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Flood risk management of Urban Territories

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ABSTRACT

The current paces of the city development is irreversibly changing environment. Additional groundwater replenishment of the urban areas is in the several times higher than the natural rainfall infiltration to groundwater. It leads to groundwater level increasing and flooding of the urban territories due to technogenic factors. For simulating the groundwater level changes in Kharkiv it has been developed mathematical model that takes into account the essential balance components, such as groundwater replenishment by atmospheric waters, additional groundwater replenishment, evapotranspiration and water extraction from underground waters. Paper treats the manage techniques of flooding prevention on the basis of world experience. Aim is to increase the environmental safety of urban territories subjected flooding process due to the flooding management on the mathematical modeling base. Foci are on flooding prevention project, the authority's functions and the tasks of flooding effects preventing and actions algorithm during monitoring of groundwater level on flooded and potentially flooded urban territories. Proposed measures might be integrated into decision-making process of flooding prevention.

Key words : *Environmental safety, Additional groundwater replenishment, Flooding prevention, Flood risk management, Groundwater level monitoring.*

Problem statement

In urban areas, environmentally hazardous groundwater level rise is very intense due to various factors of anthropogenic origin. If this process is intense, it leads to complex changes in the environment and can create conditions for flooding - emergencies of natural and technogenic origin (Sierikova and Strelnikova, 2019). Flooding causes the underground communications materials destruction, pollution the entire underground space of cities, in particular the upper groundwater horizons, the emergence of swampy areas and the flooding of underground spaces in residential buildings. Such processes provoke the mosquitoes appearance, the fungi development, poisonous vapors in the air, which adversely affects to the health of the population and leads to significant material damage. Ensuring the ecological safety of flooded urban areas by preventing the progress and elimination of the negative effects of this process is the important task for its sustainable development. It is important to note that the area of flooding within the territory of Ukraine amounted about 79,44 thousand km^2 (7,9 million hectares) in 2011-2014, and the number of flooded settlements amounted about 4702. Already in 2017 the flooding area is 89,062 thousand km^2 (8, 9 million hectares), and the number of flooded settlements is 4747. This list starts with the big cities of Ukraine (Sierikova and Strelnikova, 2019).

To date, the tasks of the comprehensive assessment of the technogenic impact of large cities on the groundwater level and the technics development for managing the urban territories groundwater level remain relevant.

Analysis of the recent researches and publications

The general concept basics of anthropogenic impact on the underground hydrosphere of built-up areas and methods of flood control have been presented at the works of Ksenofontov *et al.,* (2017); Yashchenko and Alhatter, (2016); and Yakovlev *et al.,* (2018).

Yashchenko and Alhatter (2017), Sologaev and Parfentyev (2016) have presented in the research the forecasting, monitoring and calculation techniques of groundwater level changes.

Well-known scientists and specialists, including Yakovlev *et al.,* 2018; Serikova and Yakovlev, (2011); Chebanov and Zadniprovska, (2011) have treated the groundwater level dynamics and the flooding process development of urban and industrial territories.

Flood and groundwater management, surface runoff management have been elucidated in the papers of Jha *et al.,* (2012); Bob *et al.,* (2016); Jiang *et al.* (2018).

It is necessary to improve the theoretical and methodological bases for managing the groundwater level of urban areas in order to reduce the risk of its flooding based on the world experience in dealing with this environmentally dangerous phenomenon.

Purpose is to increase the environmental safety level of urban areas prone to groundwater flooding

Aim and tasks

Aim is to increase the environmental safety of urban territories subjected flooding process due to the flooding management on the mathematical modeling base.

For achieving the aim, the following tasks have been put forward:

1. To simulate the mathematical model of groundwater level changes in the forward and reverse issue to take into account the impact of artificial soil surface coverings and evapotranspiration.
2. To predict the maximum high of groundwater level for the built-up territories due to the developed model.
3. To substantiate the methodology of groundwater level management and flooding prevention for urban territories environmental safety improving.

Materials and methods of modeling and forecasting

For simulating the groundwater level changes in Kharkiv, the typical part of the territory, partially covered with artificial surfaces on the soil, has been considered in the paper. There are influences of natural and technogenic factors occur only on the free surface of this territory.

Developed mathematical model (Serikova *et al.,* 2015; Sierikova, 2019) takes into account the essential balance components, such as groundwater replenishment by atmospheric waters, additional groundwater replenishment, evapotranspiration and water extraction from underground waters. Boundary conditions characterized the areas without infiltration process, additional replenishment, evapotranspiration, and the areas with these processes have been described in the paper. Taking into account additional groundwater replenishment, evapotranspiration, water extraction, the symmetric model has been considered. The mathematical model has been described by the boundary value problem for the differential filtration equation.

The stationary filtration equation has the follow form:

$$\frac{\partial^2 h}{\partial x^2} + \gamma^2 \frac{\partial^2 h}{\partial y^2} = 0, \qquad .. (1)$$

where $h(x,y)$ – groundwater level, ã is an anisotropy coefficient, characterized the environmental properties difference in different directions.

Scheme of calculated area is shown on Fig. 1.

Solution of equation (1) requires the boundary conditions definition. Since changes of groundwater levels and their distribution are local and simulation is carried out for limited urban territory areas (industrial objects, buildings, etc.), with homogeneous

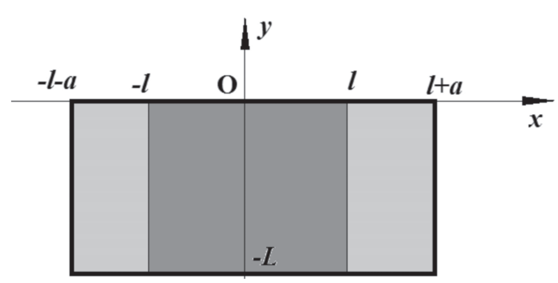

Fig. 1. Scheme of calculated area.

hydrogeological conditions, it could be assumed that the lateral inflow and outflow are equal, so

$$\begin{cases} \left.\dfrac{\partial h}{\partial x}\right|_{x=l+a} = e_1(y) \\ \left.\dfrac{\partial h}{\partial x}\right|_{x=-l-a} = e_1(y) \end{cases}, \quad e_1(y) = \frac{2}{1+(y/y_{50})^{\tau}}, \quad ..(2)$$

where $x = 0$ is the ground surface, τ is for relative variability of potential transpiration; y_{50} is a parameter characterizing the height of water capillary absorption; y be depth where the suction pressure of moisture occurs. Hereinafter τ =2,2; y_{50} =3 according to [15].

The starting level is taken as a reference point, $h=0$

$$\left. h\right|_{y=0} = 0, \quad .. (3)$$

We accept that on [$-l$, l] (Fig. 1.) there are no water extraction, evapotranspiration and groundwater replenishment by atmospheric waters through the artificial surfaces. There is only additional groundwater replenishment.

$$\left.\frac{\partial h}{\partial y}\right|_{-l \le x \le l} = 0. \quad .. (4)$$

But on the plots [$-l-a$,$-l$] and [l,$l+a$] (Fig.1.) there are water extraction, additional groundwater replenishment, evapotranspiration and groundwater replenishment by atmospheric waters.

$$\left.\frac{\partial h}{\partial y}\right|_{l \le x \le l+a,\, y=0} = f_1 + s_1 - k_1, \quad .. (5)$$

$$\left.\frac{\partial h}{\partial y}\right|_{-l \le x \le -l-a,\, y=0} = f_1 + s_1 - k_1,$$

where f_1 is the additional groundwater replenishment (profitable part of groundwater balance); s_1 is the groundwater replenishment by atmospheric waters (profitable part of groundwater balance); e_1 is for evapotranspiration, depended of groundwater depth (expenditure part of groundwater balance); k_1 is the groundwater extraction (expenditure part of groundwater balance). A similar condition has been put on the plot [$-l-a\div-l$] (Serikova *et al.*, 2015; Sierikova, 2019).

The solution of boundary value problem (1) - (5) consists of the sum of two boundary problems solutions $h = h_1 + h_2$. The formulation of it is given below.

$$\begin{cases} \dfrac{\partial^2 h_1}{\partial x^2} + \gamma^2 \dfrac{\partial^2 h_1}{\partial y^2} = 0 \\ \left. h_1\right|_{y=0} = 0 \\ \left.\dfrac{\partial h_1}{\partial y}\right|_{-l-a \le x \le l+a} = 0 \\ \left.\dfrac{\partial h_1}{\partial x}\right|_{x=\pm(l+a)} = e_1(y) \end{cases} \quad ..(6)$$

$$\begin{cases} \dfrac{\partial^2 h_2}{\partial x^2} + \gamma^2 \dfrac{\partial^2 h_2}{\partial y^2} = 0 \\ \left. h_2\right|_{y=0} = 0 \\ \left.\dfrac{\partial h_2}{\partial y}\right|_{-l \le x \le l} = 0; \\ \left.\dfrac{\partial h_2}{\partial y}\right|_{-l-a \le x < -l} = f_1 + s_1 - k_1 \\ \left.\dfrac{\partial h_2}{\partial y}\right|_{l < x \le l+a} = f_1 + s_1 - k_1 \\ \left.\dfrac{\partial h_2}{\partial x}\right|_{x=\pm(l+a)} = 0 \end{cases} \quad .. (7)$$

The solution of boundary value problem (6) describes the effect on the groundwater level caused by the evapotranspiration, depending on the depth, but without taking into account the influence of atmospheric precipitation and additional groundwater replenishment, while the solution of boundary value problem ((Jha *et al.*, 2012) takes into account the additional groundwater replenishment on separate plots, but does not take into account the evapotranspiration depth changes. Problems (Chebanov and Zadniprovska, 2011; (Jha *et al.*, 2012) are solved by decomposition into Fourier series. A numerical analysis carried out using the Maple package proved that five members of the series are sufficient to ensure the accuracy of the solution $\varepsilon = 10^{-3}$.

The value of the groundwater level changing in the unchanged evapotranspiration conditions, visualized by calculations for the limited areas of Kharkiv city in Fig. 2, where depicted the function $h_2(x,y)$, has been obtained. Also, the value of the groundwater level changing with a variable evapotranspiration has been obtained (Fig. 3).

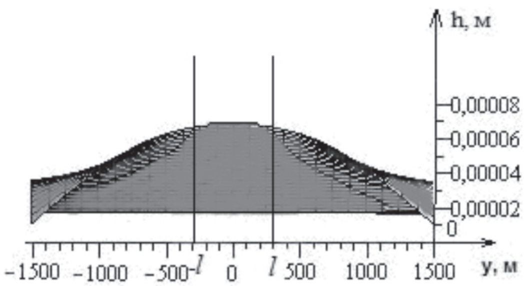

Fig. 2. Average daily groundwater level changing according to model profile, without taking into account the effect of evapotranspiration

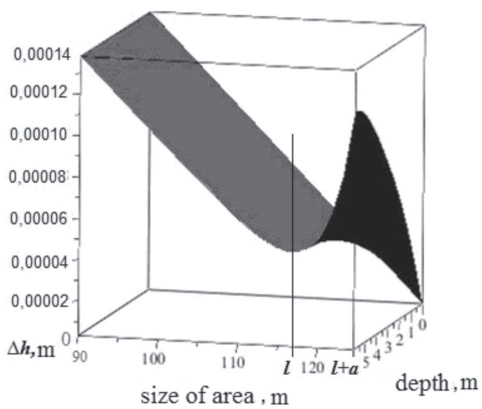

Fig. 3. 3D model. Average daily groundwater level changing according to evapotranspiration effect

Discussion

The prediction of maximum groundwater level altitude (Fig. 2.) for the Kharkiv city, without taking into account the evapotranspiration effect on the 50 years perspective, indicates that for the 1st year the level rise will be 0.03 m, and for the 50th year near 1.5 m (Serikova *et al.*, 2015).

Also, the forecast of groundwater level changing included evapotranspiration effect (Fig. 3) for the 50 years future has been provided in the paper. Under artificial covers for the 1st year, there will be 0.05 m of the level rising, and for the 50th year it will be 2.56 m. On the territory, free of artificial covers, groundwater level will be stabilized by the evapotranspiration action. Thus, the proliferation of artificial surfaces in the city will contribute reducing the evapotranspiration effect and groundwater level sustained increase and flood development (Serikova, 2015).

Materials and methods of management

There is the appropriate combination of structural, preventive and operational measures for flooding prevention and mitigation in Ukrainian settlements. Building standards and legislation must regulate proper land use, economic activity in floodplains, planning of the protective structures, flooding mitigation, early warning systems, risk assessment and preparedness of the population, how to deal with flooding. In some cases, even population relocation from flooded areas may be appropriate.

Development of proactive strategies to protect against flooding should include the technical capabilities and environment assessment, the social factors and financial assessment of corresponding techniques, considering the river basin integrated in the long-term forecast for 50 or 100 years. There is a need for interdisciplinary cooperation at all state and local levels to coordinate environmental protection policy, land use, agriculture, transport and city development planning, to coordinate risk assessment. Therefore, a complex approach is needed in scale river basin. Complex approach facilitates better understanding of the physics of the processes and supports better decision making. Effective cooperation between public authorities, environmental organizations, enterprises of water regulation and other concerned parties is possible by creating local Water Commission. This is more than is necessary for regional coordination and implementation of a holistic approach.

Paradigm shift

- One must shift from defensive action against groundwater level increasing hazards to management of the flood risk.
- Flooding Strategy Implementation should be coordinated at the local - regional - national - international levels within the river basin.
- Priority should be given to integrated measures of water sources management for the whole catchment area, not on the management of flooding as such.
- Forecasting the groundwater level changing and flooding development could be effective in combination with other preventive measures. The traditional and the new technologies should coexist in an efficient manner and be used for mutual data verification and comparison, for more effective and accurate forecast.

- Usage of historical information and experience, retrospective analysis to the maximum potential of accurate predictions.
- A timely and reliable flood warning and forecasting system, depending upon consistent hydro-meteorological basins rather than on sectors, is one of the basic conditions for an improvement of the protection against flooding. This means that it is necessary to agree the technical procedures for hydrological and meteorological forecasts, procedure for application, storage and data exchange between neighboring regions and countries.

Based on the analysis of the world and Ukrainian experience of flood control, the variant of system of groundwater level management and flood prevention which takes into account the results of the prediction of groundwater level changing using the developed model highlighted in previous works (Serikova *et al.,* 2015) has been proposed in the paper.

The system provides typical scheme of management authorities functions and tasks of prevention and elimination of the flooding effects (Fig. 1), an algorithm of actions during the groundwater level monitoring on flooded and potentially flooded territories (Fig. 2) and the project of complex measures to prevent flooding, which will facilitate increasing the environmental safety of urban areas prone to flooding (Table 1).

Typical scheme of management authority's functions and tasks of prevention and elimination of the flooding effects provides the clear picture of the value and importance of preventive measures management in the fight against flooding

For the due work of algorithm of actions during the groundwater level monitoring on flooded and potentially flooded territories it has been proposed to consider the built-up area as potentially flooded in all cases where the projected groundwater level may exceed the foundation base during the whole project life of the building.

It has been also proposed to create in the system of cities building and development its own well network. Wells could be located on sites of new construction. In the context of an annual increase of the construction sites number, it is more realistic than restoring the collapsed observation wells networks in cities. The regime network should allow monitoring the influence of drainage systems, underground structures, communications (including water-bearing systems) on the groundwater regime.

The proposed measures are advisable to integrate into the planning and decision-making process of the development of Strategic Environmental Assessment to assess the risks of flooding and the effectiveness of measures to fight with them.

Project of complex measures to prevent flooding, which will facilitate increasing the environmental safety of urban areas prone to flooding by groundwater (Table 1) has been developed taking into account the existing conditions for the measures implementation in major cities, as well as the European experience of flood control (Serikova *et al.,* 2015).

Developed measures to prevent the flooding of big cities provide the improvement of environmental, economic and social character, such as:

- rational use of water resources through justification and reduction of water consumption standards;
- improving the reliability of the water supply and sewerage system, rainwater drainage systems, their development;
- controlled water abstraction;
- how to use the pumped groundwater;
- preventing negative effects on the environment from the flooding process;
- preventing the development of flooding, mitigating the effects of flooding on the environment;
- prediction of groundwater level changes by mathematical modeling and application of preventive measures at the planning stage of construction activity;
- control over the construction development;
- creating the transparent database on the state of flooded urban area etc.

Conclusion

For simulating the groundwater level changes in Kharkiv it has been developed mathematical model that takes into account the essential balance components, such as groundwater replenishment by atmospheric waters, additional groundwater replenishment, evapotranspiration and water extraction from underground waters. It has been developed the system of groundwater level management and flood prevention on the mathematical modeling base to increase the environmental safety of urban territories subjected flooding process.

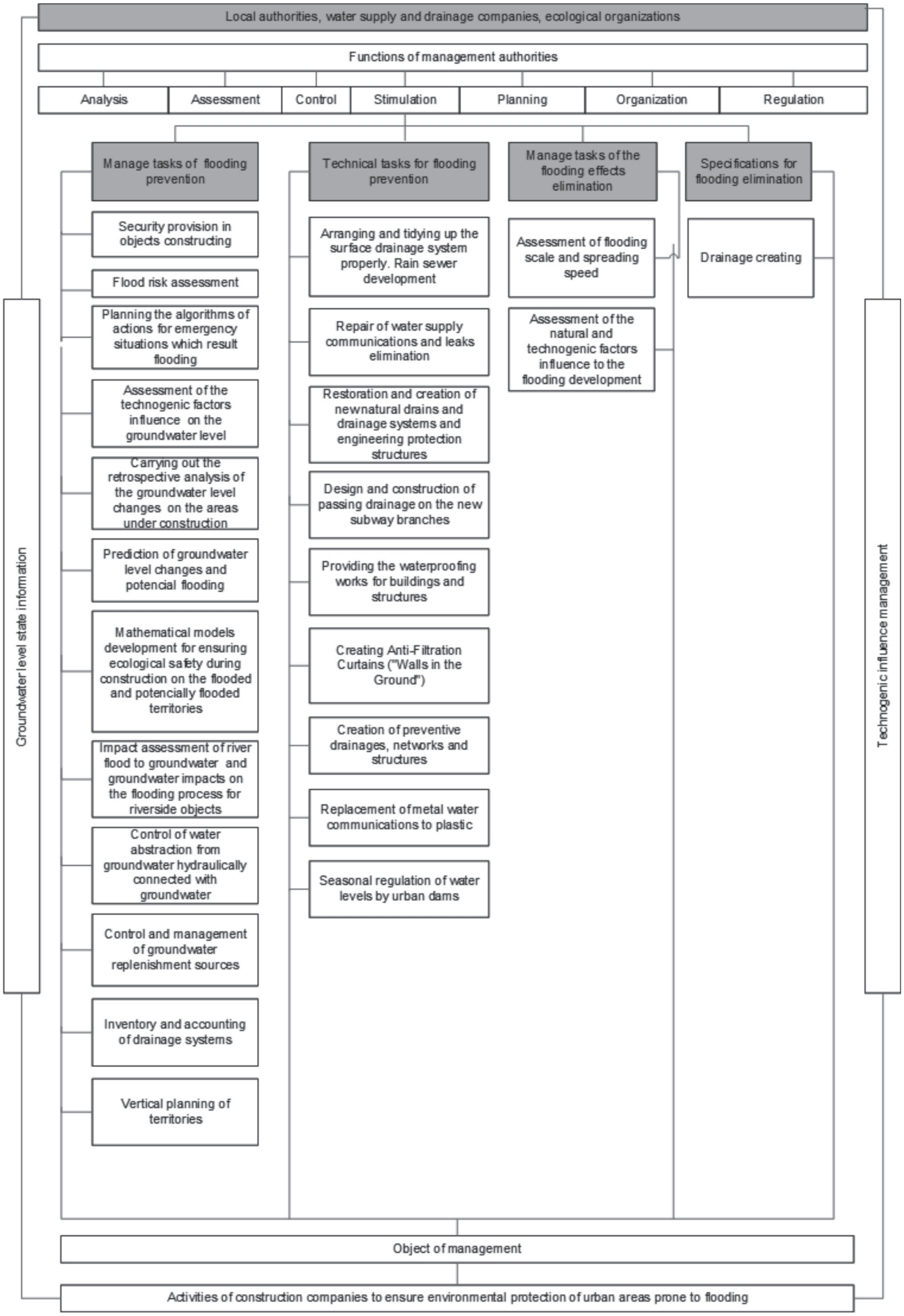

Fig. 1. Typical scheme of management authorities functions and tasks of prevention and elimination of the flooding effects.

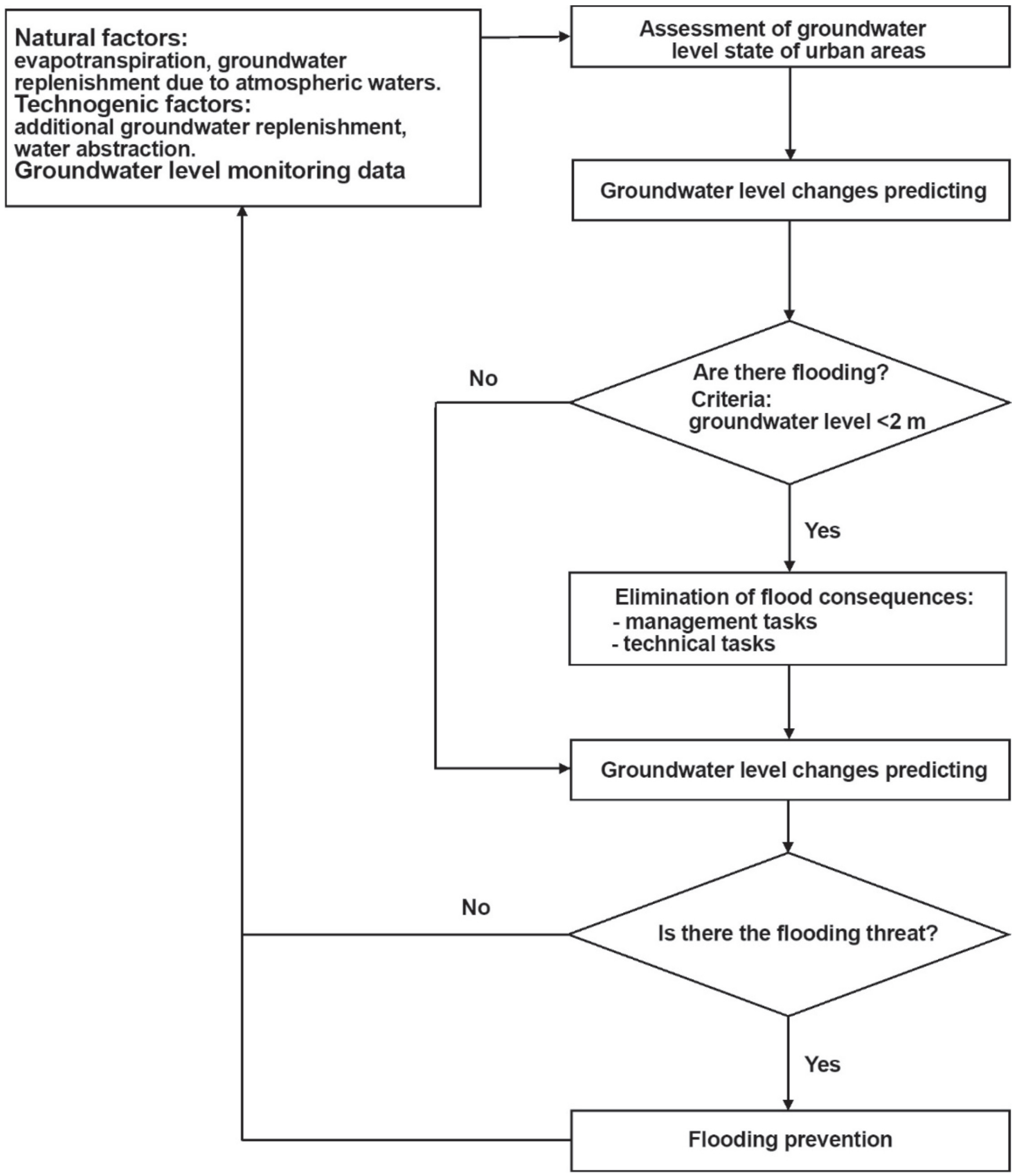

Fig. 2. Algorithm of actions during the groundwater level monitoring on flooded and potentially flooded territories. Boundary depth of groundwater level for territories, for example, cities of Ukraine according to State building codes V.1.1-25:2009 [13] is not less than 2,0 m and not less than 0,5 m from the base of the structures foundations.

Proposed typical scheme of management authority's functions and tasks of prevention and elimination of the flooding effects highlights the importance, value and complexity of managing prevention measures in the fight against flooding.

Unlike the existing ones, the proposed algorithm allows to take into account not only flooded territories but also territories with flooding risk, which significantly increases the possibility of ecological safety level improving of territories and objects from the natural and technogenic emergencies occurrence.

Proposed project of complex measures refers to the urban flooding prevention techniques and it is a multi-component system of measures and guidelines, involving the possibility and expediency of

Table 1. Project of complex measures to prevent flooding, which will facilitate increasing the environmental safety of urban areas prone to flooding by groundwater

Stakeholders	Flood prevention measures	Flood prevention tasks	The tasks purpose	Priority and timing	Sources of financing
Water supply and drainage companies	Engineering meassures	Surface drainage system arrangement and maintenance, rain sewage system development (Support of natural surface runoff within the catchment area)	To prevent surface runoff and local flooding	Constantly	Local budget, investments
Water supply and drainage companies		Repair of water supply, drainage and heat networks, elimination of leaks (Approximately 60% of the city coming water goes to groundwater)	To optimize groundwater balance parameters within urban areas		
Water supply and drainage companies		Functioning restoration and creation of new natural drains, drainage systems and structures of engineering protection of cities and settlements territories (the inventory carrying out and accounting of drainage systems and structures of engineering protection against flooding; building and reconstruction of existing drainage systems and engineering protection structures; organization of engineering services)	For surface runoff drainage and prevention of GWL increasing		
Construction companies, local authorities, water supply and drainage companies		Design and building of concomitant drainage on the new subway branches.	For flooding prevention		
Local authorities, water supply and drainage companies, ecological organizations	Control and management of groundwater recharge sources	Monitoring of additional and natural groundwater supply sources. The decentralized private sewerage limitation (prohibition of cesspools). Control and prohibition of unauthorized and inappropriate development of construction or economic activity in areas proned to flooding	For flooding prevention	Constantly	Local budget, investments
Local authorities, water supply and drainage companies, ecological organizations	Water abstraction control	Granting the groundwater abstraction licenses for large water users and privileges for enterprises to switch to technical water supply from groundwater. Water abstraction restoration from the marl-chalk horizon by municipal water intakes and use of pumped water for the city needs (roads and sidewalks washing, car washing, rollers filling and plants irrigation, in construction and industrial cooling and heat supply systems, for firefighting and many other areas).	To optimize groundwater balance parameters within urban areas	Constantly	Local budget, investments
Local authorities, water supply and drainage companies	Water consumption rates	Water consumption accounting and regulation. Reduction of drinking and industrial water supply. Revision of water standards with approximation to European standards. For example the water use rate for	To save energy and water resources, for flooding prevention	First and foremost	Local budget

Table 1. *Continued ...*

Stakeholders	Flood prevention measures	Flood prevention tasks	The tasks purpose	Priority and timing	Sources of financing
		Kharkiv is 370 l/day for 1 person, which exceeds the norm in the countries of Western Europe - 129-149 l/day for 1 person [15,16] Increasing the water use culture.			
Construction companies, local authorities, water supply and drainage companies, ecological organizations	Database	Creation of the transparent and publicly accessible database, which will include data from long-term researches on climate conditions, data on water supply volumes, volumes of leaks from underground communications, retrospective data, forecast data of groundwater level changes. Database development of flooded and potentially flooded territories of large cities. Establishment of the local Water Commission to ensure co-operation between public authorities, urban municipal organizations, public environmental organizations and other stakeholders.	For objective analysis and forecasting of GWL changes and flooding development	Constantly	Local budget
Construction companies, local authorities, water supply and drainage companies, ecological organizations	Planning the actions algorithms at emergencies	Planning the algorithms of actions for emergency situations which result flooding Risk assessment of possible emergencies	To reduce the negative effects of possible flooding	First and foremost	Local budget
Construction companies, local authorities, water supply and drainage companies, ecological organizations	Public participation in the flooding problem	Free access to information on flooding risks, measures to prevent and eliminate the effects of flooding, the possibility of using private measures in the fight against flooding, property insurance.	To reduce the negative effects of possible flooding	Constantly	Local budget, investments

public participation in the flooding problem, effective cooperation between public authorities, environmental organizations, water supply and sewerage companies and other stakeholders. The measures proposed in the project should be integrated into the strategic environmental assessment process, planning and effective decision-making process to prevent and fight with flooding in the big cities of Ukraine and world.

References

Bob, M., Rahman, N., Elamin, A. and Taher, S. 2016. Rising Groundwater Levels Problem in Urban Areas: A Case Study from the Central Area of Madinah City. Saudi Arabia. *Arabian Journal for Science and Engineering.* 41(4) : 1461–1472.

Chebanov, O. and Zadniprovska, A. 2011. Zoning groundwater flooding risks in the cities and urban agglomeration areas of Ukraine. Risk in Water Resources Management. *Proc. of Symposium H03 held during IUGG 2011 in Melbourne, Australia,* July 2011, 71-76.

Environment Agency, Management of the London Basin Chalk Aquifer. Status Report 2018 of Environment Agency (2018). 38 p.

Jha, A. K., Bloch, R. and Lamond, J. 2012. Cities and flooding: a guide to integrated urban flood risk management for the 21st century, The World Bank, Washinton DC, 638 p.

Jiang, Y., Zevenbergen, C. and Ma, Y. 2018. Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. *Environmental Science and Policy.* 80: 132–143.

Ksenofontov, B.S., Taranov, R.A., Kozodaev, A.S., Voropaeva, A. A., Vinogradov, M.S. and Senik, E.V. 2017. The Problems of Flooding of Residential Areas: European Experience. *Life Safety.* 1 (193) : 29-36.

Management of the London Basin Chalk Aquifer. Status Report 2015 of Environment Agency (2015). 58 p.

Serikova, E., Strelnikova, E. and Yakovlev, V. 2015. Mathematical Model of Dangerous Changing the Groundwater Level in Ukrainian Industrial Cities. *Journal of Environment Protection and Sustainable Development.* 1(2) : 86–90.

Serikova, E., Strelnikova, E. and Yakovlev, V. 2015. The Programme of Measures to Prevent Flooding on the Built-up Areas on Example of Kharkiv City. *International Journal of Development Research.* 5(12) : 6236–6240.

Serikova, E.N. and Yakovlev, V.V. 2011. Additional infiltration to underground waters of big cities territory (on example Kharkiv region). In: Babaev V.N. (Ed.): *Proc.: Municipal Economy of Cities* !97, Kharkiv, KNAME, 344-348.

Sierikova, E. and Strelnikova, E. 2019. Environmental safety of building development on the kharkiv city flooding areas example. *Noble International Journal of Scientific Research.* 3(8) : 72-78.

Sierikova, O.M. 2019. The groundwater level forecasting and management for increasing the ecological safety of the built up territories of Ukraine: Cand. tech. Sciences thesis, 21.06.01 – environmental safety. O.M. Beketov National University of Urban Economy in Kharkiv, 166 p.

Sologaev, V.I. and Parfentyev, O.A. 2016. On the monitoring of underflooding of cities and rural settlements on the example of a five-floor brik building. *Bulletin of Om GAU.* ¹2(22) : 127-133.

State building codes V.1.1-25:2009 Engineering protection of areas and structures against flooding and submersion. Kiev. (2010). Minregionstroy of Ukraine. 91 p.

Yakovlev, Ye. O., Shcherbak, O.V. and Dolin, V.V. 2018. Modeling of hydrogeofiltration groundwater field in the influence zone of metallurgical production. *Mineral Resources of Ukraine.* 3 : 19-25.

Yashchenko, K.V. and Alhatter, S. 2016. Groundwater level regulation to protect land from flooding and drainage. *Proc. of the IX All-Russian Conference of Young Scientists. Krasnodar, 24-26 November 2015*, 908-909.