imperfection according to the degree of opening of the aquifer thickness, h_g - water pressure (water level) in the drain.

Prediction of groundwater level rise is an important task in the calculations of territory flooding process. This is especially concerns to the territories, where surface water bodies are located, because they are the main source of groundwater supply. One of the methods of calculating the groundwater level rising near canals and reservoirs is a method of filtration resistance, which allows to bring imperfect by the type of opening of the aquifer thickness aquifer reservoirs to perfect and greatly simplify the filtration calculation technique.

In the case of the lateral outflow in open drain transient filtering mode can be observed. In this case, groundwater level lowering the in the soil slope at any moment of time can be calculated by the proposed simplified equation obtained by analytic solutions:

a) homogeneous aquifer soil layer:

$$y(x,t) = H_0 - \frac{2H_0^2}{L}\sum_{n=1}^{\infty}\left(e^{-\alpha_n C \frac{tk}{\mu H_h} th\alpha_n} - 1\right) \times \times \sin\alpha \frac{x}{H_0}, \qquad (6)$$

b) two-layer aquifer soil structure:

$$y(x,t) = H_0 - \frac{2H_0^2}{L}\sum_{n=1}^{\infty}\left(R_2 - \frac{k_2}{k_1}R_1\right)e^{-\alpha_n Cth\alpha_n \frac{tk_1}{\mu H_0}} \times \times \sin\alpha_n \frac{x}{H_0}, \qquad (7)$$

where:

$$C = 1 - \frac{\varepsilon}{k_1}; \ \alpha_n = \frac{(2n-1)\pi H_0}{2\left(L + \frac{b}{2}\right)},$$

where: L – the distance from the drain to the filtration area boundary, R_2 and R_1 – dimensionless quantities, which depend on the parameters of the filtration, H_0 – groundwater level on the flooded territory.

FEATURES OF FILTRATION RESISTANCE CALCULATING FOR FLOODING PROCESS

Definition values of the filtration resistance in the case of enclosed drains and small canals are pretty detailed researched, and there is the defined methods of their precise calculation. However, for cases of wide open reservoirs when there is a disparity: $\frac{B_k}{m} \rangle 2$ (where: B_k - width of the reservoir on the bottom, m - aquifer layer thickness), the value of the filtration resistance offered to accept by the approximate dependencies, that overstate the real value of the filtration resistance, which in its turn lead to a decrease in the calculated values of the groundwater levels.

Thus, there is a need of delineate of recommended in the literature formulas use, depending on hydrogeological conditions of the filtration area, for which it is necessary to investigate the changing values of the filtration resistance of the drain imperfection according to the degree of opening of the aquifer thickness calculated by the recommended formulas (1)-(4) under different hydrogeological conditions of filtering for the further their use in forecasting groundwater level on the flooded territories.

The equations for filtration resistance calculating the in cases of wide water reservoir are next:

- for the case of homogeneous aquifer soil layer:

$$\Delta L = 0{,}44m, \qquad (8)$$

- for the case of two-layer aquifer soil structure:

a) under condition of $k_2 / k_1 \geq 10$:

$$\Delta L = \sqrt{\frac{k_2 m_2 m_в}{k_1}}, \qquad (9)$$

b) under condition of $1 \leq k_2 / k_1 \langle 10$:

$$\Delta L = 0{,}5(h_в + m_2 + m_в\sqrt{\frac{k_2}{k_1}}, \qquad (10)$$

c) under the condition of: $\frac{k_2}{k_1} \leq 1$,

d)

$$\Delta L = 0{,}5(h_в + m_в + m_2\frac{k_2}{k_1}), \qquad (11)$$

- for the case of three-layer aquifer soil structure:

$$\Delta L = \frac{T}{T_1}\Delta L_1 - 0{,}5\frac{T_3}{T_1}B_k + \frac{T_3}{T_1 c}(1 - c\overline{B_k}\Delta L_1). \qquad (12)$$

In these equations: ΔL - filtration resistance of water reservoir; $m_в$ - upper aquifer layer thickness; m_2 - the thickness of the second aquifer layer; $h_в$ - the depth of the water in the reservoir; k_1, k_2 - filtration coefficients of the first and second aquifer layers.

On the basis of the analysis of existing methodologies for determining filtration resistance have been constructed dependences, presented in Fig. 1-3.

ENVIRONMENTAL SAFETY LEVEL OF FLOODED TERRITORIES IN DEPENDENCE WITH LANDSLIDE PROCESS

Development of the territory flooding processes is one of the leading factors of reduce of the bearing capacity of soil slope upper part, which activates landslides. In recent years there has been a rapid increase of landsliding processes on the territory of Ukraine – up to the 23100 objects with the doubling of its number in the last 30 years.

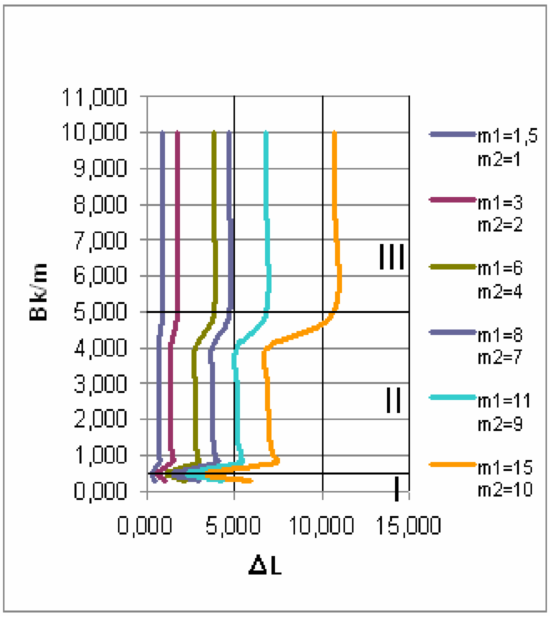

Fig. 1. Value of the filtration resistance for case of homogeneous aquifer soil layer

In this figure: zone I - water flow is calculated by analogy with round drain for a case of open channels with the small width of the channel on the bottom under condition of the $B_k / m \leq 0,5$; zone II - for medium-sized channels under condition of the $0,5 \langle B_k / m \langle 5$; zone III - for channels with large sizes for under condition of the $B_k / m \rangle \rangle 5$.

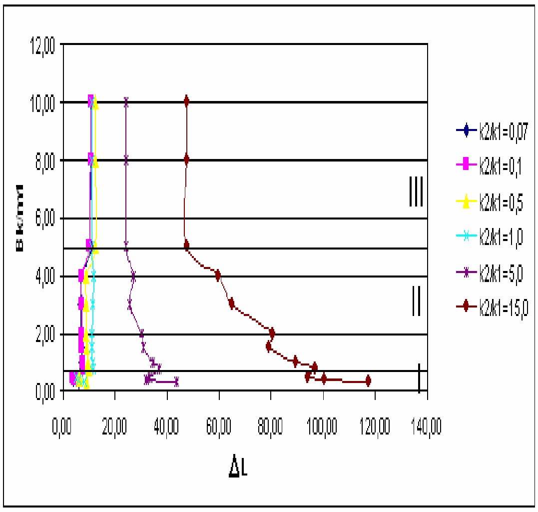

Fig. 2. Value of the filtration resistance for the case of the two-layer aquifer soil structure with the different ratios of filtration coefficients

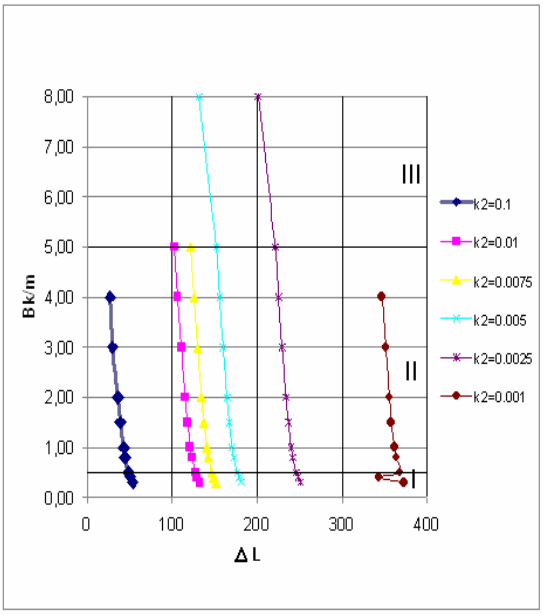

Fig. 3. Value of the filtration resistance for the case of the three-layer aquifer soil structure with the different ratios of filtration coefficients

When considering the risk of landslide processes in time, it should be noted that under the condition of other immutable weight coefficients the largest impact on the slopes sustainability has a process of regional water-balance equilibrium breaking in the upper zone of the geological environment, i.e. the regional revitalization of flooding processes . There is a direct dependence between the generalized data about progress of landslips depending on progress of territory flooding processes.

The Table 2 shows data on areas of flooding and landslides on the administrative distribution on the Ukraine territory of for 1982-2013.

The annual probability of dangerous geological processes such as landslides, within a 1 km2 is defined by the formula:

$$K_{dgp} = K_{sc} K_t , \qquad (13)$$

where: K_{sc} – the factor of spatial areas contamination (% of total landslide areas f_{tl} within the general area that is considered):

$$K_{sc} = \frac{f_{tl}}{f}, \qquad (14)$$

Table 2. The data on areas of flooding and landslides on the administrative distribution on the Ukraine territory of for 1982-2013

№	Administrative area	1982-1984		1997 рік		2006 рік		2013 рік	
		Area of flooding, ths. km^2	The number of landslides	Area of flooding, ths. km^2	The number of landslides	Area of flooding, ths. km^2	The number of landslides	Area of flooding, ths. km^2	The number of landslides
1	2	3	4	5	6	7	8	9	10
1	Vinnytsia	0,3	234	0,895	225	8,96	338	0,05	339
2	Volyn	-	-	12,9	-	13,91	-	9,14	-
3	Dnipropetrovsk	1,04	214	7,28	303	7,3	382	7,29	382
4	Donetsk	0,35	123	3,03	125	3,04	188	0,23	189
5	Zhytomyr	0,02	10	19,75	11	20,13	10	0,04	10
6	Zakarpattia	-	1278	3,02	1596	3,02	2880	0,01	3274
7	Zaporizhia	0,73	244	3,19	218	3,2	205	0,01	206
8	Ivano-Frankivsk	-	487	0,008	1005	0,008	769	-	805
9	Kiev	0,21	764	8,1	816	8,1	790	0,02	814
10	Kirovohrad	0,01	99	0,14	95	0,142	143	0,01	140
11	Luhansk	0,48	564	0,16	593	0,164	1138	0,03	769
12	Lviv	0,15	421	0,21	524	0,116	1289	0,25	1347
13	Mykolaiv	0,73	707	12,82	985	17,767	1150	17,3	1148
14	Odessa	1,37	938	13,52	5167	19,685	5885	20,6	5835
15	Poltava	0,81	732	8,5	761	8,5	824	0,15	824
16	Rivne	0,01	-	12,79	-	12,8	-	11,7	-
17	Sumy	0,4	397	0,42	490	0,474	567	0,07	567
18	Ternopil	-	54	-	119	-	117	-	117
19	Kharkiv	0,77	518	3,02	851	3,02	1659	0,12	1615
20	Kherson	0,62	37	10,45	63	11,945	43	11,3	43
21	Khmelnytskyi	0,02	364	-	203	0,014	425	0,06	420
22	Cherkasy	0,35	685	0,08	810	0,08	1034	0,06	1033
23	Chernivtsi	0,03	1272	0,42	1435	0,4	1622	-	1468
24	Chernihiv	0,4	8	4,4	11	4,4	11	0,15	9

t - the coefficient of the temporal landslides development dynamics, or frequency activation processes for a specific period of time T, determined by the formula:

$$K_t = \frac{1}{T}, \qquad (15)$$

and depends on the complex of effects and anthropogenic factors within territory that is considered. Taking into account the impact of stabilization systems and engineering protection measures (which are calculated, as a rule, for a period of up to 30 years), in formulas also introduced the corresponding coefficient:

$$K_c = \frac{30}{T'}, \qquad (16)$$

where: T' – small cycle of landslides activation.

For the conditions of the development of geographically distributed dangerous exogenous geological processes should be taken into account the density of the building on the landslide territories K_{pol} and population density within the territorial estimation.

When calculating the individual risk of landslide processes activisation on built-up flooded territories it is necessary to consider to consider differentiated approach of building density landslide areas K_{pol} in the areas. Its value is offered to be taken by the formula:

$$K_{pol} = \frac{S_{a.f.}}{S_{t.a.}}, \quad (17)$$

where: $S_{a.f.}$ – the area of flooding in the localities of the oblast, $S_{t.a.}$– total area of the flooding area.

The value of the coefficient K_{pol} built in Table 3.

Individual life risk from dangerous exogenous processes is calculated by the formula:

$$R_{ind} = d \times K_{sc} \times K_t \times K_{pol} \times K_{SF}/(K_c N),$$

where: d i N – the density of population and the total citizen number in the territory which is considered, K_{SF} - the activation of landslides due to flooding process.

Using the data given in Table 3, were calculated the rates of increase in the flooded areas and landslides in years for those Ukrainian areas, where landslide process is most active (Table 4). Based on these calculations,

Table 3. The value of the coefficient K_{pol}

№	Administrative area	The value of the coefficient $К_{заб}$
1	Vinnytsia	0,1
2	Volyn	0,012
3	Dnipropetrovsk	0,013
4	Donetsk	0,04
5	Zaporizhia	0,22
6	Kirovohrad	0,0065
7	Luhansk	0,61
8	Mykolaiv	0,03
9	Rivne	0,018
10	Khmelnytskyi	0,96
11	Chernihiv	0,005
12	Ukraine	0,014

Table 4. The rates of increase flood areas and landslides

Administrative area	Odessa	Mykolaiv	Zakarpattia	Ukraine
Increasing the area of flooding, attitude indicators 1997. indicators in 1982, times	9,89	17,56	3	13,6
Increasing the number of landslides, attitude indicators 1997. indicators in 1982, times	5,5	1,39	1,25	1,58
Increasing the area of flooding, attitude indicators 2006. indicators in 1997, times	1,46	1,38	1	1,01
Increasing the number of landslides, attitude indicators 2006. indicators in 1997, times	1,14	1,17	1,8	1,32
Increasing the area of flooding, attitude indicators 2013. indicators in 2006, times	1,04	0,96	1,0	0,6
Increasing the number of landslides, attitude indicators 2013. indicators in 2006, times	1,0	0,99	1,14	0,99
Increasing the area of flooding, attitude indicators 2013. indicators in 1982, times	15,0	23,33	3,0	8,26
Increasing the number of landslides, attitude indicators 2013. indicators in 1982, times	6,22	1,62	2,56	2,1

it is possible to deduce dependence between an increase of landslips quantity and an increase of the flooding area through coefficient $K_{ΠA}$. The coefficient of landslips activization of due to flooding process K_{SF} is determined separately for each area.

CONCLUSIONS

Progressive development of the flooding process on the Ukraine territory leads to a further study of the causes of its occurrence, as well as the impact of this process on the quality of the major life-supporting resources in order to increase the level of environmental safety.

The analysis of existing methods of calculating filtration stages of flooded territories indicates the need for further and more detailed study of this process.

A method of filtrational resistance used for calculation of filtering on flooded territories in detail studied for closed drains and narrow channels, whereas for broad channels this method amounts to a simplified formula. According to the calculations on these formulas with increasing the width of the channel increases the filtration resistance, and thus the value calculated levels of groundwater will fall.

In the case of $k_2/k_1 \leq 1$ the simplify of aquifer structure to the homogeneous leads for inflating the values of filtration resistance which is undesirable, because when calculating the level groundwater it will lead to underestimated values of them; in the case of $k_2/k_1 \rangle 1$ the simplify of the aquifer structure to homogeneous leads the understatement of the value of the filtration resistance and in such cases groundwater levels are calculated with some margin.

A preliminary analysis showed that taking into account the magnitude of the filtration resistance for coastal areas flooded by water reservoir requires further studies under different hydrogeological conditions and different modes of filtration.

The process of regional flooding in its turn is one of the leading factors boosting landsliding processes on the territory of Ukraine. Analysis of annual monitoring data of flooded territories and activating of landslides on the administrative areas allowed to enter an additional factor, which takes into account the increased risk of landslides caused by raising the groundwater level in built-up areas.

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РАЗВИТИЕ ПРОЦЕССОВ ПОДТОПЛЕНИЯ НА ТЕРРИТОРИИ УКРАИНЫ; ОЦЕНКА ЕГО ПАРАМЕТРОВ И ВЛИЯНИЯ НА УРОВЕНЬ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ

Аннотация. Рассмотрено современное состояние развития процесса подтопления на территории Украины; приведены стадии фильтрации в процессе подтопления и методы их расчета. Проанализирован метод фильтрационных сопротивлений при расчете фильтрации в процессе подтопления. Показана зависимость развития процесса подтопления и оползневых процессов на территории Украины.

Ключевые слова: экологическая безопасность, процесс подтопления, уровень грунтовых вод, метод фильтрационных сопротивлений, оползневые процессы.

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