The Assessment of the Influence of the Hydrogeological Regime of Rivers on the Conditions of the Decentralized Water Supply in Karst Areas

R V Romanov¹, O R Kuzichkin², N V Dorofoeev¹ and A V Grecheneva²

¹Vladimir State University named after A. G. and N. G. Stoletovs, Gorkovo St. 87, Vladimir 60000, Russia
²Belgorod National Research University, Pobedy St. 85, Belgorod 308015, Russia

E-mail: romanov.roman.5@yandex.ru

Abstract. The article shows that the level of river flow has a significant impact on the development of destructive karst-suffusion processes. Karst water exchange systems have a high natural and anthropogenic vulnerability of groundwater resources and low ability to self-purify. The water quality of decentralized water supply sources largely depends on the presence of active karst processes. The studies were conducted in the territory of the village of Chud Navashinsky district of the Nizhny Novgorod region, subject to karst-suffusion processes. The hydrogeological characteristic of the study area is determined; the generalized characteristics of the seasonal fluctuations of the river flow are calculated. The development of karst processes in the study area is assessed. It has been determined that during the year, the period of spring flood on the Oka River has the greatest impact on landfall formation. It has been established that unauthorized dumps of municipal solid waste located in the karst zones of the Chud village affect the chemical composition and increase the total salinity of groundwater used for decentralized water supply. The results can be used to improve the regional model for assessing the resources of vulnerability and protection of groundwater and predicting the activation of destructive karst processes in the karst zone of the Oka River basin, Nizhny Novgorod Region.

1. Introduction

The intensity of manifestation and the activity of karst processes is determined by the territorial features and hydrology of the movement of karst water [1,2]. The most sensitive indicator of karst activity in a controlled area is the behavior of rivers feeding on groundwater in the summer, summer and autumn low water. Therefore, the low-flow discharge of the river is the total discharge of groundwater drained by the river [3]. The most sensitive characteristic of the hydrogeological regime of rivers is the minimum river flow. The river flow is formed due to surface and underground flow. In this case, the surface waters flowing in the depression are absorbed by the ponors and feed the rivers. Karst processes violate the zonal nature of the distribution of underground flow, and lead to the redistribution of underground flow in rivers [4-6]. During the spring flood, the value of underground river feeding decreases due to the hydrostatic pressure of the river wave on the fractured-karst aquifer. During this period, rivers serve as a source of groundwater for floodplains and banks. [7]. Accordingly, the level of river flow has a significant impact on the development of destructive karst-
suffusion processes, both on a local and regional scale. Karst water exchange systems, unlike similar systems in insoluble rocks, have high natural and anthropogenic vulnerability of groundwater resources, extremely low ability to self-purify and disperse pollutants [8]. In this case, control over the water quality of sources of decentralized water supply is an urgent and rather difficult task, especially in the presence of active karst processes and in difficult hydrogeological conditions in the territory of settlements. Taking into account the influence of river flow on the intensity of karst processes in areas with decentralized water supply makes it possible to organize geoecological monitoring of water use at local and regional levels [9].

The aim of the work is to assess the influence of the hydrogeological regime of rivers on the conditions of vulnerability and protection of groundwater and to forecast the activation of destructive karst processes in the right-bank Oka karst zone of the Oka River basin, Nizhny Novgorod Region. The Chud village located on the right bank of the Oka River in the northwestern part of the Navashinsky district of the Nizhny Novgorod Region, where decentralized water supply is used, was selected as the territory under study.

2. The study area and the assessment of runoff parameters
The territory of the village of Chud belongs to the Pozdnyakovskoye village settlement located in the western part of the Volga Upland and is a hilly-plain relief in the interfluve of the Oka and Tesh

![Figure 1. Study area.](image_url)

Geologically, the settlement territory belongs to the upper part of the Perm system, the lower sub-tier of the Kazan tier. Deposits are represented by dolomites, limestones, marls and clays. In the North-Western part of the settlement in the valley of the Oka river two right-bank terraces are well
expressed. In the southwestern part of the settlement, rivers flow along flat-bottom valleys and have wide floodplains. The relief of the territory as a whole is flat with alternating low-lying plains and hills with fluctuations in absolute elevations of 100-300 m.

A significant part of the settlement is subject to karst formations, which is manifested by the presence of craters, hollows and lakes of karst origin [10-13]. Table 1 presents the average values of precipitation at meteorological stations in Murom, Pavlovo and Vyksa.

**Table 1. Average rainfall, mm (1961-2018).**

| Station | I  | II | III | IV | V  | VI | VII | VIII | IX  | X  | XI | XII |
|--------|----|----|-----|----|----|----|-----|------|-----|----|----|-----|
| Murom  | 37 | 35 | 27  | 37 | 39 | 70 | 69  | 71   | 63  | 65 | 49 | 46  | 608 |
| Pavlovo| 36 | 32 | 27  | 35 | 44 | 64 | 70  | 64   | 55  | 56 | 51 | 47  | 581 |
| Vyksa  | 31 | 29 | 23  | 31 | 42 | 68 | 71  | 66   | 55  | 55 | 46 | 40  | 557 |

The territory is in the zone of sufficient moisture. On average, 550 mm of precipitation falls annually, of which the rainfall of the warm season in the form of rain is 64%, approximately 380 mm. Solid precipitation accounts for 22% of the total, 14% - mixed.

For the study area, generalized characteristics of seasonal variations in river flow were calculated (Table 2). In particular, these include the parameters of the distribution of river flow by months (coefficient of variation $C_v$ and ratio of asymmetry coefficients to coefficient of variation $C_v/C_s$).

**Table 2. Distribution parameters of average monthly river water discharge for the study area.**

| Months | I  | II | III | IV | V  | VI | VII | VIII | IX  | X  | XI | XII |
|--------|----|----|-----|----|----|----|-----|------|-----|----|----|-----|
| $C_v$  | 0.27| 0.32| 0.35| 0.50| 0.51| 0.23| 0.24| 0.18 | 0.21| 0.21| 0.26| 0.28|
| $C_s/C_v$ | -1.89| -0.98| 1.15| 2.93| 1.84| 2.52| 3.64| 2.33 | 3.12| 0.34| 1.58| -0.02|

The information base was the data of long-term observations of Roshydromet over river flows at hydrological posts in the vicinity of the village of Chud: the Oka river (Murom, Gorbatov), the Tesha river (Natalino village), Serezha river (Lesunovo village), the Bolshaya Kutra river (Pertovo village). As a result of the initial processing, an array of data was obtained for these hydrological posts in the vicinity of the village of Chud: the Oka river (Murom, Gorbatov), the Tesha river (Natalino village), Serezha river (Lesunovo village), the Bolshaya Kutra river (Pertovo village).

As a result of the initial processing, an array of data was obtained for these hydrological posts with monthly average water discharges and the coordinates of the observation centers.

The analysis of the dynamics of the annual river flow shows that on the rivers of the studied territory the low-water periods in recent decades have become much more [14]. This is due to an increase in temperature in the cold season and, accordingly, more frequent winter thaws, contributing to an increase in winter flow. The same pronounced growth trend is also observed for the time series of the minimum annual average monthly water flow.

3. **The influence of river flow on karst processes**

As an assessment of the development of karst processes in the study area, the generally accepted methodology for the presence and prediction of surface karst manifestations was used [15,16]. The karstological monitoring data provided by ltd “Stroykarst” for the territory of Dzerzhinsk, Nizhny Novgorod Region, which is an analogue of the study area, is used. Most of the craters, which are not more than 50 years old, are located in the zone of influence of the Oka river on groundwater, as well as on the state of karst rocks and sediments.

In this regard, it can be considered that during the year the greatest impact on the sinkhole has a period of spring floods on the Oka river. In the Western part of the village on the observation wells clearly visible seasonal fluctuations in groundwater levels. The rise of the groundwater level in the spring is due to snowmelt and the influence of the backwater from the flood waters on the river Oka. Between the time series of the annual number of karst sinkholes and the average annual water level in the Oka river (the level in the Oka river above the level of 67.2 m BS) recorded at the post in the city of Murom there is a clear almost one hundred percent negative correlation figure 2.
4. The influence of the hydrogeological regime of the Oka river on the conditions of decentralized water supply during the activation of karst processes

At the selected site, preliminary hydrogeological work was carried out to determine the conditions for the movement of karst waters associated with the lithological heterogeneity of the massif. The zones of location of the main sources of decentralized water supply in the village of Chud are determined. The key points of hydrogeological control of the territory, the area of underground flow and the area of discharge of fractured-karst waters in the Oka river are determined. As a result, eight observation wells were also used, which are also used to supply water to users in the village of Chud. At selected wells, seasonal trends in the level of river flow, infiltration of precipitation and surface water, and unloading of groundwater in the karst massif are well manifested [17,18].

Regime observations were carried out from February to September 2018. According to chemical analysis, the waters of the first horizon are sulphate-calcium-sodium. During the spring flood period in the zones of karst formation surface and groundwater accumulate from the flood waters on the Oka river. Pollutants infiltrate with surface water and precipitation and end up in groundwater used for decentralized water supply, changing their chemical composition and increasing overall mineralization and aggressiveness to karst rocks [19,20]. With the development of karst processes in this territory, the use of wells for drinking water supply during the spring and autumn low water periods is unsafe for the population. This period is quite short and is approximately 15-30 days a year. This is confirmed by regime observation data table 3.

Table 3. Experimental data on mineralization.

| Moths     | Mineralization, mg/dm³; observation well numbers |
|-----------|--------------------------------------------------|
|           | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| March     | 189 | 296 | 400 | 297 | 1203 | 486 | 1030 | 443 |
| April     | 195 | 304 | 559 | 300 | 1570 | 650 | 1500 | 590 |
| May       | 200 | 317 | 700 | 316 | 1510 | 781 | 1662 | 722 |
| June      | 177 | 209 | 626 | 266 | 1375 | 720 | 1549 | 662 |
| July      | 163 | 192 | 570 | 257 | 1210 | 670 | 1451 | 620 |
| August    | 167 | 280 | 600 | 260 | 1340 | 688 | 1480 | 652 |
| September | 184 | 294 | 653 | 285 | 1310 | 689 | 1509 | 703 |

5. Conclusion

The minimum river flow is the most sensitive characteristic of the hydrogeological regime of rivers during karst-suffusion processes. Analysis of the dynamics of the annual flow of the Oka, Tesha, Bolshaya Kutra, Serezha rivers shows that on the rivers of the territory under study the low-water periods in recent decades have become much more watery. This is due to an increase in temperature in the winter months of the year and frequent thaws that contribute to an increase in winter flow. The greatest influence on the sinkhole has a period of spring flood on the Oka river. In the western part of the village, seasonal fluctuations in the groundwater level are clearly visible through observation.
wells. The rise in groundwater level in spring is due to snowmelt and the influence of backwater from flood waters on the Oka river.

The feedback of the annual number of dips with the maximum water level in the flood on the Oka river is visible. High water years are characterized by the absence or small number of karst sinkholes. In dry years, as a rule, more active dip formation is observed, which is confirmed by a clear negative correlation with $K = 0.875$. During the spring flood period in the karst zones of the village of Chuds, there is an increase in the mineralization of sources of decentralized water supply complicated by unauthorized dumps of municipal solid waste in karst sinkholes. At the same time, pollutants infiltrate with surface water and precipitation and fall into groundwater used for decentralized water supply, changing their chemical composition and changing the overall mineralization.

References
[1] Pecherkin A 1986 Geodynamics of sulphate karst (Irkutsk: University Press)
[2] Dublyansky V and Kiknadze T 1984 Hydrogeology of the Karst of the Alpine folded region of the USSR (Moscow: Science, Russia) p 128
[3] Bochever F, Garmonov V, Lebedev A and Shestakov V 1965 Fundamentals of hydrogeological calculations (Moscow: Nedra) p 201
[4] Klimchuk A 2008 Speleology and karstology 1 pp 23 – 46
[5] Klimchuk A and Tokarev S 2014 Speleology and karstology 12 pp 5 – 16
[6] Ford D and Williams D 1989 Karst geomorphology and hydrology (London: Unwin Hyman, England) p 103
[7] Polyakov B 1946 Hydrogeological analysis and calculations (Moscow: Hydrometoeizdat) p 10
[8] Tokarev S 2018 Mountain Crimea geography Questions 147 pp 143–160
[9] Romanov R V, Kuzichkin O R and Grecheneva A V 2015 Fundamental and applied problems of technology and technology 311 pp 137–142
[10] Sharapov R V, Kuzichkin O R, Ermolaeva V A and Pervushin R V 2014 Mechanical engin. and life safety 4 pp 47–56
[11] Sharapov R V and Pogorelova A S 2017 Mechanical engin. and life safety 2 pp 39–51
[12] Tolmachev V 1968 About a technique of the quantitative estimation of the natural factors influencing formation of karst sinkholes Collection of MIIT (Russia) vol 273 pp 14–75
[13] Grecheneva A V, Kuzichkin O R, Mikhailova E S and Romanov R V 2017 J. of Eng. and Appl. Sci. 12 pp 6628–6634
[14] Sentsova N I 2011 Environmental engineering 5 pp 76–80
[15] Territorial building norms 22-308-98 1999 Engin. surveys, design, construction and operation of buildings and structures in the karst areas of the Nizhny Novgorod region (Nizhny Novgorod) pp 3–139
[16] Maksimovich G 1963 The basics of karstology (Perm: Perm book publishing house) p 445
[17] Romanov R V, Kuzichkin O R and Tsaplev A V 2015 Proc. Int. Conf. on 8th IEEE Internat. Conf. on Intell. Data Acquisit. and Advanced Comp. Sys.: Tech. and Appl. vol 1 (Poland: Warsaw) pp 42–46
[18] Vasilyev G S, Kuzichkin O R, Romanov R V, Dorofeev N V and Grecheneva A V 2018 Proc. Int. Conf. on Internat. Multidisciplinary Sci. GeoConf: Surveying Geology and Mining Ecology Management vol 18 (Albena:Bulgaria) pp 727-734
[19] Bodrievsky A V 2009 Report of Institute for Engineering Surveys Zoning of the territory of the Nizhny Novgorod region on the development of especially dangerous natural and technogenic processes (Nizhny Novgorod) pp 36–81
[20] Romanov R V and Dorofeev N V 2018 Proc. Int. Conf. Inf. Tech. in Sci. Educ. and Produc/: VII Internat. Sci. and Tech. Conf. (Belgorod: Russia) p 566
Acknowledgments
This work was supported by a scholarship of the President of the Russian Federation SP-254.2019.5
This work was supported in part by the Ministry of Science and higher Education of the Russian Federation under grant No. 5.3606.2017/PCH.