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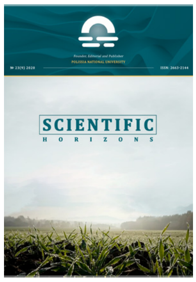

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Environmental problems from rainfall runoff

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Abstract. The state of surface water objects requires constant attention, since on the one hand – they are the sources of fresh water, and on the other hand – the wastewater receivers. Whole range of factors influence the state of surface waters: climatic characteristics, hydrology, soil features and water quality. The relevance of this topic is due to the difficult socio-ecological situation in the river basins of Ukraine; during decades, the aquatic ecosystems have been considered and used only as an economic resource for industrial and agricultural production and the discharge of pollutants, which has led to a rapid decrease in the ecological potential of natural water objects. The purpose of the study is to analyze the natural and anthropogenic impacts on the formation of surface runoff, to determine mathematical dependencies for an adequate calculation of volumes of surface runoff, considering the anthropogenic impacts, which changes the natural features of hydrographs in watercourses and the quality of surface waters. To determine the volumes of surface runoff, it is used the methods that are based both on the direct instrumental measurements and on the construction of various digital models. In the course of the study, it has been identified the main factors influencing the formation of anthropogenic floods, as well as the most typical pollutants, which are present in the surface runoff from the areas with residential construction and artificial coating. The article proposes a number of improvements to the existing mathematical dependencies based on the theory of isochrones for a more accurate display of the processes that form the surface runoff. The resulting mathematical model can be used for predicting the surface runoff from various surfaces, both natural and those that have undergone changes as a result of anthropogenic impact, which in the future can become the basis for the development of environmental measures

Keywords: surface wastewater; contaminants; isochrone theory; drainage basin; ground water

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INTRODUCTION

Surface runoff water that enter water ponds and watercourses (most often without treatment) is one of the main reasons for the deterioration of their condition. The solution of this problem is difficult due to the peculiarities of the regime of formation of surface runoff and its entry into surface water objects, which differ significantly from the conditions for the formation of domestic and industrial wastewater. Therefore, building a model that reflects all the factors affecting the qualitative and quantitative characteristics of surface runoff is of great importance.

The state of surface water objects, compared with the end of the twentieth century, has experienced significant impacts; this applies to both an increase in the mineralization of surface waters and pollution with biogenic compounds. The intensification of agricultural production has led to an increase of pesticide and mineral fertilizer residues in the surface waters, namely: nitroammophos, diammofos, potassium nitrate and others. These are the most common pollutants from the category of pesticides for the surface water: DDT, chlorophos, metaphos. The article by S. Pokhrel (2020) is devoted to this topic, in which the author examines the negative impact of such pollutants on the aquatic biogeocenoses, in particular, the destruction of phytoplankton by pesticides, which is the producer of primary production, which (as a result) leads to a loss of ecosystem stability.

In the work of the group of authors such as A. Butkovskyi *et al.* (2021), it is also described the consequences of pollution of surface water ponds with pesticides such as bentazone, 2-methyl-4-chlorophenoxyacetic acid (MCPA), metalaxyl, propiconazole and imidacloprid. At the same time, the authors proposed methods to prevent pesticide leaching with the surface runoff, namely: the use of vermiculite, pumice, water-absorbing polymer (SAP) for the retention of pesticides belonging to the group of water-soluble ones. On the other hand, the development of organic farming leads to a reduction in the use of mineral fertilizers and plant protection products, which has a direct impact on the quality of wastewater. In the work by M. Trenciansky *et al.* (2022), it is shown a decrease in the pollution of surface wastewater after switching to organic farming. The results of reduction of substances such as nitrates and chlorides became the most significant ones. However, with a prolonged use of organic fertilizers, it was observed an increase in bacterial pollution of surface runoff, in particular, with the coliform bacteria.

The development of cities and the expansion of infrastructure causes significant changes in the processes of formation of surface runoff. This theme is described in detail in the article by K. Sokur and L. Palamarchuk (2021). In the article, it has been carried out a cluster analysis of rainfall, which can be classified as very strong and dangerous according to their nature. As a result of the study, it has been revealed that the runoff from an entirely built-up area is 100-300% more that the runoff formed in the area with a lack of artificial coatings and with minimal buildings. The problem of increased flood runoff during the heavy rainfall is described in the article by T. Morales-Pinzon *et al.* (2015). In particular, the authors of the article argue that the pollution accumulated during the rainless period is rinsed off the surface of urban coatings and significantly worsens the state of surface runoff.

Climate change also contributes to the formation of surface runoff. Thus, in the work by O.V. Stepova and V.V. Roma (2018), the results of changes occurring in the climatic conditions are given, namely: an increase in the average annual temperature and fluctuations in the annual rainfall. This direction is very important, and as the authors of the article have shown, in addition to changes in the formation of surface runoff, climatic characteristics (in particular, the temperature value) affect such indicators as the level of dissolved oxygen and indicators of the presence of organic compounds, namely: biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Separately, it is worth noting that the state of surface wastewater can also affect the quality of groundwater. For example, in the work by W. Morsy and Z. El-Fakharany (2012), based on the statistical analysis and mathematical modeling, it has been determined that the pollution of surface runoff can lead to an increased risk of migration of plume pollution, resulting in a deterioration in groundwater quality.

Thus, the surface runoff can affect both the state of surface water objects and the quality of underground aquifers; thus, determining the volume of surface runoff is very important. The purpose of this work is to improve the existing methods for calculating the volume of surface runoff that enters the water ponds and water courses with rain and meltwater. This will make it possible to predict the possible consequences of the influence of surface wastewater on the state of surface and groundwater objects, as well as to determine possible ways to minimize these consequences.

MATERIALS AND METHODS

The calculation of river runoff is an important part of hydrology. It can be based both on the traditional methods for measuring the level and flow of water, and on the mathematical modeling methods. In the case of direct instrumental measurements, the flow meters of various designs are used, which are compared with the water levels in the watercourse. To obtain correct data on the volume of runoff, the obtained data is subjected to various types of mathematical analysis. If possible, the data obtained during the operation of hydrotechnical structures (such as locks, gates and others, installed on regulated watercourses) are used to determine the volume of river flow.

The formulas used can be classified into two main types: empirical formulas (which in general consider the basic regularities of the formation of surface runoff) and genetic formulas (which is based on the theoretical foundations of the formation of runoff on slopes and in waterways. The reduction and volumetric methods are the most widely used empirical methods. The reduction formulas are based on a schematic representation of slope and waterway hydrographs (Medvedeva & Shakirzanova, 2015). In the methods related to mathematical modeling, it is possible to distinguish genetic and probabilistic-statistical approaches, which are combined to some extent. The probability-statistical methods are based on the principle of grouping runoff's characteristics into statistical series (or combinations), which are studied by the methods of mathematical statistics and probability theory. The ability to track changes both in space and time is an important advantage of probabilistic-statistical methods. With the help of these methods, it is possible to obtain general interdependencies.

Particular attention has been paid to research on how the floods form and what consequences they have for calculating the maximum runoff, layers, runoff's time and hydrographs. All these properties can be determined as a result of direct field studies. With the lack of observations, they are based on the concept of general principle of the formation of spring floods. It is typical for the genetic methods to study river runoff to rely on the cause-and-effect relationships. At the same time, much attention is paid to the study of water systems, their classification, implementation of regional hydrological zoning. Genetic methods include the methods of hydrological analogy, hydrological interpolation, regional coefficients, water balances and dissection of runoff hydrographs by source (genetic dissection). Genetic methods may also include some runoff models (for example, runoff isochrones, deterministic models).

Genetic formulas and formulas of boundary intensity are based on the assumptions regarding the formation of surface runoff as a hydro-mechanical process. As a rule, such models consider several stages of runoff formation, starting from the first phase – the slope runoff, when the moisture is transformed from water intakes into a slope hydrograph; and then, due to the flow stratification and factors of waterway regulation related to the second phase of transformation, it becomes a waterway hydrograph. Adjustment for the individual characteristics of water intake is carried out by means of constructing an isochrone curve based on the empirical data. Separately, it is worth noting the advantage of such methods, which lies in the fact that they can be applied to water intakes, regardless of their size. In this study, the reduction formula specified in the Building Regulations SNiP 2.01.14-83 "Determination of calculated hydrological characteristics" (2014) was taken as a basis for the development of a mathematical model. It determines the maximum discharge of surface runoff during the spring snowmelt:

$$Q_{P\%} = \left[\frac{K_0 h_{P\%} \mu \delta \delta_1 \delta_2}{(A+A_1)^{n_1}}\right] A\,. \qquad (1)$$

At the same time, the data obtained as a result of long-term observations of rivers-analogues are used for determining the values of coefficients included in equation 1, such as the parameter characterizing the friendliness of spring flood (K_0), the estimated layer of the total spring runoff ($h_{P\%}$), the coefficients considering the impact of water ponds (δ), the impact of afforestation (δ_1), the impact of wetland areas (δ_2).

RESULTS

Water resources on the territory of Ukraine are unevenly distributed. The volumes of surface runoff also change over time. In summer, it usually makes up 7-10% of the annual runoff, and in autumn and winter – it increases up to 15-16%. In low-water years, surface runoff can decrease to 40-60% of similar indicators based on the results of long-term observations (Rybalova & Melnik, 2021). Separately, it is worth noting the low quality of water in many watercourses, which makes it unsuitable even for the use for cultural and domestic purposes. It often happens that a watercourse has a negative water balance, which leads to a violation of hydrological regime of the river, and accordingly, makes it impossible to use this water for the needs of national economy.

Surface runoff is the main source of power for the rivers, namely the spring snowmelt, and in the summer period – the replenishment of river runoff occurs due to the groundwater. A number of factors influence the formation of surface runoff: land cultivation, deforestation, construction of housing and industrial facilities (including the environmentally hazardous ones). In addition to the fact that a change in the underlying surface affects the volume of surface runoff, this also leads to a change in the qualitative composition of wastewater. Therefore, the identification of dependencies that would most fully characterize the process of formation of surface runoff is an urgent problem. The equations for calculating the volume of rainfall runoff from a certain area should be based on the basic factors, which form the volume of runoff. They primarily include: local parameters, such as relief, intensity and duration of rainfall, the absorption capacity of soils and features of the regime of underground water and groundwater, the cross section of water-collecting relief by ravines and gullies The nature of land use is necessarily considered; for the ploughed up lands, it is worth considering the water consumption by agricultural crops, the timing of vegetative period. Based on the above-mentioned indicators, the maximum rainfall volumes can be represented in the simplest form using the equation:

$$q_{P\%} = 13.2 h_{в_{max,\,1\%}} \delta_{sn} \delta_E G_p^{0,5} \lambda_p K_{wa}, \qquad (2)$$

where $h_{вmax,1\%}$ – the maximum value of water accumulation and with a supply of 1%, mm; δ_{sn} – a coefficient characterizing the soil nutrition (this parameter can vary from 0.9 for the areas, in which the water-catchment is characterized by the low level of soil nutrition; 1.05 – for the areas in which the water-catchment is characterized by an average level of soil pressure feeding; 1.25 – for the areas, in which the water-catchment is characterized by a high level of soil nutrition); δ_E – is the coefficient of water consumption accounting, which depends on the type of agricultural crops grown in the territory under consideration and the duration of vegetation period (this indicator ranges from 0.85 to 1); λ_p – the coefficient of transition from the provision of 1% to another given one; K_{wa} – the coefficient of reduction of maximum water accumulation; G_p – is a parameter that depends on the soil nutrition and the area subject to anthropogenic impact.

The value of G_p is determined according to the equation:

$$G_p = \left(\delta_{ld} P_p^{\chi} + \sqrt{\frac{\delta_l (1-\delta_{ld})}{A+30}} \right) \delta_e \,, \qquad (3)$$

where δ_{ld} – the coefficient characterizing the scale of land development (calculated by the formula:); δ_l – the coefficient depending on the level of afforestation of the territory under consideration; δ_e – is an empirical coefficient reflecting the level of changes that occurred under the influence of anthropogenic or technogenic intervention (δ_e for the Dnieper basin and the northern part of Ukraine is 1.23); P_p – the parameter of feeding, its value depends on the type of soil and the depth of aquifers; χ – the indicator of the level of feeding parameter.

The equation for calculating the volume of rainfall runoff is structurally similar to the formula given in SNiP 2.01.14-83 "Determination of calculated hydrological characteristics" (2014). However, at the same time, there are several significant differences. For example, in SNiP, it is proposed to calculate the maximum drainage rate based on the runoff coefficient and the layer of precipitation that fell during the day. This dependence does not consider the fundamental factors such as the state of soil, as well as the terrain, the level of groundwater, the volume of water consumed by agricultural crops, the duration of vegetation period, melioration measures, the topographic features of the area under consideration, and other criteria. All characteristics are considered when forming the equation (1). Considering the larger number of parameters makes it possible to more accurately predict the volume of maximum runoff. This especially affects the calculations of flood runoff for small rivers and watercourses subject to the anthropogenic impact. However, the parameters of the above-mentioned equation do not fully consider the physics of the process of the flood flow formation. According to the analysis of the channel network of rivers in the upper and middle flow of the Dnieper region, the configuration of the river catchment basins can have quite diverse forms, while the equation (1) is based on the assumption that the rivers' basins have a rectangular form. Thus, in order to increase the reliability of calculations, it is necessary to add an empirical coefficient to formula (1) – a constructive-hydrographic one, with the help of which it would be possible to proceed to the modeling of realistic river basins.

The time of the channel running has main influence on the process of formation of flows of anthropogenic floods (the ratio of hydrographic length of the watercourse to the running speed). While the running speed is one of the most important indicators that can significantly affect the runoff transformation in the channel). The calculation formula considers the mutual dependence of time of the channel running and the parameter of the forming costs related to the unit of time. Determination of the maximum integral discharge of surface runoff is based on the isochrone theory. The work by C. Xi *et al.* (2021) is devoted to the application of this theory regarding the calculation of flooding. Methods of mathematical modeling based on the isochrone theory are reflected in the article by C. Cui *et al.* (2022).

According to the isochrone theory, the value of the maximum water accumulation is calculated on the basis of the ratio of the slope run time (τ_{srt}) to the channel run time (τ_{crt}). At the same time, if τ_{crt} is more than τ_{srt}, then the formation of the maximum occurs as a slow runoff, as a result of which the greatest water accumulation is observed. If τ_{crt} is less than τ_{srt}, the maximum is formed as a developed runoff. In this case, there is a maximum water accumulation (h_{vmax}), which is calculated through the coefficient of the layer of the largest water accumulation φ. Thus, water accumulation can be determined using the equation $h_{в}=\varphi{*}h_{vmax}$. Based on the above-mentioned dependencies, it is possible to conclude that the layer of slope runoff differs from the highest water accumulation ($h_{вmax}$). This difference is equal to the loss of flood runoff (R_{fr}), which (for convenience) will be determined using the coefficient of runoff loss in recession R_{fr}. It should be noted that the value of R_{fr} is always less than 1. When multiplying the runoff loss coefficient in recession by the maximum water accumulation, it will be obtained the value of the layer of slope runoff.

According to the theoretical scheme for the formation of flood runoff as a result of anthropogenic changes, the maximum water accumulation directly depends on the groundwater regime. This indicates that different levels of groundwater can generate different maximum water volumes, even if other factors (such as the volume of rainfall and soil conditions) are the same. Changes in the volumes of water accumulation through the groundwater levels are considered using the empirical coefficient ξ_{gw}. The coefficient of groundwater level indication (ξ_{gw}) considers the mechanical composition of the soil and the vegetation period. Anthropogenic changes that affect the nature of redistribution of the surface runoff are considered using the coefficient for accounting for the level of anthropogenic changes K_{ac}. Anthropogenic changes are usually expressed as an increase in the land occupied by agricultural production within a particular water-catchment area. This coefficient is determined by comparing the volumes of runoff from agricultural land and natural landscapes. Due to the variety of factors affecting the formation of composition of the surface wastewater, as well as the nature and degree of inorganic and organic pollution, the surface runoff is a priority indicator that should be considered among the components of various origins to determine the state of surface water. The proposed model does not consider the features of the water basin such as afforestation and waterlogging; these parameters are considered in the indicators of maximum water accumulation. For watercourses with the most regulated runoff due to the presence of ponds and lakes, the coefficient of accounting for the influence on lakes' runoff is introduced for the proposed methodology (Traskova, 2015).

Various territories of Ukraine, such as the upper and middle Dnieper and the northern part of Ukraine have a significant number of karst formations (geological formations that are formed during the process when the rocks is leached and dissolved by the surface water or groundwater). These formations make their additional contribution to the formation of surface runoff. Depending on the type of supply, these formations can lead to both an increase in the flood runoff and its significant decrease. This influence is considered in the calculation model using the empirical factor of accounting for the state of cavernous porosity δ_c. The degree and nature of pollution of surface runoff from the residential and commercial facilities varies and depends on the sanitary conditions of the water catchment area, the level of development of the territory and the meteorological characteristics of precipitation, namely: the duration and strength of precipitation, the duration of preliminary dry weather and the intensity of spring melting process, as well as the impact of rainwater pollution, which occur due to pollution of atmospheric air by the emissions from industrial enterprises and transport.

High concentrations in the surface runoff are observed at the beginning of rain; after reaching the maximum volume of runoff, as a rule, a significant decrease can occur. Irrigation waters and household wastewaters have a stable composition and high concentrations of pollutants. As a rule, these are the most characteristic pollutants: the suspended solids, oil products, BOD and COD indicators characterizing the presence of organic compounds in wastewater. The presence of suspended solids in the surface wastewater is due to the presence of soil particles carried from the open surfaces, the road surface components, dust, household waste and building materials that can be stored in open areas. The presence of oil products in the rainwater is a separate problem; they are formed as a result of leaks of fuel and lubricating fluids during the operation of vehicles and other machines and mechanisms. The specific components of the surface runoff from areas with residential development include: synthetic surfactants, heavy metal salts, phosphates, biogenic elements (primarily – nitrogen compounds, which can be present both in organic and in inorganic forms in the wastewater: ammonium, nitrate and nitrite nitrogen). The presence of such substances indicates an unsatisfactory sanitary and hygienic condition of the underlying surface or a violation of the tightness of sewer networks. Excessive bacteriological pollution of the surface runoff is also caused by the same reason.

Thus, in the course of the study, it has been improved the existing model for estimating the volume of surface runoff that enters the surface water ponds, both as a result of direct precipitation and during the floods caused by snowmelt. The features of pollution of water ponds by surface runoff are revealed: the most characteristic pollutants are determined, as well as the specific conditions (unevenness in time) regarding the concentrations of pollutants in rain and melted wastewater.

DISCUSSION

The problem of environmental pollution, namely the water objects, is one of the most urgent for today. A number of articles by both domestic and foreign authors are devoted to the study of influence of the surface runoff on the state of water objects. Thus, in the collection of articles formed on the basis of results of the first international-scientific and practical conference "Modern directions of scientific search", Chicago, USA, 2021, it was presented the work by Ukrainian authors O.V. Rybolova and L.V. Melnik (2021) devoted to the influence of rainwater runoff on the state of water objects. The authors in their work also used a method based on the calculation of environmental index to determine the state of surface waters. The rivers of the Kharkiv region, belonging to the basins of the Dnipro and Siverskyi Donets rivers, were chosen as the basis for the research. Based on the assessment of environmental index, it has been determined that almost all water objects (that were investigated) are classified as the quality class 4. This means that ecological state of these watercourses is bad. Small rivers appeared to be the most vulnerable to anthropogenic impact. The authors of the article have come to conclusion that urbanization is the most significant source of influence, which changes the normal formation of the natural flow of rivers due to the disturbance of natural relief and intervention in the underground horizons. Agriculture is another factor influencing the state of surface runoff. As a rule, the surface runoff from agricultural land contains biogenic elements, such as nitrogen and phosphorus compounds, which are part of the most mineral fertilizers. At the same time, the following factors has a great importance for the composition of surface runoff: the type of agricultural crops grown in certain areas, their yields, methods of land cultivation, in particular, whether the artificial irrigation is used. The conclusions of these authors are fully consistent with the results obtained in the course of research by the authors of this work.

Authors P. Smilii *et al*. (2021) conducted similar studies on the territory of the Zhytomyr region within the Pripyat river basin. Based on the obtained results, an assessment of water quality was carried out in three blocks: salt composition, block of ecological and sanitary indicators and block of indicators of toxic action. According to the results of such assessment, the integral ecological coefficient was determined. It is especially worth noting that the block of ecological and sanitary (trophic-saprobiological) indicators is the limiting indicator that most affected the value of integral-ecological index; this indicates that anthropogenic factors have the greatest influence on the state of water objects in the Pripyat river basin. The authors of publication I. Gopchak *et al*. (2021) made similar conclusions. The small rivers of the right-bank of Polissia became the subject of their research. As in the previous study, the block of ecological-sanitary (trophic-saprobiological) indicators was the characteristic that most influenced the overall ecological index. Thus, in comparison with the block of salt indicators, or the block of indicators of toxic action, the block of ecological and sanitary indicators has the highest values. This proves once again that the quality of surface water in Ukraine depends primarily on the quality of surface runoff, which suffers greatly from anthropogenic load.

Similar studies are being carried out in many countries around the world. For example, the work by M. Suchowska-Kisielewicz and I. Nowogonski (2021) is based on the studies conducted in Poland. The software complex "Storm Water Management Model" developed by the United States Environmental Protection Agency (EPA) was used to simulate the rainfall runoff. This software complex is based on number of hydrological parameters, namely: variable duration of precipitation and its amount, evaporation of water from the open surface of water ponds and watercourse, accumulation of precipitation (rainwater and snow), further snowmelt, leakage and filtration of rainwater and meltwater into the soil thickness, the risks of groundwater overflow into underground and surface sewer networks and structures and vice versa, as well as the specificity of movement of the rain and melt water flows along the underlying surface. Although the methods of researching the problem differ significantly from those ones adopted on the territory of Ukraine, the conclusions made by these authors coincide with the conclusions obtained in the course of this study.

The combined sewer systems are common problem for the state of surface waters, that is when both surface runoff waters and domestic-industrial wastewaters are collected in one network. This problem is primarily associated with the possibility of wastewater overflow during the most intense precipitation, when part of runoff is discharged into a surface water pond without treatment. On the other hand, the composition of pollutants contained in the domestic-industrial wastewater can be radically different from the pollutants in rainwater, which makes it difficult to clean them; in particular, this significantly impairs the operation of treatment facilities, the main treatment type of which is based on biological methods. The article by L. Soriano and J. Rubio (2019) is devoted to this problem, in which (using the example of the city of Zaragoza) the studies regarding the impact of surface wastewater on the state of the Ebro River were carried out. The article proposes a number of measures to improve the state of water resources within the city; first of all, the authors paid attention to improving the sanitary condition of the city, which largely depends on the composition of rainwater. This fully coincided with the opinion of the authors of this study.

If there is no possibility of continuous monitoring of the volume of surface runoff, it is very important to have a correct model for mathematical calculations of such quantities. Therefore, there are several different approaches to determine the volume of surface runoff, each of which tries to consider all existing factors as much as possible. Modern approaches to determining the volume of surface runoff are also based (in addition to the isochrone theory) on a geometric approach to the slope and/or channel runoff hydrograph. This approach is developed in their works by the teams of authors such as S. Wei *et al*. (2022) and L. Wang *et al*. (2021). In particular, empirical models have been proposed, which combine the descriptors of hydrograph and rainfall storage reservoir to make reasonable predictions depending on the types of individual hydrographs.

In an article by A.A. Dokus *et al*. (2019), it has been proposed to use mathematical model of runoff formation, which use both the main parameters of meteorological characteristics (snowfalls and precipitation) and runoff coefficients. The model was tested to determine the maximum modulus of spring flood runoff for rivers with a large catchment area located in different physical-geographical conditions in the Southern Bug river basin. However, this model can only be used for spring floods. Using it to predict the volume of surface runoff during rainfall is not possible. Although it showed a high accuracy for calculating spring floods. The method proposed by the authors of this article, based on the isochrone theory, can be used to calculate the volume of surface runoff, including during rains.

In the study by D. Deka and B.M. Das (2022), the precipitation model was built with specified parameters of intensity and duration in order to promptly drain rainwater from the streets of Guwahati, using the SWMM 5.1 software complex. The SWMM 5.1 software complex implements a technique based on the Gumbel distribution.

Based on the calculations obtained, the authors of the article have come to conclusion that the existing rainwater sewer network cannot completely remove rainwater from the city, and therefore, it requires reconstruction.

CONCLUSIONS

The problem of environmental pollution is one of the most urgent in the modern society. This is especially true for the quality of surface waters, which are for the most part a source of fresh drinking water for the population, as well as satisfy a number of other needs, starting from the recreational ones and ending with melioration. Therefore, it is very important to maintain the proper quality of surface water ponds and watercourses. The surface runoff (rain and snowmelt) is the main factor that worsens the condition of surface waters.

In this article, it is determined the list of the most characteristic pollutants inherent in surface runoff; at the same time, it has been clarified the features of distribution of pollutant concentrations, the dependence of concentration on the duration and intensity of precipitation, the nature of underlying surface, including the fact how much the indicated territory has been subjected to anthropogenic and technogenic impacts. Due to the lack of possibility to conduct the direct instrumental and laboratory studies of volumes of surface runoff, a mathematical model has been developed. This model makes it possible to estimate with considerable accuracy the volumes of water entering water ponds and watercourses during precipitation and snow melting. The developed dependences are based on the isochrone theory. For a more accurate reflection of reality, a number of empirical coefficients have been introduced in the formula, such as the coefficient of accounting for the impact on lake runoff, the coefficient of indication of the level of groundwater, the coefficient of accounting for the state of cavernous porosity.

The presence of an adequate model that reflects all the features of formation of the surface runoff for a given drainage basin is of great importance, because it allows effectively predicting the volume of surface runoff entering the water ponds, as well as assuming to what extent and with what substances the runoff from a particular area will be polluted. This will allow developing the appropriate measures to reduce the pollution levels. The direction of further research may lie in the study of impacts that climate change can make on the formation of surface runoff.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Екологічні проблеми від дощового стоку води

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Анотація. Стан поверхневих водних об'єктів потребує постійної уваги, оскільки з одного боку вони є джерелами прісної води, а з іншої – приймачі стічних вод. На стан поверхневих вод впливає цілий комплекс факторів: кліматичні характеристики, гідрологія, особливості ґрунтів та якості води. Актуальність даної теми зумовлена складною соціально-екологічною ситуацією в басейнах річок України, адже впродовж десятиліть водні екосистеми розглядалися та використовувалися лише як економічний ресурс для промислового й сільськогосподарського виробництва та скидання забруднюючих речовин, що призвело до швидкого зниження екологічного потенціалу природних водних об'єктів. Метою дослідження є аналіз природних та антропогенних впливів на процес формування поверхневого стоку, визначення математичних залежностей для адекватного розрахунку обсягів поверхневого стоку з урахуванням антропогенних впливів, що змінює природні особливості гідрографів у водотоках та якості поверхневих вод. Наразі для визначення обсягів поверхневого стоку використовуються методи, які базуються як на безпосередніх інструментальних вимірюваннях, так і на побудові різноманітних цифрових моделей. В ході дослідження визначені основні фактори, які впливають на формування антропогенних паводків, а також найбільш характерні забруднюючі речовини, які наявні в поверхневому стоці з територій із житловою забудовою та штучним покриттям. В статті запропонована низка вдосконалень існуючих математичних залежностей, побудованих на теорії ізохрон, для більш точного відображення процесів, що формують поверхневий стік. Отримана математична модель може бути використана для прогнозування поверхневого стоку з різноманітних поверхонь, як природних, так і тих, які зазнали змін в результаті антропогенного впливу, що в подальшому може стати підставою для розробки природоохоронних заходів

Ключові слова: поверхневі стічні води; забруднюючі речовини; теорія ізохрон; водозбірний басейн; ґрунтові води