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An integrated method for predicting technogenic flooding in groundwater–dominated catchments in Kherson region

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SUMMARY

Regional flooding caused by disruption of water-energy exchange between the surface and underground hydrosphere has become more frequent in Kherson region. The article analyses changes in the upper zone of regional hydrogeofiltration, engineering-geological and seismo-geophysical changes in the geological environment (GE). The anthropogenic factors and dynamics of the flood process formation and its ecological and anthropogenic impact on the GE are revealed. The quantitative characteristic of infiltration feeding of ground waters as the main eco-geo-information factor depending on natural-technogenic factors of its formation is given. The estimation and forecast of possible increase of a level of underground waters in the region, using GIS-technologies, and also the risk of emergencies in the system of functioning of industrial and agricultural potential of the whole region is shown.

Introduction

Kherson region is located in the zone of regional drainage of ground and surface waters by the Black Sea and the Dnipro River. Active development, in recent decades, of water irrigation (up to 25% of the area), the damming of the Dnipro River as a regional drain (+ 14 meters above sea level), the construction of a large number of ponds (about 200) have led to a backflow of surface and groundwater. Reduction of groundwater depth or groundwater table level has intensified landscape flooding, landslides, surface subsidence, salinization and soil water (wind) erosion. Moreover, over-watering of loess soils has led to the decrease of their seismic strength as foundations, deterioration of seismic stability (up to 2-3 points). Recently, regional flooding of landscapes reduces the protective capacity of the geological environment and accelerates the migration of pollutants into surface and subsurface flows.

It should be noted that a significant proportion of the land has found itself in flooded and potentially flooded areas (Anpilova et al., 2020; Greben et al., 2020; Lukianova et al., 2020; Kaliukh et al., 2015; Trofimchuk, 2002; Trofimchuk and Vasyanin, 2015). According to data for 2015-2020, over 70% of the region's territory and more than 260 towns and settlements with a total area of 12000 km^2 were flooded, which is more than 20 times more than in 1982. As the regional environmental monitoring data show, the annual increase of flooded areas is 500 km^2. It is important to note that geological hydrogeological conditions in the territory of Kherson oblast have a complex and diverse lithological composition, filtration parameters, hydrochemical indicators and have not been sufficiently studied during the design and development of the Kakhovka reservoir, North Crimean canal, modern irrigation systems and water management facilities, which led to the current dynamics of regional flooding of the territory. A combination of natural and anthropogenic factors, the main ones being poor natural drainage, changing climatic conditions (warming, shortening time of soil freezing, uneven precipitations etc.), creation of various technogenic water bodies, losses from engineering networks, lack of effective drainage systems, numerous irrigation structures and unobstructed irrigation conditions, have resulted in further flooding of the area at present. The complicated hydrogeological melioration situation in the given territory requires conducting forecasting assessments of groundwater system changes and developing a set of measures to protect lands and built-up areas from this negative phenomenon.

Method and Theory

The approach to flood forecasting is prediction, which is based on an analysis of the long-term monitoring of precisely the rate of groundwater level rise which is influencing on the soil and landscape spectral parameters. The authors used monitoring data from numerous original sources, including the regional remote long term materials. Since the irrigation sites are mostly located on terraces and alluvial and denudation plains, the average values for the rate of groundwater level rise are about 0.25-0.3 m per year based on the analysis of the data on them. A more detailed analysis of groundwater level rise data shows that within the study area, the groundwater level rise rate is 0.3-1.0 m per year. In the Kakhovka irrigation system the groundwater level rise rate is approximately 0.8 m per year (2-3 times more than regional data) and 0.15 m per year in the adjacent areas on average. In areas where groundwater lies in Pliocene sands and limestone and Quaternary sediments are irrigated only in small areas, the average annual rate of increase is about 0.1-0.2 m per year. Thus, the average annual rate of groundwater level increase is 0.1-0.5 m per year on irrigated land and 0.1-0.3 m per year on adjacent areas. On the basis of these data a long-term forecast was made. The authors used a linear extrapolation of the irrigated area and its surroundings, which showed that potential flooding becomes possible as early as 2030.

Examples

For predictive tasks of groundwater level rise the main criterion is the maximum depth of the groundwater level, which depends on the nature of exploitation of the potential flooding area and the natural and man-made factors affecting this process. The ratio should be as follows:

$$[Z - (h + \Delta h)] < NCD \quad (1)$$

Where Z is the land surface mark; h is the known value of the groundwater level at the beginning of the forecast; Δh is the forecasted rise of the groundwater level at the defined period; Normal Critical Depth (NCD) is the groundwater level bedding (Gomilko et al., 1999; Gomilko and Trofimchuk, 2001; Kaliukh et al., 2019; Karpenko et al., 2020; Myrontsov et al., 2020; Myrontsov et al., 2021; Trofymchuk et al., 2014; 2015; 2019; 2021a). The NCD on irrigated land in Kherson region depends on many factors. For the fresh groundwater it is 2.0 m and higher with drainage systems; 2.5 m and higher for low salinity water; 3.0 m and higher for groundwater with increased salinity (dry residue over 3.0 g/l); over 3.0 m for groundwater with different salinity levels and pH > 8, which causes carbonate salinization of sodium; in rice systems the NCD is 1.6-1.7 m.

When critical depths are reached, an effective method of identifying their impact on the activation of hazardous processes is the application of GIS and remote sensing technologies. The authors applied such methods in the analysis and construction of predictive assessments of the impact of flooded Solotvino salt mines (Trofymchuk et al., 2020; Trofymchuk et al., 2021b; Myrontsov, 2020a; 2020b).

The above projections, based on the analysis of the annual rate of groundwater level rise, show that there is a debatable risk of complete inundation in those irrigated areas and adjacent areas where the groundwater level is at a depth of 3.0-5.0 m from the land surface under current conditions. According to the balance estimates of water exchange in irrigated lands, the level rise is formed over time, taking into account the correlation between infiltration groundwater recharge and the water availability factor based on the transition to the Neogene high permeability complex.

The nature and intensity of feeding depends on the position of the groundwater table (aeration or unsaturated zone capacity), we consider two types of feeding: at great depths of the underlying groundwater table and at shallow depths after development of drainage to maintain the groundwater table at an appropriate safe depth from the ground surface. Numerous field observations show that at groundwater table depths(more than 3-4 m) groundwater recharge occurs throughout the year. With increasing depth this value becomes constant.

At the shallow depth of the groundwater table, recharge occurs mainly during irrigation, although part of it occurs after irrigation is completed through water movement into the groundwater surface in the aeration zone. Based on the analysis of numerous data, it can be assumed that the value of infiltration feeding outside the irrigation massifs averages 124 mm/year due to precipitation and losses from water supply and sewerage networks, as well as from irrigation of homestead plots (Figure 1 and Figure 2).

A regional assessment of infiltration feeding shows that irrigation increases feeding by a factor of 1.6-3 and causes a regional rise in groundwater levels to a critical depth.

In addition, flooding of agro-industrial areas and landscapes in arid climatic conditions intensifies waterlogging and soil erosion, which leads to changes in the near-surface spectral parameters. Correlation of groundwater table depth data and changes of near-surface spectral parameters provides an opportunity to verify development of flooded and over-watered areas.

Further inundation of the region's territory can be estimated from the rate of groundwater level rise, which was determined using the analysis of the dynamics of the inundation process over the last 30 years. These assessments made it possible to summarise the magnitude and rate of groundwater level rise depending on the geological hydrogeological conditions of the flooding area.

Figure 1 Catastrophic moisture of subsurface soil layer in rural settlements of the Kherson region, April 2015 (Sources: https://khersontv.com/; https://youtu.be/yMJa5Q91EGA)

Figure 2 Destruction of residential structures due to flooding (Urban-type settlement Nova Maiachka, Kherson region, 2019).

Thus, if the indicated rate of groundwater level rise remains unchanged over the next 15-20 years, the main areas of irrigated land with a groundwater table depth of less than 5.0 m from the ground surface could be flooded.
The above data indicate that a rather critical ecological hydrogeological condition may develop on almost the entire territory of the region, which will lead to disruption of normal life activities in the region, complication of agro-industrial complex, buildings and other facilities of various purposes. In addition, as a result of flooding, the strength of bedrock and the seismic stability of buildings are reduced, their destructive deformation increases, the protection of drinking water sources is impaired due to pollution, and soil fertility is lost.
The above raises the question of protecting these sites through effective and reasonable measures to eliminate their flood zones.
The only effective activity to protect potentially hazardous sites is drainage. Based on the hydrogeological conditions, vertical drainage is more effective on the territory of the region. Vertical drainage is used for protection of Skadovsk city and some settlements of Hola Prystan, Skadovsk, Novotroitske and Henichesk districts, on irrigated massifs, in areas of rice crops and adjacent canal zones.

Conclusions

The analysis of data on vertical drainage operation shows that its use together with horizontal drainage and their stable operation provide the necessary groundwater level reduction. The rate of decline depends mainly on the lithological composition of the aquifer.
In spite of the use of drainage measures to protect these sites, a number of measures had to be developed and implemented to improve the environmental situation in the region as a whole, which should have been large-scale and systematic, as follows:

- Reconstruction of main canal systems sush as main Kakhovka magistrale canal etc.;
- Reconstruction of an irrigation distribution network;
- Optimisation and control of irrigation rates to reduce irrigation water losses to groundwater infiltration, accelerated development of drip irrigation systems;
- Design and implement vertical planning projects to regulate the diversion of surface and domestic wastewater outside built-up areas;
- The use of GIS and RS technologies to identify, analyse and predict the activation of hazards to ensure environmental safety in flooded area management.

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