ECOSYSTEMS: ECOLOGY AND DYNAMIC, 2022, Vol. 6, No. 3, P. 68-86

METHODS FOR STUDY, MAINTENANCE AND PRESERVATION OF ECOSYSTEMS AND THEIR COMPONENTS

UDC 551.574.9

ON THE METHODOLOGY OF MONITORING OF THE LOCAL WATERLOGGING IN THE STEPPE ZONE AGROECOSYSTEMS

© 2022. N.M. Novikova*, N.A. Volkova*, O.G. Nazarenko**

**Water Problems Institute of the Russian Academy of Sciences*
Russia, 119333, Moscow, Gubkina Str. 3. E-mail: nmnovikova@gmail.com
***State Center of Agrochemical Service "Rostovsky"*
Russia, 346493, Rostov Region, Aksaysky District, Rassvet Village. E-mail: nazarenkoo@mail.ru

Received April 22, 2022. Revised August 30, 2022. Accepted September 01, 2022.

The local waterlogging in the south steppes of the European part of Russia is caused by the natural (climate fluctuation) and anthropogenic (total plowing) factors. The sizes of the transformed plots ("mochar", i.e. pools) are unstable and relatively small (up to tens of thousands of square meters), but their total area in the field crops can be up to 15%, which causes undesirable changes in agroecosystems, such as crop loss and weeds distribution. A long-term study of mochar and the data on the reliability of a close relations between periods of exceeding values of the average annual precipitation, increasing area and intensity the nidus of local waterlogging, and distribution of hydro-halophilic plants (*Phragmites australis, Elytrigia repens, Tripolium aster*) according to the salinity level and soil moisture reserves, allowed us to develop a system of indicators and criteria for the methodology on the monitoring of the development of this phenomenon in a specific territory.

We suggest an algorithm, which includes identification of the areas, subject to local waterlogging, and study and evaluation of the natural complexes transformation within each area. The impact assessment is based on a system of biological and ecological criteria that indicate the hydrogenic transformation of the environment and the biota of agroecosystems such as groundwater, soil and vegetation. Combined, they make it possible to assess the degree and depth of the changes, to give recommendations for reducing or even ceasing the negative waterlogging processes, while forecasting the climatic trends. The novelty of this study is the aforementioned system of indicators and criteria, and the algorithm of monitoring based on our methodology.

Keywords: nidus of local waterlogging, indicators, plant species, soil subtypes, criteria, salinization, moisture reserves, water regime, hydro-halophilic vegetation, Rostov Region.

DOI: 10.24412/2542-2006-2022-3-68-86

EDN: HSZJZB

A moisture shortage during certain seasons, determined by the climate, is common for the natural regime of ecosystems in the forest-steppe and steppe zones, usually occuring in the summer or spring-summer. This is the reason for the groundwater level on the plains of said zones to reach down to 3-6 m only, without any participation in the soil-forming processes. Since the middle of the XX century and in the early XXI century, precipitation and winter temperatures have increased in the forest-steppe and steppe zones of Russia, which indicates the development of humid warming trend, a result of global climate warming (Kuzmina, 2007).

Due to the large-scale plowing preformed on the watersheds, the replacement of natural ecosystems with agrocenoses, agricultural practices that aim at storing soil moisture, climate change and ecological destabilization of these natural zones contributed to an increase in moisture supply and changed the water regime of automorphic and hydromorphic landscapes. Many regions of Russia are dealing with flooding and soils salinization due to the rising level of groundwater in some areas. This problem is very relevant, since it reduces the efficiency of agricultural activities in the fields of automorphic landscapes with fertile chernozem soils, due to waterlogging of soils, followed by salinization and bogging, and also due to the refugia of quarantine weeds and ruderal species forming in agrocenoses.

The phenomenon of hydrogenous transformation of the structure, functions and composition of agroecosystems is known as «neohydromorphism» (Novikova, Nazarenko, 2007). It is common for the European and Asian parts of Russia. During the continuous studies that have been carried out in the forest-steppe and steppe zones since the middle of the XX century, a lot of data have been accumulated on the conditions and causes that lead to formation of niduses of local waterlogging, causing an impact on the components of ecosystems. They are covered well in scientific publications, including information on the structural and functional organization, cause-and-effect relationships of the components of hydromorphic ecosystems, and their impact on adjacent agrocenoses (Volkova, Nazarenko, 2005; Elizarov et al., 2020; Zaidelman et al., 2012; Kravtsov, 2009; Nazarenko, 2002; Novikova, Nazarenko, 2007; Khitrov, 2002; Khitrov, Nazarenko, 2012; Khitrov et al., 2013; Cheverdin et al., 2019).

Monitoring is the main method to control the state of the environment. Its general schemes and scientific foundations were laid by academician I.P. Gerasimov (1985), who believed that geosystemic or natural-economic monitoring should follow and complement bioecological monitoring that controls the health of the population. One of the important tasks of geosystem monitoring is to control and track the environmental resources used in agriculture. In our opinion, the monitoring of the modern hydromorphism development is of an ecosystem kind. It is quite specific due to the fact that it is used to control the development of the local processes and phenomena, while observational data make it possible to solve regional tasks concerning nature protection.

We present the development of a methodology for neohydromorphism monitoring carried out in the peculiar landscapes of the southeastern spurs of the Donetsk Ridge (Fig. 1) in the Rostov Region as an example. This methodology aims to identify the niduses of waterlogging, to track and assess the intensity of manifestation and the area of hydrogenously transformed areas on the basis of qualitative and quantitative indication features of ecosystem components. One of the most necessary parts of monitoring is to develop a correct solution for eliminating or weakening the development of the negative phenomenon and for further forecasting.

The purpose of this article is to highlight the main steps of our methodology and demonstrate its main solutions to assess the disturbances in agroecosystems both for the ecosystem in general and for its individual biotic and abiotic components; as well to identify dynamic trends, predict the further development and give recommendations.

Theoretical Justification of the Methodology

Modern hydromorphism monitoring is based on the study of specific niduses where hydromorphism manifests itself. Thus, it is the main approach of the work when it is carried out according to our methodology. For years the ground-based observations of ecosystem components have been made at the stationary key plots out, with the usage of remote sensing data, in order to justify the methodology theoretically. We used GIS-technology to systemize the data. To develop diagnostic and evaluation indicators of waterlogging in 58 centers of the Oktyabrsky and Kuibyshev Districts of the Rostov Region, we studied ecological relationships between some components, such as «plant species – soil moisture reserves», «plant species – soil salinity». Our work was carried out together with the fellow researchers O.G. Nazarenko from the Don State Agrarian University and N.B. Khitrov from V.V. Dokuchaev Soil Institute.

The relief of the studied area is an elevated, slightly undulating plain. According to the «Landscape Map» that was compiled under the editorship of I.S. Gudilin (1987), the area belongs to the plain subboreal, moderately continental, true steppe, loess accumulative-denudation East

European landscapes of wavy and flat plains, with flattened residual interfluves, strongly, moderately and sometimes weakly dissected river valleys with asymmetric slopes of dry valleys, with depressions composed of loess-like loams on the terrigenous, intrusive and metamorphic rocks, with agricultural lands, with patches of forb-cereal steppes on common chernozems. The main soil-forming rocks of the studied areas are yellow-brown silty-limous heavy loams, red-brown, yellow-brown and green clays, on which the common chernozems have formed.

In addition to ordinary chernozems, foci with semi-hydromorphic and hydromorphic soils are formed in the studied areas. Groundwater in the catchments lies at a depth of 15-25 m . The mineralization of the waters is different, there are both fresh and salt waters. Salinization of waters is chloride-sulfate and sulfate-chloride.

In addition to chernozems, the niduses of semihydromorphic and hydromorphic soils have formed there. The groundwater in the catchment areas reach down to 15-25 meters, with both the fresh and salty types of mineralization. Water salinity is chloride-sulfate and sulfate- chloride.

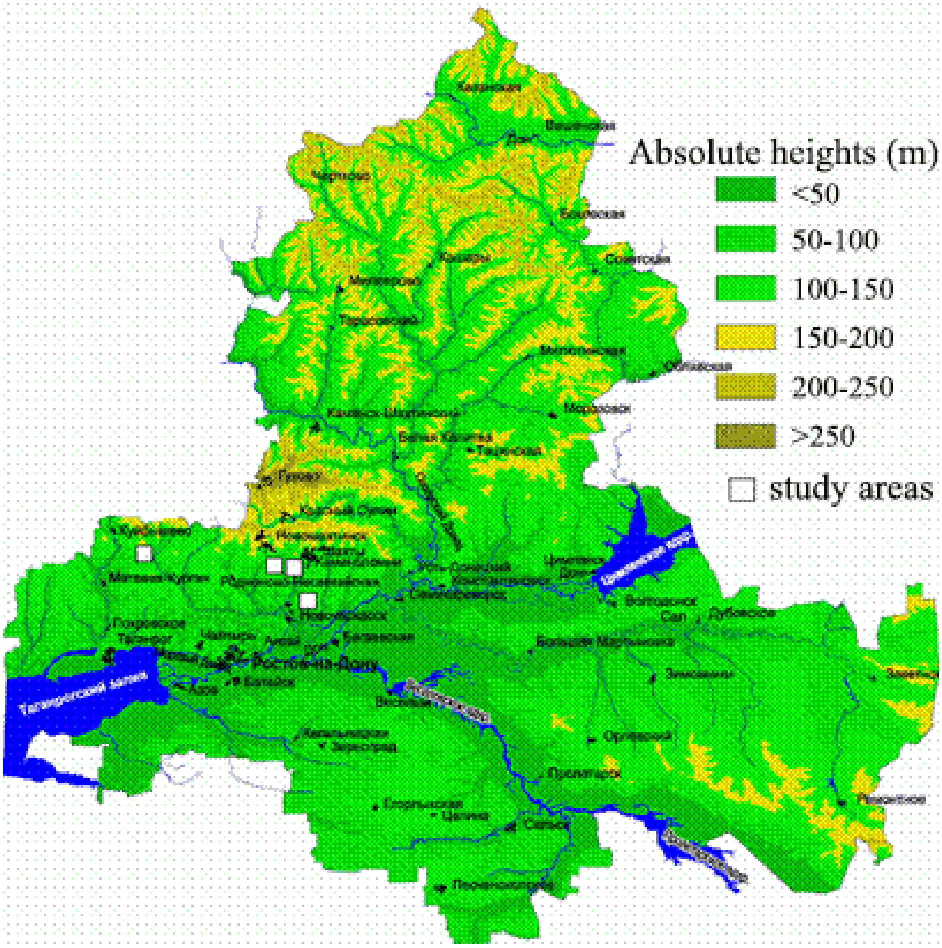

Fig. 1. Studied area in the territory of the Rostov Region (Volkova, Nazarenko, 2005).

The territory is fully developed, with its largest part being the arable land (60%) that is used mainly for grains and oilseeds. Hayfields and pastures occupy 20%; a significant part is covered with fallows (15%). The remaining areas are filled with forest belts and roads.

Our studies showed that the modern hydromorphism of originally automorphic soils develops in the steppe landscapes under certain natural (climatic, geomorphological, hydrogeological) conditions that limit the natural water outflow, as well as under the anthropogenic activities that directly and indirectly change the water flow/inflow, its distribution and migration though the landscapes. After studying the effect of these factors we will be able to understand the formation mechanism of hydromorphic conditions on the plains of the steppe zone.

Natural reasons of neohydromorphism are connected to the natural development of the territory. They include:

- structural features of the soil-ground layer: lithological heterogeneity, and an aquiclude at a depth of 2-3 m;
- geomorphological conditions for the accumulation and redistribution of surface runoff due to geomorphological structures of different levels: modern and ancient mega-, meso-, micro- and nanoreliefs;
- climatic conditions: seasonal, annual, long-term and secular cycle of meteorological indicators, such as precipitation, temperature, evaporation and radiation balance.

The most clearly showing factor is the dependence of waterlogging on atmospheric precipitation. The observations that took place in 1997-2004 on 58 sites of local waterlogging areas in the plains determined that the maximum areas were recorded at probability of precipitation $P \leq 25\%$, while the minimum was recorded at $P \geq 75\%$ (Volkova, Nazarenko, 2005).

The anthropogenic factors of intense human activities contribute to the moisture accumulation in the soil and are as follows:

- land management factors: creation of fields and dirt roads, forest reclamation activities;
- agrotechnical factors: destruction of natural plant communities, application of technologies that transform surface runoff into an internal one, non-adapted structure of sown fields, soil consolidation.

The study of waterlogged areas made it possible to establish that their structure is usually irregularly concentric, which is apparent judging by the change in the dominant plant species. A generalized scheme of the vegetation structure in the waterlogged area is shown in Figure 2. Our studies showed that for every plant contours there are different conditions of moisture regime and salinity. The relationship of species and communities with the waterlogged conditions of soils is rather close, fitting to be used as an indicator when the hydromorphism conditions in the niduses are analyzed.

1. Monocenoses with tall, up to 2-3 m reeds (*Phragmites australis*[1]) are characterized by constant high moisture. The agrotechnical tillage is extremely rare there and usually is not present at all.

2. The communities of couch grass (*Elytrigia repens*) and bluejoint (*Calamagrostis dubia*) are characterized by stable average waterlogging. These areas do not get any cultivation for long periods of time. Often a quarantine ragweed (*Ambrosia artemisiifolia*) dominates these communities.

3. The communities of weeds (*Cirsium arvense*, *Xanthium strumarium*) are characterized by average waterlogging which tends to decrease periodically. These areas undergo the plowing from time to time.

4. The sparse plants of reeds or couch grass that grow at the plowing site of this year (Fig. 2, Profile 4) are characterized by the moisture regime that fluctuates from high to average, depending on the yearly water content.

5. The cultivated plants in the adjacent agrocenoses usually have a low vitality, often with a large number of weeds among them (Fig. 2, Profile 5) due to the fact that these areas have low waterlogging and the high soil moisture prevents them from being cultivated in the usual time. Plowing and sowing take place much later there, which is bad for the normal development of crops.

When studying the moisture reserves in the soil under each plant, it was confirmed that the plants distribution in the waterlogged areas is associated with the water factor. The differences in moisture reserves down to 0-50 cm under different communities in the waterlogging nidus are

[1] Latin species names are given according to the work of S.K. Cherepanov (1995).

weak, but significant the soil thickness is evaluated down to 200 mm. These differences remain throughout the entire growing season. As our studies showed, the periods of moisture reserves in the layer of 0-200 mm during early spring (first number) and late summer (second number), are 1000-800 mm under *Phragmites australi,* 980-820 mm under *Phragmites australis* and *Elytrigia repens*, 940-820 mm under *Elytrigia repens*, 820-650 mm under *Tripolium aster*, 800-600 mm under *Xantium strumarium,* and 740-520 mm under *Cirsium arvense*.

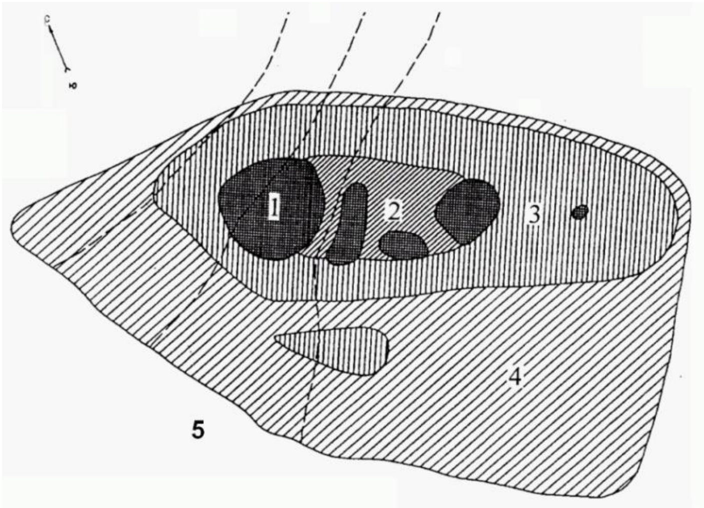

Fig. 2. Generalized scheme of the spatial structure of the waterlogged area. *Legend.* Dominant plant species: 1 – high reed (*Phragmites australis*), 2 – couch grass (*Elytrigia repens*), 3 – weeds on the site that was plowed this year (*Ambrosia artemisiifolia, Cirsium arvense, Xanthium strumarium*), 4 – low reed on the site that was plowed this year, 5 – a site with later sowing.

Groundwater in the studied waterlogged areas contains easily soluble salts, therefore the soils have a secondary salinization with the salts of sulfate, chloride-sulfate, sulfate-chloride calcium-magnesium-sodium composition. Among other things, the communities' distribution depends on the characteristics of the salt composition of soils.

In our methodology the ecological relationships between plant species and soil salinity are formalized through an assessment of the closeness of the said relationships. Based on the theoretical indication (Viktorov et al., 1962), 4 gradations of indicators can be distinguished (Table 1).

Table 1. Quantitative and qualitative indices of indicative value of plant species and communities.

No.	The number when both the indicator and the indicative object were encountered from all description sites, %	Qualitative evaluation of indicative value
1	60-74	questionable indicator
2	75-89	passable indicator
3	> 90	true indicator
4	100	absolute indicator

When we studied the closeness of the relationships between plant species, depth of the saline horizon (saline soils – 0-30 cm, deep solonchak soils – 80-150 cm) and salinity degree (dense salt residue in the highly saline soils – 0.4-0.8%, in the weakly saline soils – 0.1-0.2%) in the chosen areas, we found indicators with different closeness between plants and salinity (Table 2). When the encounters of a certain species under certain conditions exceeded 60%, the species was considered an indicator (Tables 2, 3).

Table 2. Species of herbaceous plants associated with soil salinity (indicative value) at different depths, in %.

Plant species	**Dynamic types of soils**		
	Solonchak highly saline	**Solonchak slightly saline**	**Deep solonchaks slightly saline**
Artemisia austriaca	80		
Tripolium pannonicum	100		
Lappula squarrosa		86	
Puccinellia distans	60		
Thlaspi arvense		86	
Artemisia absinthium	78		
Sinapis arvense			71
Lactuca serriola			88

Table 3. Plants species (%) associated with soil salinity degree (indicative value) in a 1-meter-depth on a key site.

Indicators (plant species)	**Salinity degree**		
	Non-saline common chernozems (EC < 4 dS/m)	**Slightly saline common chernozems (4 < EC < 8 dS/m)**	**Averagely saline common chernozems (8 < EC < 12 dS/m)**
Tripolium pannonicum			82
Coronilla scorpioides	60		
Lactuca tatarica		67	
Senecio vernalis	67		
Cichorium intybus	69		
Euphorbia volhynica	80		
Salvia verticillata	80		
Sonchus arvensis	82		
Atriplex oblongifolia			100

When the data from Tables 2 and 3 was analyzed, we concluded that *Artemisia austriaca* and *Tripolium pannonicum* can be the indicators of highly saline common chernozems (the frequencies of their encounters were 80% and 100%). *Lappula squarrosa* is an indicator of the slightly saline solonchak soils (86%), *Sinapis arvensis* – slightly saline deep solonchak soils (71.4%), *Thlaspi arvense* – slightly saline solonchak soils (86%), *Veronica agrestis* – non-saline (66.7%) and alkaline slightly saline chernozems (67%). *Lactuca serriola* is a satisfactory indicator of slightly saline deep solonchak soils. We found no close relationship between reed and chernozems salinity; only its dominance decreased due to the declining salinity in its growth places.

Indicators of averagely saline common chernozems are communities with dominant *Tripolium pannonicum* (82%) and *Atriplex oblongifolia* (100%). Steppe species such as *Coronilla scorpioides*, *Euphorbia volhynica* and *Salvia verticillata* are the satisfactory indicators of non-saline soils.

Ambrosia artemisifolia, Convolvulus arvensis, Elytrigia repens, Lactuca tatarica, Lappula squarrosa, Melilotus officinalis, *Thesium linifolium* and *Daucus carota* are the species with wide ecological amplitude that were found in every salinity variant with different frequency and abundance.

Hydromorphism characteristics in soils can be used as the indices of the groundwater depth (Table 4). Soil subtypes serve as an indicator.

Summarizing the data obtained during field studies for our methodology, we compiled a table of indicators of hydromorphism degree in the local areas with agrocenoses. The specific quantitative data in Table 5, such as the depth and mineralization of groundwater, nature of water regime in a biotope, signs of hydromorphism in soils and vegetation, were assessed ecologically.

Table 4. Diagnostic features of hydromorphic conditions in the different subtypes of soils (Volkova, Nazarenko, 2005).

Soil type	**Soil subtype**	**Depth of gleization signs in a soil profile showing as bluish tones and ferruginous-manganese concretions**	**Soil-groundwater level, m**
Chernozems	Common chernozem	No bluish tones	Different level
Meadow-chernozem	Slightly meadow-chernozem	2 meters deeper	3-4
	Meadow-chernozem	Lower part of the profile down to 2 m	2-2.5
Meadow	Chernozem-meadow		1.5-2
	Meadow	Under a humus horizon in a 50-80 cm layer	1-1.5

The Main Provisions of the Methodology

The purpose of the methodology. It was developed to standardize the monitoring of the dynamics of terrestrial ecosystems under the changes of such natural factors as the regional background climate and moisture, while using the algorithm of sequential actions. The methodology is aimed at solving the following tasks: 1) identification of the local waterlogged areas, determination of their distribution throughout the region; 2) assessment of the waterlogging degree and water regime using a system of various indicators and criteria.

Field of application. This methodology can be used for the monitoring of the ecological safety and to rationalize the land resources usage.

Sources of information. We used land management plans (scale 1:25000), soil maps of farms (scale 1:10000 and 1:25000), funds materials and official data on the territory of adjacent landscapes that were not affected by any impact. Data collection and accumulation is provided for various components of natural complexes, according to a specially developed algorithm.

The general theoretical platform of our methodology is a study of the structural-functional organization and dynamics of biotic/abiotic ecosystems components, based on the relationships in the «biocenosis indicators – water factor indicators» system.

The methodological approaches and methods used in our work are listed below.

- Materials of remote sensing for detection of waterlogged niduses.
- A methodological approach «key – experience» for comparison and evaluation of the natural complexes transformation. The areas of landscape with no waterlogging are the "key" ones, while the «xperimental» ones are under the influence of waterlogging.
- A methodological approach that considers the waterlogging nidus as a block ecotone system, which is constructed according to the increasing gradient of soil waterlogging. This makes it possible to assess the hydrological impact of waterlogging on agroecosystems, as well as its features through the characteristics of the groundwater depth and quality, soil moisture, waterlogging degree.
- Field works and remote sensing materials for identification of the boundaries of various types of impacts.
- The soil profiles are described, the agricultural productivity of species and communities is taken into account, and the depth of soil-groundwater, plants species composition, projective cover and abundance of species are described. Large-scale (1:1000) mapping of soils should be carried out every 3-4 years; while the mapping of vegetation using the telescopic alidade should be performed every year. The soil sampling to determine the salinization level is carried out for a number of layers: 0-10, 10-30, 30-50, 50-70, and 70-100 cm.
- To obtain the modern data on the state of natural complexes, the methods of field ecological and geographical research are used. They include instrumental topo-ecological profiling, laying out of the transects and plots for soil and geobotanical key studies, description of the composition and vegetation structure, while taking into account aboveground phytomass and identification of the modern hydromorphism indicators. The presence of hydromorphism indicators is registered separately. All topo-ecological points should be tied to the relative elevation marks in the area, and the geoposition should be recorded at the date of the survey.
- The assessment of hydrogenic transformation of natural complexes is based on a set of indicators of the main landscape components, such as vegetation and soils, for which the qualitative and quantitative indicators and environmental criteria for their values were developed. The evaluation criteria are the state and spatial structure of the vegetation in the hydromorphism nidus. It helps to distinguish 3 categories: *high*, *average* and *low* waterlogging degree. The areas with different degrees are used as the additional indicator.
- The methods of mathematical statistics, used to process and analyze the data, reveal the closeness and reliability of the relationship between vegetation and the main factors, i.e. the water factor (soil moisture content) and soil salinity.
- For easy storage and handling the experimental data are compiled into thematic tables in EXCEL. Other programs are used for processing and analysis as well: ECOL, STATISTICA, SPSS, ARCVIEW.
- Salinity of soils and parent rocks is estimated using a brief description of their chi-ion-salt composition (Guidelines ..., 1990). We used an ion meter "Ecotest pH-120", an ion-selective electrode pNa made by "Econix", and an Ag/AgCl electrode "EVL-1M3". We estimated the spatial salts distribution at key plots by measuring the activity of sodium ions in the pastes of many samples. Up to 95% of the roots of most of the species that were found on the plot are located in the 0-50 cm layer, therefore we studied the salinity indicators mainly in the said layer.
- Sampling for soil moisture is carried out at the dynamic sites of the key plots throughout the entire year: one time every two weeks during the warm season, one time per month during the cold season. Samples are taken in three replications from the 10-cm-deep soil layers down to where groundwater starts.

The algorithm of work, according to our methodology, is given here using the specific examples of 58 waterlogging niduses in the steppe zone of the Rostov Region, in the south of the European part of Russia. The algorithm includes several stages that should solve the main tasks of monitoring.

Table 5. Indicators of the local hydromorphism manifestation degree and their ecological significance.

No.	**Indicators**	**Ecological** significance **(criteria)**
1	Flooding, duration and frequency, days	Weak – from 10 to 15 days, non-annual. Average – 16-40 days, annual. High – over 40 days, annual.
2	Groundwater, depth, m	Found in a soil profile – down to 3 m from the surface.
3	Groundwater, flooding, m	High – 0.3-1 m. Average – 1.25 m. Weak – from 2.5 to 5 (6) m.
4	In a soil profile	• Increased depth of a humus horizon (A+AB) of the slightly meadow-chernozem and meadow-chernozem soils below 130 cm, of the wet-meadow soils below 100 cm. • Intense black color of the upper humus layer. • Occurrence of the horizons with developed signs of modern redox reactions that shows as hydroxide membranes of iron (ocherous spots), bluish tones, manganiferrous growths (beans) down to 1 and 2 m, which is a weak manifestation of a meadow process; active meadow process under the humus horizon in a 50-80 cm layer. • Deep gleization that shows as bluish spots, peculiar carbonate profile (lime noduls, washed carbonates down to 100 cm); peculiar saline profile when the water is saline. • For the steppe zone it is the depth of primary and secondary gypsum (pencil gypsum) that indicates the rising level of the capillary fringe of groundwater, and carbonate mold or blurry yellow spots of loess with lime nodules ($CaCO3$). • Loess with lime nodules is a sign of the modern hydromorphism. • Depth of the secondary fine gypsum is an indicator of the level of the capillary fringe or groundwater and the temporary water.
5	In vegetation	Dominance or occurrence of the indicator species • of waterlogging: high – *Phragmites australis*, average – *Elytrigia repens*, weal – *Cirsium arvense*; • of soil salinity; dominance or occurrence with 70-100% confidence: high (sum of the salts is 1-2%) down to 0-30 cm – *Tripolium aster*, *Artemisia austriaca*, *Artemisia absinthium*, *Puccinellia distans*; weak shallow (0.5-0.25%) down to 0-30 cm – *Lappula squarrosa*, *Thlaspi arvense*; weak deep (0.5-0.25%) down to 80-150 cm – *Sinapis arvense*, *Lactuca serriola*.

The first stage reveals the distribution of waterlogging niduses throughout the study area. For that the materials of remote sensing are used with their resolution of 30 m and higher. They clearly show the darker phototone and various geometric outlines of the waterlogged patches on a monotonous background of agrolandscapes (Fig. 3). Remote sensing makes it possible to survey territories of various sizes, from a field to a district or even a region, and to identify the scale of waterlogging.

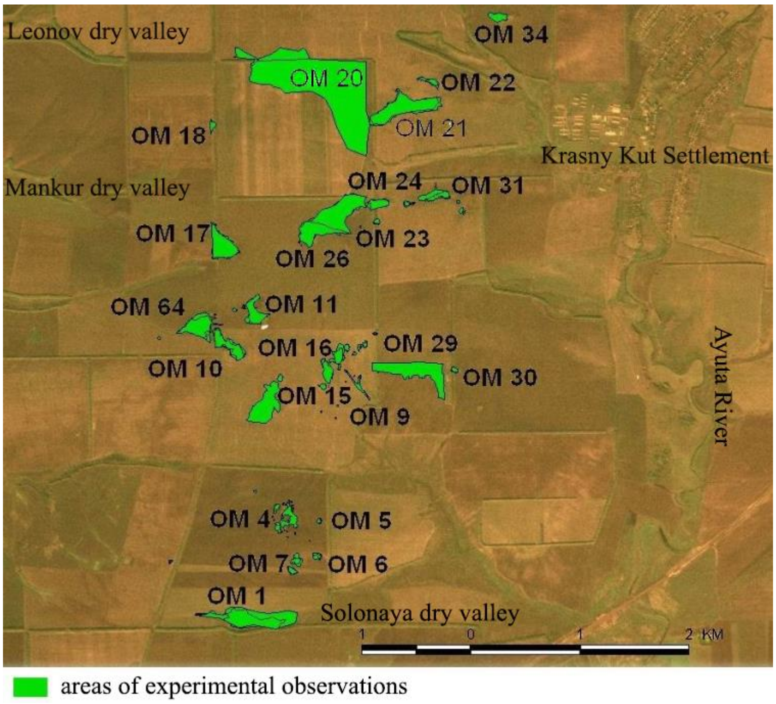

Fig. 3. Waterlogged areas in agrocenoses in the territory of the state farm «Russia», Oktyabrsky District, Rostov Region.

The results are made into maps, showing the share of the waterlogged areas as a percentage of the administrative unit area they were found in (Fig. 4).

The second stage evaluates the waterlogging degree and regime of each nidus. The direct sources of waterlogging are determined. The degree assessment is based on the internal structure of each nidus that was explored during the field studies, with the usage of remote sensing materials. Vegetation is the most obvious indicator of waterlogging, because it characterizes the current environmental state. Soils are a more conservative ecosystems component, and so they characterize the long-term changes, especially the moisture regime.

The waterlogging degree and soils salinity are determined according to the data given in Table 5 for indicator plants based on the internal structure of vegetation in the waterlogging nidus. The yearly ratio of areas occupied by each of the indicator species is also taken into account (Fig. 5). The data is presented in the form of a table (Table 6).

Assessment of the waterlogging regime is based on exploring the depth of soil transformation in the areas of local waterlogging. There are 3 categories of waterlogging: *episodic*, *regularly pulsating* and *permanent* (Nazarenko, 2002). We used the following diagnostic features:

- the *episodic* hydromorphism, which shows up during the extremely wet years, includes niduses that have formed where the groundwater is located down to 3 m, in the absence of any morphological signs of hydromorphism in the soil profile, such as ocherous membranes, salt and gypsum horizons; their internal structure is homogeneous and simple;
- the *regularly pulsating* hydromorphism includes areas with very deep humus horizons (down to 100 cm) and with the signs of hydromorphism in the soil profile. Additionally, the

common chernozem merges into the subtype of slightly meadow-chernozem, meadow-chernozem and even chernozem-meadow soils, with various manifestations of iron oxides, salinity, carbonate content, gypsum content or alluviums, with industrial blocks; their internal structure is complex and usually integral;

- the *permanent* hydromorphism includes areas with originally semi-hydromorphic soils, where the slightly meadow-chernozem soils transformed into meadow-chernozem soils, which can be seen by the increased gleization signs, i.e. bluish tones and ferruginous-manganese concretions or spots in the lower part of the profile; or where the meadow-chernozem soils transform into meadow and wet meadow soils; the internal structure is integral or complex.

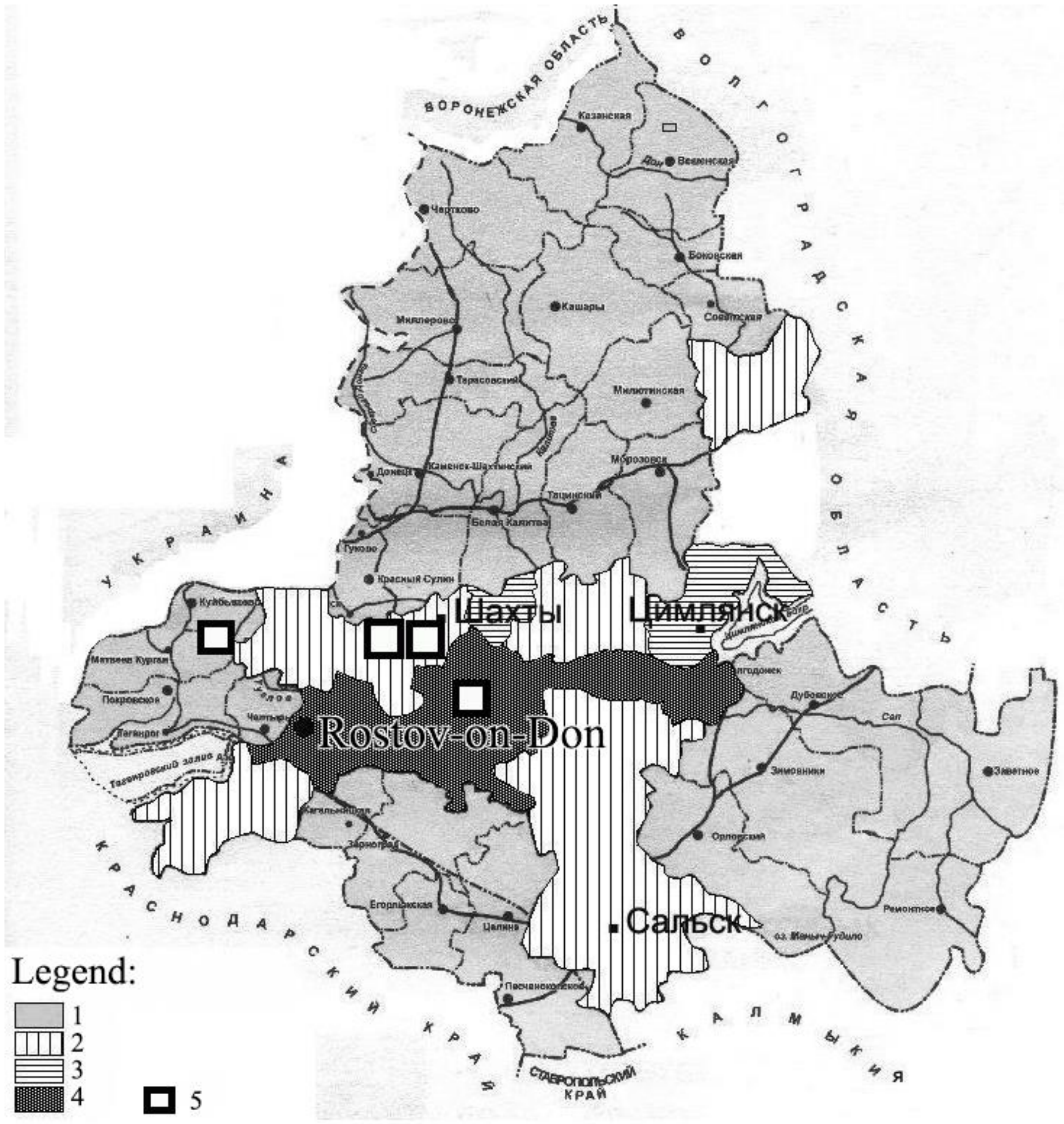

Fig. 4. Schematic map of waterlogged lands of the Rostov Region (Volkova, Nazarenko, 2005). *Legend*. Share of waterlogged areas: 1 – 0 to 5.0%, 2 – 5.1 to 10.0%, 3 – 10.1 to 15.0%, 4 – > 15%, 5 – study areas.

<u>The third stage.</u> A long-term study allowed us to develop a typology of waterlogged areas using the main factors of their formation, such as relief and waterlogging source (Table 7).

Based on Table 7, the specific position in the relief and the source of waterlogging, the areas of modern hydromorphism development in the study territory were classified. In the Photos 1-3 the main types of waterlogging niduses are shown, marked in Figure 3 in accordance with the indicators and criteria from Table 7.

The evaluative indicators of the modern hydromorphism areas are the basis required to monitor the waterlogging in agrolandscapes of the study area. They show that the frequency of remote and field observations should be consistent with the dynamics of atmospheric moisture.

Recommendations for further observations. Since the intensity and sizes of waterlogged areas closely depend on the amount of precipitation and manifest themselves by falling behind by 1.5-1 year, within this methodology we recommend to observe them 0.5-1 year after the sum of average long-term precipitation has exceeded by more than 25%, or after several years (3-4 years) in a row with the long-term average precipitation remaining higher by more than 10%.

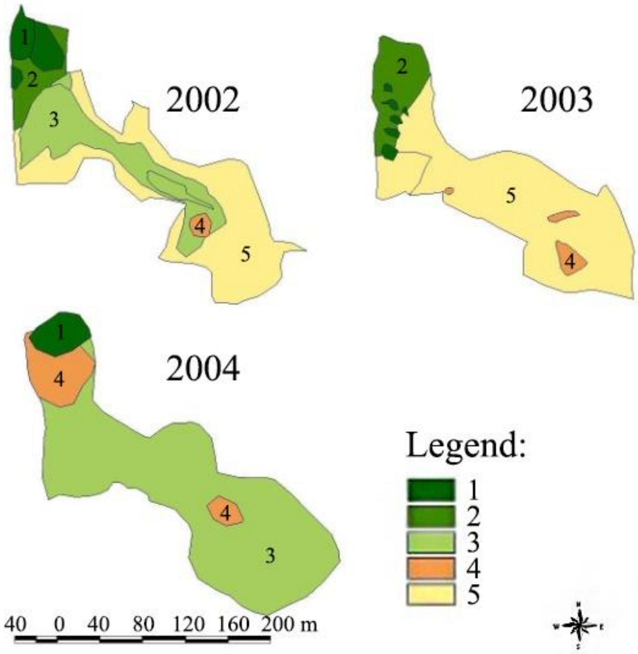

Fig. 5. Changes in the spatial structure of the OM 10 site over the years. *Legend*: 1 – *Phragmites australis, Bolboshoenus maritimus* communities – high waterlogging; 2 – *Elytrigia repens* communities with halophytes – average waterlogging; 3 – *Tripolium aster, Artemisia absinthium, Puccinellia distans* halophyte communities – average waterlogging, saline soils; 4 – reed communities along the sites plowed during this year – high to average waterlogging; 5 – weeds (*Triglochin palustre*, *Rumex* spp.) along the sites plowed during this year, suppressed crops – weak waterlogging.

Suggestions to reduce the waterlogging. After analyzing the existing experience of practical work to reduce local waterlogging, we found out that there are 2 approaches to solving this problem. In the first approach, waterlogging is considered a negative phenomenon; it is a degradation of fertile agricultural lands, and therefore measures are being developed to eliminate its consequences, i.e. its local manifestations, instead of the waterlogging. Usually those are engineering solutions, such as various types of drainage. However, this approach does not solve the problem, but rather creates new ones. For example, various types of land reclamation were proposed in Moldova (Suvak, 1977, 1986); in the Eastern Donbass in the early 1980s, the Don State Agrarian University under the guidance of Professor M.B. Minkina et al. (1991) developed various measures for engineering melioration of waterlogged lands.

Table 6. An example of hydromorphism assessment in the waterlogged areas.

No.	Index of a nidus	Plant and soils indicators	Waterlogging degree	Soil salinity	Waterlogging regime
1	OM 1	1-5*; meadow-chernozems	High – weak	Non-saline – highly saline	Constant
2	OM 2	1; common chernozem	High	Absent	Episodic
3	OM4	1-5; slightly meadow-chernozem	High – weak	Non-saline – highly saline	Regularly pulsating
4	OM7	4, 5; slightly meadow-chernozem	High – average	Non-saline – highly saline	Regularly pulsating
5	OM 10	1-5; slightly meadow and meadow chernozem	High – weak	Non-saline – highly saline	Constant and regularly pulsating

Notes to Table 6: * – vegetation boundaries, as shown in Fig. 2.

Table 7. Types of sites of modern hydromorphism that were selected according to the conditions they had formed under (on the example of the Oktyabrsky and Kuibyshev Districts of the Rostov Region).

Hydration source	Natural complexes of modern hydromorphism				
	on a plain		on a slope near a watershed		
	tops	depressions	amphitheaters	hollows	slopes
Stagnant surface water leaks	–	2*	4	7	–
Waterlogging caused by soil-groundwater	1	3	5	8	10
Mixed hydration	–	–	6	9	11

Notes to Table 7: * – number of a type.

We advise to use biological amelioration methods to change the water balance in the locally waterlogged areas. These methods include the following activities listed below.

1. It is preferable not to plow the areas with the primary signs of hydromorphism, such as the individual reeds, while in their catchment areas it is required to change agrotechnical activities and crop rotation by including grass mixtures in it for a longer period of time.

2. It is desirable to move the borders of the plowed areas over and beyond the periodically waterlogged parts and spring flooding zones around the long-existing waterlogged areas, where all degrees of hydromorphism can be found, in order for the annual weeds to not accumulate in the disturbed areas.

3. It is desirable to plant perennial rhizomatous fodder cereals in the areas with average and weak waterlogging, in order to regulate the species composition of plant communities and remove the annual weeds. In the future those areas can be used for haymaking.

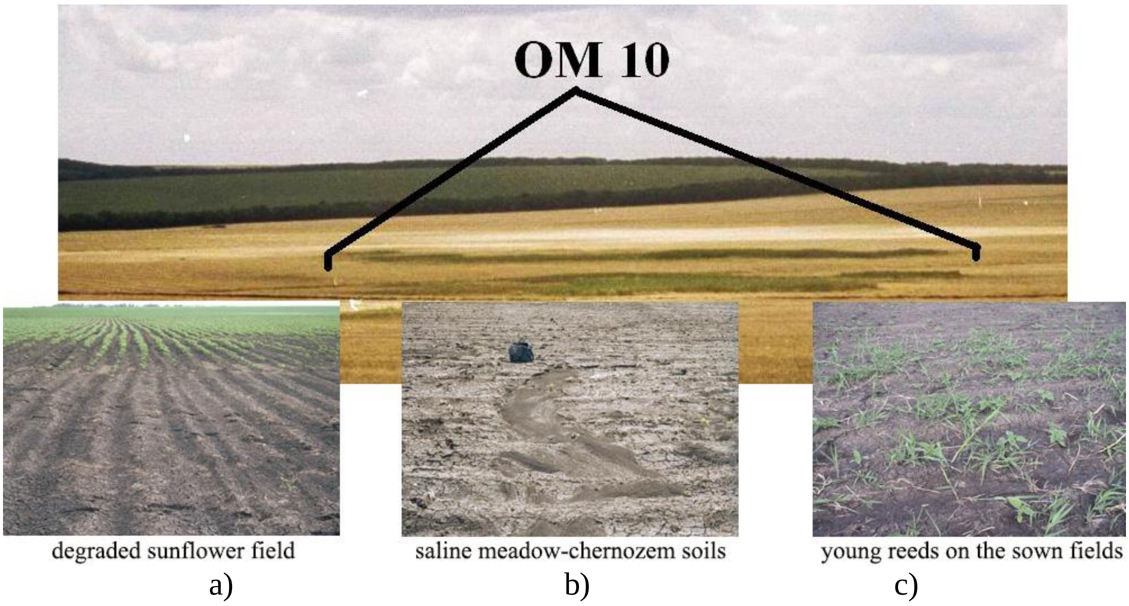

Photo 1. Sites in depressions (Table 7, type 3) with soil-groundwater waterlogging (OM 10 site from Fig. 3; photo by N.A. Volkova). *Legend*: a – absence of vegetation on a site that was plowed this year; b – absence of vegetation, traces of water erosion; c – reeds on this year's plowing site and degrading crops.

Photo 2. Sites in the amphitheaters at the slopes near watersheds with soil-groundwater waterlogging (OM 7 site from Fig. 3, Table 7, type 5) and mixed hydration (OM 4 site from Fig. 3, Table 7, type6; photo by N.A. Volkova).

Photo 3. Sites in the hollows at the slopes near watersheds with stagnant surface water leaks (OM 1 site from Table 7, type 7; photo by N.A. Volkova).

Conclusions

1. The modern local waterlogging is of a natural-anthropogenic character, developing in specific environment that creates preconditions, while the anthropogenic activities lead to their implementation.

The leading factors in the formation of secondary hydromorphic natural complexes are humidification and salinization of chernozems and meadow-chernozem soils.

2. The monitoring the local waterlogging development on the plains with deep groundwater occurrence, is aimed at identifying, determining the causes, the degree of hydromorphism of specific foci and developing recommendations for its weakening or elimination.

Monitoring of the development of local waterlogging on the plakors, with deep groundwater occurrence, is aimed at identifying, determining the causes, the degree of hydromorphism of specific foci and developing recommendations for its weakening or elimination.

3. The monitoring methodology is based on the developed indicators of the manifestation and degree of hydromorphism. Those are the indicators of the state of natural components, such as vegetation (its composition, ecology of plant species and communities), dynamic characteristics of chernozems, groundwater depth, soil-forming and underlying rocks.

4. The algorithm of work within this methodology includes identification and standardization of the waterlogging niduses according to selected indices and criteria, consideration of their internal structure, assessment of the transformation depth of the local waterlogged areas and their regime.

5. The recommendations to decrease the waterlogging area and intensity or completely cease its development are created and based on the assessment that was carried out according to the established indicators, such as the type, internal structure and depth of transformation of natural complexes.

We should also add that this methodology is still geographically limited and can be applied for the steppe zone only. However, its further development is possible due to the studies that will take place in other zones.

Funding. This work was carried out within the theme No. FMWZ-2022-0002 of the State Assignment of the Water Problems Institute of the Russian Academy of Sciences “Study of Geoecological Processes in Hydrological Land Systems, Quality Formation of Surface and Ground Waters, Problems of Water Resources Management and Use under Climate Change and Anthropogenic Impacts”.

REFERENCES

1. Viktorov SV, Vostokova EA, Vyshivkin DD. Introduction to indicator geobotany [*Vvedeniye v indikatsionnuyu geobotaniku*]. Moscow: Publishing House of MGU, 1962:227.
2. Volkova NA, Nazarenko OG. Vegetation of natural-territorial complexes of modern hydromorphism on the southeastern spurs of the Donetsk Ridge [*Rastitel'nost' prirodno-territorial'nykh kompleksov sovremennogo gidromorfizma na yugo-vostochnykh otrogakh Donetskogo kryazha*]. Moscow: RASKHN, 2005:201.
3. Gerasimov IP. Environmental problems in the past, present and future geography of the world [*Ekologicheskiye problemy v proshloy, nastoyashchey i budushchey geografii mira*]. Moscow: Nauka, 1985:247.
4. Elizarov NV, Popov VV, Semendyaev NV. Modern hydromorphism of solonetzes in the forest-steppe zone of Western Siberia [Sovremennyy gidromorfizm solontsov lesostepnoy zony Zapadnoy Sibiri] *Eurasian Soil Science [Pochvovedeniye]*. 2020;12:1451-1459.
5. Zaidelman FR, Ivanov AL, Kashtanov AN. Degradation of rain-fed and irrigated chernozems under the influence of waterlogging and their reclamation [*Degradatsiya bogarnykh i oroshayemykh chernozemov pod vliyaniyem pereuvlazhneniya i ikh melioratsiya*]. Moscow: OOO APR, 2012:212.
6. Kravtsov YuV. Groundwater rise in the Ishim Steppe [Pod″yem gruntovykh vod v Ishimskoy stepi] *Siberian Ecological Journal [Sibirskiy ekologicheskiy zhurnal]*. 2009;2:217-222.
7. Kuzmina ZhV. Analysis of long-term meteorological trends in the south of Russia and Ukraine (from forest-steppe to deserts) [Analiz mnogoletnikh meteorologicheskikh trendov na yuge Rossii i Ukrainy (ot lesostepi do pustyn′)] *Arid Ecosystems*. 2007;13(32):47-61.
8. Landscape map of the USSR, Scale 1:2500000 [*Landshaftnaya karta SSSR*] / ed. I.S. Goodlin. Moscow: GUGK, 1987:1.
9. Minkin MB, Kalinichenko VP, Nazarenko OG. Reclamation of wet soils of Eastern Donbass [*Melioratsiya mocharistykh pochv Vostochnogo Donbassa*]. Moscow: Publishing house of

REFERENCES

1. *Викторов С.В., Востокова Е.А., Вышивкин Д.Д.* 1962. Введение в индикационную геоботанику. М.: Изд-во МГУ. 227 с.
2. *Волкова Н.А., Назаренко О.Г.* 2005. Растительность природно-территориальных комплексов современного гидроморфизма на юго-восточных отрогах Донецкого кряжа. М.: РАСХН. 201 с.
3. *Герасимов И.П.* 1985. Экологические проблемы в прошлой, настоящей и будущей географии мира. М.: Наука. 247 с.
4. *Елизаров Н.В., Попов В.В., Семендяев Н.В.* 2020. Современный гидроморфизм солонцов лесостепной зоны Западной Сибири // Почвоведение. № 12. С. 1451-1459.
5. *Зайдельман Ф.Р., Иванов А.Л., Каштанов А.Н.* 2012. Деградация богарных и орошаемых черноземов под влиянием переувлажнения и их мелиорация. М.: ООО АПР. 212 с.
6. *Кравцов Ю.В.* 2009. Подъем грунтовых вод в Ишимской степи // Сибирский экологический журнал. № 2. С. 217-222.
7. *Кузьмина Ж.В.* 2007. Анализ многолетних метеорологических трендов на юге России и Украины (от лесостепи до пустынь) // Аридные экосистемы. Т. 13. № 32. С. 47-61.
8. Ландшафтная карта СССР, М 1:2500000. 1987 / Ред. И.С. Гудилин. М.: ГУГК. 1 л.
9. *Минкин М.Б., Калиниченко В.П., Назаренко О.Г.* 1991.

MSKHA, 1991:131.

10. Nazarenko OG. Modern processes of development of local hydromorphic complexes in steppe agrolandscapes [*Sovremennyye protsessy razvitiya lokal'nykh gidromorfnykh kompleksov v stepnykh agrolandshaftakh*]. PhD Thesis in Biology. Moscow: MGU, 2002:46.
11. Novikova NM, Nazarenko OG. Modern hydromorphism: processes, forms, manifestations, signs [Sovremennyy gidromorfizm: protsessy, formy, proyavleniya, priznaki] *Arid Ecosystems.* 2007;13(33-34):70-82.
12. Guide to laboratory research methods [Rukovodstvo po laboratornym metodam issledovaniyam]. 1990:236.
13. Suvak PA. Reclamation of wet solonetzic soils of Moldova [*Melioratsiya mocharistykh solontsovykh pochv Moldavii*]. Chisinau: Kartya Moldovenyaskae, 1977:105.
14. Suvak PA. Cultivation of soils of hydromorphic and automorphic solonetz-saline complexes under intensive agriculture in Moldova [*Okul'turivaniye pochv gidromorfnykh i avtomorfnykh solontsovo-solonchakovykh kompleksov pri intensivnom zemledelii Moldavii*]. Chisinau: Shtiintsa, 1986:162.
15. Khitrov NB. Development of waterlogging of chernozems in initially automorphic agrolandscapes [*Razvitiye pereuvlazhneniya chernozemov v iskhodno avtomorfnykh agrolandshaftakh*] *Reports of the Russian Academy of Agricultural Sciences [Doklady RASKHN].* 2002;2:31-34.
16. Khitrov NB, Nazarenko OG. Distribution of waterlogged soils in the initially automorphic agrolandscapes of the Rostov region during the “dry” farming system [*Rasprostraneniye pereuvlazhnennykh pochv v iskhodno avtomorfnykh agrolandshaftakh Rostovskoy oblasti pri vedenii sistemy «sukhogo» zemledeliya*] *Degradation of rain-fed and irrigated chernozems under the influence of waterlogging and their reclamation [Degradatsiya bogarnykh i oroshayemykh chernozemov pod vliyaniyem pere uvlazhneniya i ikh melioratsiya].* Moscow: OOO APR, 2012:125-166.
17. Khitrov NB, Cheverdin YuI, Chizhikova NP, Rogovneva LV. Soils of the Kamennaya Steppe

Мелиорация мочаристых почв Восточного Донбасса. М.: Изд-во МСХА. 131 с.

10. *Назаренко О.Г.* 2002. Современные процессы развития локальных гидроморфных комплексов в степных агроландшафтах. Автореф. … док. биол. наук. М.: МГУ. 46 с.
11. *Новикова Н.М., Назаренко О.Г.* 2007. Современный гидроморфизм: процессы, формы, проявления, признаки // Аридные экосистемы. Т. 13. № 33-34. С. 70-82.
12. Руководство по лабораторным методам исследованиям ..., 1990. 236 с.
13. *Сувак П.А.* 1977. Мелиорация мочаристых солонцовых почв Молдавии. Кишинев: Картя Молдовеняскэ. 105 с.
14. *Сувак П.А.* 1986. Окультуривание почв гидроморфных и автоморфных солонцово-солончаковых комплексов при интенсивном земледелии Молдавии. Кишинев: Штиинца. 162 с.
15. *Хитров Н.Б.* 2002. Развитие переувлажнения черноземов в исходно автоморфных агроландшафтах // Доклады РАСХН. № 2. С. 31-34.
16. *Хитров Н.Б., Назаренко О.Г.* 2012. Распространение переувлажненных почв в исходно автоморфных агроландшафтах Ростовской области при ведении системы «сухого» земледелия // Деградация богарных и орошаемых черноземов под влиянием пере увлажнения и их мелиорация. М.: ООО АПР. С. 125-166.
17. *Хитров Н.Б., Чевердин Ю.И., Чижикова Н.П., Роговнева Л.В.*

with signs of lithogenesis (vertigenesis) [Pochvy Kamennoy Stepi, imeyushchiye priznaki slitogeneza (vertigeneza)] *Bulletin of the Soil Institute.* 2013;72:3-25.

2013. Почвы Каменной Степи, имеющие признаки слитогенеза (вертигенеза) // Бюллетень Почвенного института. Вып. 72. С. 3-25.

18. Cheverdin YuI, Titova TV, Bespalov VA. Features of the formation of the hydrological regime of seasonally waterlogged soils of the Stone Steppe [Osobennosti formirovaniya gidrologicheskogo rezhima sezonno pereuvlazhnennykh pochv Kamennoy Stepi] *Agrochemistry.*2019;2:60-73.

18. *Чевердин Ю.И., Титова Т.В., Беспалов В.А.* 2019. Особенности формирования гидрологического режима сезонно переувлажненных почв Каменной Степи // Агрохимия. № 2. С. 60-73.

19. Cherepanov SK. Vascular plants of Russia and neighboring states (within the former USSR) [*Sosudistyye rasteniya Rossii i sopredel'nykh gosudarstv (v predelakh byvshego SSSR)].* Saint-Petersburg: Mir i sem'ya, 1995:990.

19. *Черепанов С.К.* 1995. Сосудистые растения России и сопредельных государств (в пределах бывшего СССР). СПб.: Мир и семья. 990 с.

УДК 551.574.9

К МЕТОДИКЕ МОНИТОРИНГА ЛОКАЛЬНОГО ПЕРЕУВЛАЖНЕНИЯ АГРОЭКОСИСТЕМ В СТЕПНОЙ ЗОНЕ

© 2022 г. Н.М. Новикова*, Н.А. Волкова*, О.Г. Назаренко**

**Институт водных проблем Российской академии наук*
Россия, 119333, Москва, ул. Губкина, д. 3. E-mail: nmnovikova@gmail.com
***Государственный центр агрохимической службы «Ростовский»*
Россия, 346493, Ростовская обл., Аксайский р-он, пос. Рассвет. E-mail: nazarenkoo@mail.ru

Поступила в редакцию 22.04.2022. После доработки 30.08.2022. Принята к публикации 01.09.2022.

Локальное переувлажнение территорий степной зоны на юге европейской части России обусловлено природными (флуктуацией климата) и антропогенными (тотальной распашкой) факторами. Размеры трансформированных участков «мочар» нестабильны и относительно невелики (в пределах десятков тысяч квадратных метров), но суммарная их площадь в посевах может достигать 15%, что вызывает нежелательные изменения агроэкосистем: приводит к потере урожая и становится постоянным источником расселения сорных видов. Долговременное изучение мочар и полученные данные о достоверности тесной связи периодов превышения среднегодовых сумм осадков с увеличением площади и интенсивности очагов локального переувлажнения, расселением гидро-галофильных растений (*Phragmites australis, Elytrigia repens, Tripolium aster* и др.) в зависимости от величины засоления и запасов влаги в почве позволили разработать систему показателей и критериев для методики мониторинга развития этого явления на конкретной территории. Предложен алгоритм работы, включающий этап выявления участков территории, подверженных локальному переувлажнению, и этапы изучения и оценки трансформации природных комплексов на каждом из участков. Оценка воздействия базируется на системе биологических и экологических показателей и критериев – индикаторов гидрогенной трансформации среды и биоты агроэкосистем (грунтовых вод, почв и растительности). Их совокупность дает возможность оценить степень и глубину произошедших изменений, дать рекомендации по уменьшению или прекращению развития негативных процессов переувлажнения на фоне прогноза климатических тенденций. Новизна содержания заключается в изложенной системе показателей и индикаторов, алгоритме работы по методике в рамках мониторинга.

Ключевые слова: очаг локального переувлажнения, индикаторы, виды растений, подтипы почв, показатель, критерий, засоление, запасы влаги, водный режим, Ростовская область.
Финансирование. Работа выполнена в рамках темы № FMWZ-2022-0002 Государственного задания ИВП РАН «Исследования геоэкологических процессов в гидрологических системах суши, формирования качества поверхностных и подземных вод, проблем управления водными ресурсами и водопользованием в условиях изменений климата и антропогенных воздействий».
DOI: 10.24412/2542-2006-2022-3-68-86
EDN: HSZJZB