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Analysis of groundwater recharge in Nadvirna district by the Korkmaz method

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Abstract. The identification of groundwater sources and the prediction of possible water level fluctuations are crucial, as the study of these indicators is important for understanding the renewal of water resources and their efficient use in specific territorial conditions. The purpose of this study was to identify groundwater sources in the area of Mykulychyn village and assess their changes during the period from 2016 to 2022. The study was based on the Korkmaz method and analysis of data on water level in the well and precipitation level in the study area. The structural analysis of groundwater recharge in the Mykulychyn village in Nadvirna district was carried out using the Korkmaz method. It is established that groundwater recharge in Mykulychyn village is due to precipitation. The correlation between the water flow rate from the source and the water level in the well is demonstrated, allowing for projection of the study results to both objects. The average annual rainfall on the territory was 1,055.7 mm. The results of the linear regression analysis showed a connection between the water level and the total precipitation. The analysis of water level fluctuations in the well revealed that the annual water level recharge varies from 782 mm in 2017 to -254 mm in 2022. This indicates that some smaller aquifers may have dried up in 2022. The average annual recharge for the period from 2017 to 2022 is 347 mm, which is about 32.88% of the average annual precipitation. The results of the study can be useful in practice for water management and planning in Mykulychyn village, as well as in similar geographical conditions

Keywords: precipitation; source renewal; level fluctuations; wells; seasonality

Introduction

In 2023, the world is facing numerous challenges in the field of water resources, such as the reduction of the amount of available freshwater, groundwater pollution, and the instability of aquatic ecosystems. These problems are becoming increasingly serious due to the growth of the world's population and the increasing pressure on water resources. The issue of water resources management is becoming particularly relevant due to the increasing burden on natural water sources and the impact of climate change. One of the key components of water resources is groundwater, which

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plays an important role in meeting the needs of the population, the agricultural sector, and industry. The analysis of groundwater recharge and understanding of its cycle is of scientific and practical importance for sustainable development and ensuring access to water resources.

Recent scientific research in the field of hydrology and hydrogeology, such as P. Varnakovida *et al.* (2023), describes the growing interest in the analysis of groundwater recharge and their impact on water resources, noting the consensus on the urgency of this issue. They emphasize that modern hydrology and hydrogeology require a deep understanding of the processes that determine the quantity and quality of groundwater resources to ensure sustainable use and planning of their use. P. Chacuttrikul & S. Thueksathit (2023) focus on the importance of understanding the water balance and sources of groundwater recharge. They consider issues related to the processes that determine the quantity and quality of water that enters underground reservoirs. These studies provide the opportunity to establish which sources of water input to groundwater systems are the most important, as well as which factors affect the level of groundwater.

Other studies, including M.N.H. Mahmud *et al.* (2023), focus on the relationship between precipitation and groundwater level. They study the impact of precipitation on groundwater level fluctuations and develop methods for predicting these changes. The results of these studies provide the opportunity to better understand the relationship between precipitation and groundwater level, which is important for rational water resources management, especially in the context of extreme climate change. Z. Hossain & S.K. Adhikary (2023) proposed an interesting method of groundwater replenishment by applying the definition of potential groundwater recharge zones in the Barind Region of Bangladesh using geospatial techniques. This research method is convenient for faraway regions but it includes subjectivity in assigning hierarchical expert assessments, which can lead to inaccurate results. D.N. Dralle *et al.* (2023) applied a modified method based on the Korkmaz method to study groundwater replenishment in a forested remote region. The researchers also studied a particularly wet cycle in conditions of limited monitoring and taking into account the steepness of the slopes of the hills of the mountainous region. O.A. Bamisaiye (2023) studied the impact of climate change on groundwater replenishment, using historical rainfall data obtained by satellite observation for analysis. By predicting climate change and comparing the obtained data with historical periods, the feasibility and accuracy of using satellite observation data for rainfall have been proven.

Among Ukrainian researchers, V. Khilchevskyi & R.L. Kravchynskyi (2020) are studying groundwater in the region. Based on their monitoring data and local exploration and mapping of sources, a sufficient amount of input data has been obtained for research to determine the level of groundwater replenishment. The importance of replenishment regimes is further traced in the studies of M. Korchemlyuk *et al.* (2019), which note the close links between diffuse pollution and the feeding of water bodies. However, taking into account the regular monitoring component of these authors and access to the necessary input data on changes in water levels in springs and wells, it would be advisable to use a variety of methods for analysing groundwater replenishment.

Although enough attention has been paid to monitoring aspects by scientists, the issue of determining the percentage of groundwater recharge from precipitation has not been resolved and has been considered insufficiently thoroughly for the study region, has not been considered in the context of the use of more accurate satellite data, but used data on precipitation obtained from local meteorological stations. The totality of these aspects served as the reason to carry out this study. The purpose of this study was to analyse the recharge of groundwater in the Mykulychyn village of the Nadvirna district, to identify sources of recharge, and to study possible trends and fluctuations in water level in the period from 2016 to 2022.

Materials and Methods

To analyse the impact of precipitation on groundwater recharge, data from the Earth Observing System (EOS) satellite observation systems were used. These data included historical precipitation observations from local meteorological zones, as well as data from EOS satellites. Data on the amount of rainfall were available from 2016 to 2022 (EOSDA crop monitoring, n.d.).

The study also used data from monitoring of water levels in wells and the discharge of a spring, which allowed to determine the recharge of groundwater by precipitation in the study area of the Mykulychyn village. A well located in the Mykulychyn village, Nadvirna district, Ivano-Frankivsk Region, was selected for the study and analysis of groundwater recharge. It is located at coordinates 48°25′6″ latitude and 24°36′31″ longitude, at an altitude of 650 meters above sea level; it is located in an area with great tourist potential for the study of water resources.

Groundwater recharge in this area is mainly due to atmospheric precipitation, in particular rainfall. These precipitations affect soil moisture and the water level in the well. The well is located 20 meters from the spring. There is a high degree of correlation between the discharge of water from the spring and the water level in the well, which is confirmed by the Pearson correlation coefficient $r^2 = 0.99$. To obtain the correlation relationship, the average daily monitoring data of the water level in the well and the discharge for 2017 were analysed. This means that changes in the water level in the well almost 100% correspond to changes in the water level in the spring, which justifies the choice of these objects for comparative analysis and further research.

To analyse the level of groundwater and its recovery, monitoring of the mentioned well and a nearby spring was established. The monitoring was conducted by the authors in cooperation with the staff of the Carpathian National Nature Park (CNNP) from 2016 to 2022. Data on the fluctuations of the groundwater level were systematically measured several times an hour every day. These data were used to establish seasonal patterns of groundwater level fluctuations, which allowed to obtain more detailed and accurate data on its fluctuations.

In this study, only rainfall is considered among the forms of precipitation. The study was conducted using the method of N. Korkmaz (1990), a detailed description of which is contained in one of his works, where an assessment of groundwater recharge from the hydrography of springs was conducted. To analyse the data on precipitation and groundwater levels, Excel software was used. In this study, Excel and a computerized approach were used for convenience, in contrast to the original Korkmaz method, which was performed manually with paper and graphs. Using Excel, the data were processed and analysed, including the calculation of the average annual precipitation and the construction of graphs of the relationship between precipitation and groundwater level.

Results and Discussion

Recharge of groundwater is a hydrological process where water is directed from surface sources to underground areas. It is the primary mechanism by which water enters an aquifer. Recharge can be defined as the water that is introduced into an aquifer through the unsaturated zone after infiltration and percolation as a result of any intense rainfall. This process occurs through infiltration on the surface of the land (land infiltration) or under a surface water body, such as a pond (pond infiltration). In both cases, some of the water evaporates through evapotranspiration, and the remainder is eventually delivered to the groundwater level as recharge. This process is important for addressing agricultural challenges, forming river flows, and providing local populations with drinking water, and groundwater problems.

The amount of moisture that an area loses through evapotranspiration primarily depends on the amount of precipitation, secondly on climatic factors such as temperature, humidity, etc., and thirdly on the type, method of cultivation, and degree of vegetation cover. In a dry period, when evapotranspiration rates exceed the available moisture from precipitation, groundwater table recharge is negligible, and groundwater levels decline. In the study region, I. Klymchuk *et al.* (2022) conducted sociological surveys among the local population. The results showed that 48.8% of the surveyed residents of the region use water from underground reserves for everyday consumption, and 17.5% have surface waters as a source of water supply. This distribution of water sources necessitates research to determine the recharge of groundwater reserves and to analyse climate change with an emphasis on geographical and topographic factors of the region.

Records of water level fluctuations in wells are important and laborious to collect as they are used as the basis for hydrological interpretations. Therefore, the authors of the study joined monitoring expeditions of the Carpathian National Natural Park, as their monitoring group already had historical data on the parameters of the source discharge and water level in the well in the Mykulychyn village. Monitoring studies of water levels in the region are important for reaching conclusions about the distribution and development of groundwater in specific areas, and many records are still waiting for interpretation. Regular measurements and access to accurate EOS climate data in the study region allowed for a deeper investigation of the dynamics of water level changes in wells and their change according to precipitation. Daily precipitation indicators for the periods of 2016-2022 were selected and the sums of annual precipitation are presented in Table 1.

Table 1. Monthly precipitation by year in the Mykulychyn village, mm

Years	months											
	1	2	3	4	5	6	7	8	9	10	11	12
2016	-	-	-	-	-	-	-	-	-	142	155.2	45.9
2017	32.1	107.8	112.5	170.5	193.6	227.2	119.5	98.5	129.1	149.5	100.8	190.5
2018	30.8	66.7	63.1	26	70.7	195.6	174	78.4	42	38.3	48.2	76
2019	55.1	25.6	32.3	55.1	247	80.1	95	73.1	47.5	36.9	36	72.2
2020	20.3	90.4	56.5	25.8	163.5	204.4	98.2	44	120.4	81.7	26.5	41.8
2021	79.6	184.8	107.4	212.9	213.8	159.1	208.4	76.7	15.2	7.9	16.9	55.8
2022	31.5	26.6	11.2	34.6	34.9	18.1	55.5	32	37.4	-	-	-

Source: created by the authors based on EOSDA crop monitoring data (n.d.)

The Korkmaz method was applied due to the correspondence of the data that this method requires, and the data collected during monitoring and satellite observation analysis. This distinguishes this study from the article by D. Nayak *et al.* (2023). It was not possible to apply the methods mentioned by these scientists to the study region to determine similar goals, since the authors did not have enough input data to apply the method using geographic information systems, which requires a different amount of input data by type and by representation. All of these factors made the well in the Mykulychyn village an ideal object for research using the Korkmaz method to carefully analyse and understand the processes of groundwater recharge in this region. Table 2 contains data on the average monthly water levels in the observation well located in the Mykulychyn village. These data show the average monthly water level in this well during the study period. Data on the water level above the discharge level for the period from January 2016 to January 2022 are given in Table 3.

Table 2. Average monthly water levels in the observation well in the Mykulychyn village

Years	months											
	1	2	3	4	5	6	7	8	9	10	11	12
2016	-	-	-	-	-	-	-	-	-	-	-	-
2017	25.2	31.7	32.2	30.1	37.2	30.6	26.9	25.5	33.8	27.1	26.8	33.1
2018	24	24.6	27.5	26.4	31.9	37	34.8	37.4	26.9	23.3	22.7	21.2
2019	22.8	19	16.4	16.8	30.5	34.5	27.9	27.8	21.4	16.6	16.2	18.3
2020	16	18.9	20.1	20.9	28.4	33.3	28.1	19.8	24.2	29.7	24	18.8
2021	15.8	27	38.6	36.8	39.1	32.7	38.7	34.5	24	22.1	16.8	22.5
2022	18.5	19.9	20.1	18.6	17.5	16.2	17	19.5	20.1	18.8	19.1	17.5

Source: created by the authors

Table 3. Water level from the maximum level in the observation well in the Mykulychyn village

Years	months											
	1	2	3	4	5	6	7	8	9	10	11	12
2016	-	-	-	-	-	-	-	-	-	-	-	-
2017	15.8	9.3	8.8	10.9	3.8	10.4	14.1	15.5	7.2	13.9	14.2	7.9
2018	17	16.4	13.5	14.6	9.1	4	6.2	3.6	14.1	17.7	18.3	19.8
2019	18.2	22	24.6	24.2	10.5	6.5	13.1	13.2	19.6	24.4	24.8	22.7
2020	25	22.1	20.9	20.1	12.9	7.7	12.9	21.2	16.8	11.3	17	22.2
2021	25.2	14	2.4	4.2	1.9	8.3	2.3	6.5	17	18.9	24.2	18.5
2022	22.5	21.1	20.9	22.4	23.5	24.8	24	21.5	20.9	22.2	21.9	23.5

Source: created by the authors

The level of groundwater fluctuates naturally in response to the sequence of climatic events and the limitations imposed by hydrogeological and topographic characteristics. Groundwater recharge is greatest during the late autumn, winter, and spring when plants are dormant and evaporation intensity is low. In the summer, when evaporation intensity exceeds the available moisture from precipitation, groundwater recharge is negligible and the groundwater level decreases. The recovery of the water level (ΔH) and the total amount of precipitation (Pt) during the wet period of the year for 2016-2022 are shown in Figure 1 and Figure 2.

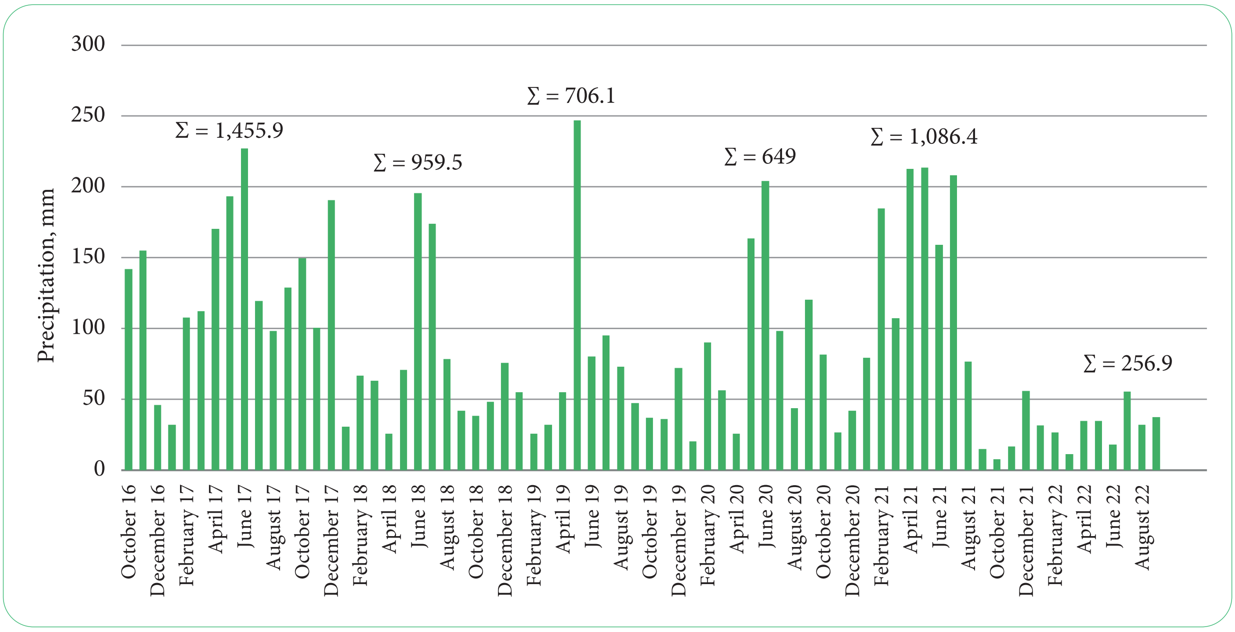

Figure 1. Months with significant average monthly precipitation that affect the increase in water level in the well
Source: created by the authors

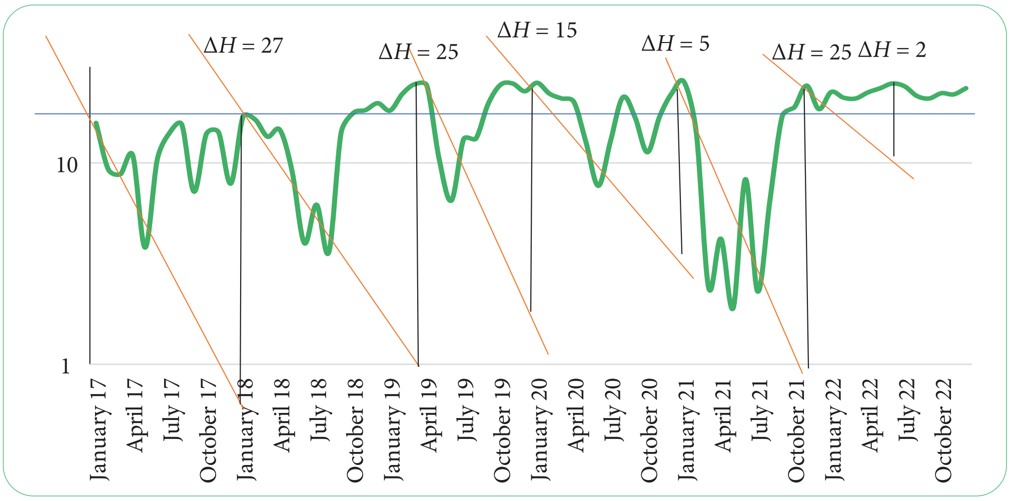

Figure 2. Fluctuations of the water level in the studied well are caused by precipitation that replenishes water reserves
Source: created by the authors

The results of the linear regression analysis are shown in Figure 3. The equation of the linear regression for the selected period is given below. The average level of precipitation (*Re*) for this aquifer is 170 mm.

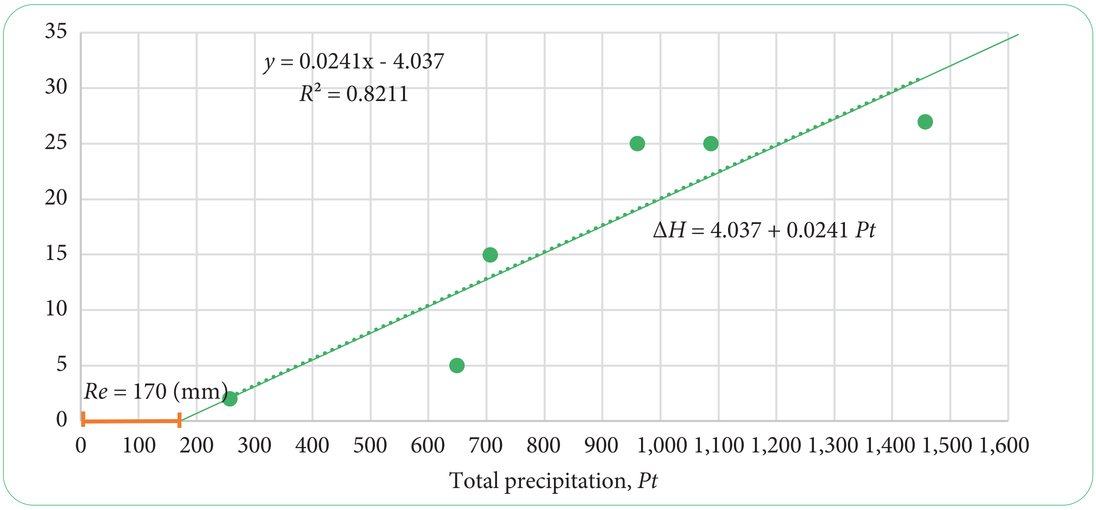

Figure 3. Total precipitation during the wet period – recovery of the groundwater level in the Mykulychyn village and the studied well
Source: created by the authors

Calculated values of total precipitation for the years 2016-2022 are given in Table 4. The results of the calculation of recharge due to atmospheric precipitation of this aquifer for the same period are given in Table 4 and Figure 3.

Table 4. Combined hydrological characteristics of the Mykulychyn village and the studied well

Well: Mykulychyn village, 48°25´6″ 24°36´31″				$(\Delta H\text{-}b)/m$	Precipitation computed – Recharge
Year	Precipitation ΔH	Total Precipitation	ΔH	Precipitation computed	Recharge
2017	1,455.9	1,533.9	27	952.8215768	782.8215768
2018	959.5	1,188.1	25	869.8340249	699.8340249
2019	706.1	873.3	15	454.8962656	284.8962656
2020	649	968.6	5	39.95850622	-130.0414938

Table 4, Continued

Well: Mykulychyn village, 48°25′6″ 24°36′31″				$(\Delta H\text{-}b)/m$	Precipitation computed – Recharge	
Year	Precipitation ΔH	Total Precipitation	ΔH	Precipitation computed	Recharge	
2021	1,086.4	1,407.9	25	869.8340249	699.8340249	
2022	256.9	362.4	2	84.52282158	-254.5228216	
Average	**852.3**	**1,055.7**	**16.5**	**517.13693**	**347.1369**	**Recharge 32.88%**

Note: $b = 4.037$; $m = 0.00241$

Source: created by the authors based on rainfall data of EOSDA crop monitoring (n.d.)

Annual recharge in this area during the study period ranged from 782 mm in 2017 to -254 mm in 2022, indicating possible drying up of some smaller aquifers in 2022. A similar pattern of decreasing precipitation and drying up of water sources was found in 2022 in the work of I.Ya. Klymchuk (2022). As a result of monitoring studies during the periods of spring flood and autumn low water in the region, the scientists traced the drying up of some water sources. A similar situation is observed in Iran in the work of R. Noori *et al.* (2023). Iranian scientists note groundwater depletion and the tendency to deplete drinking water reserves. The key role in this process is played by climate change. Similar conclusions were also reached by C. Yang & F.P. Bertetti (2023): on the territory of the United States, there are also such trends towards decreasing precipitation and changes in the renewal of water reserves. The trend toward depletion of groundwater is noted in all the mentioned works, and the authors of this study also join this opinion. It can be assumed that climate change has a global, not regional significance and can pose a threat to the population's access to drinking water not only in the studied region but also in the world as a whole.

The average annual recharge for the period from 2017 to 2022 is 347 mm. This is about 32.88% of the average annual rainfall. The study of groundwater recharge using the Korkmaz method, which was used in this article, proved to be an effective alternative to complex methods, such as the method using geographic information systems, which is presented in the study of D.M. Gururani *et al.* (2023), which requires a large amount of additional data, such as soil and rock composition, density, angles of inclination, drainage characteristics, and other parameters. Due to the high correlation between the water level in the well and the source, the Korkmaz method allowed to achieve significant scientific results and understand the processes of groundwater recharge using a minimum set of input data. This method opens up new opportunities for the study and monitoring of water resources, especially in conditions where other methods become extremely expensive and difficult to implement due to the lack of necessary data.

For the studied region, it is proposed to adopt the experience of Chinese colleagues R.-F. Meng *et al.* (2023), who, based on similar results for the restoration of shallow groundwater depression, developed a plan for optimizing the processes of groundwater recharge. According to the authors, this approach can be applied in Ukraine. The methods of combining several methods have been well established in the work of M.H. Ali *et al.* (2022). These methods of combining methods can have a positive projection on the Nadvirna Region since there is a large amount of other climate data that can be used in combination with several methods to obtain more accurate and comprehensive results of similar studies.

Groundwater management, including artificial recharge proposed by A.S. Jasrotia *et al.* (2019), plays an important role in ensuring the sustainability of water resources on the surface and in-depth. The study was aimed at identifying suitable sites for artificial groundwater recharge in the Himalayas, Jammu division, India, using geospatial techniques and groundwater modelling. It is important to apply the proposed approach in the studied region of Ukraine, anticipating possible climate changes and analysing periods with low precipitation. Artificial recharge could prevent critical loss of groundwater or lack of natural recharge. S.G. Ratna *et al.* (2023), in their conclusion, identified key aspects of the impact of climate change on the hydrogeological systems of Tumakuru, India. The recommendations for optimizing the use of groundwater and increasing groundwater recharge can be applied to the studied region to preserve sustainable groundwater recharge and mitigate the sharp impact of climate change on them.

An important aspect is the monitoring of water quality in aquifers, which is based on measurements at specific points with a limited number of wells, which causes uncertainty in the assessment of the distribution of parameters due to limited data availability. An important problem is to reduce uncertainty to obtain accurate and reliable monitoring results. According to the work of D.W. Gladish *et al.* (2023), who used geostatistical kriging and a differential evolution algorithm to optimize the design of a groundwater monitoring network in the Namoi Region of Australia, the author's study has taken on the challenges of monitoring the Mykulychyn village aquifer. The authors propose the integration of geostatistical methods for parameter interpolation.

Foreign practices for determining groundwater recharge often involve complex methods that require significant resources and, in some cases, participation in state environmental monitoring or supervisory programmes. The

Korkmaz method used in the study of water resources in Mykulychyn village offers a new approach to analysing and understanding groundwater recharge processes in Nadvirna district. This method may help to address the issue of groundwater use.

Conclusions

As a result of the study on the analysis of groundwater recharge in the Mykulychyn village, Nadvirna district, using the Korkmaz method, the following conclusions were drawn, which will contribute to a better understanding of the groundwater regime and its use in this region. The study results show that atmospheric precipitation is the main contributor to groundwater recharge in the Mykulychyn village, accounting for a significant share of the total precipitation in the region. On average, the amount of precipitation was 1,055.7 mm per year, which emphasizes the importance of atmospheric precipitation as a key source of water for groundwater in this area. No less important is the high correlation between the discharge of water from the spring and the water level in the well, which almost reached 0.99. This indicates a close relationship between these two parameters and suggests the possibility of using the results of the study for effective water management and forecasting.

The study revealed the dynamics of changes in the water level and the amount of precipitation over the years. The annual water recharge, which ranged from 782 mm in 2017 to -254 mm in 2022, may indicate the possible drying up of some aquifers in 2022. The average annual recharge during the study period was 347 mm, which is approximately 32.88% of the average annual rainfall. The study also traces the global trend of climate change, as similar conclusions are made by scientists from the United States and China. The results obtained are important for further research and strategic planning of water resources in the Mykulychyn village and similar regions. In connection with climate change and economic development, understanding groundwater recharge is a key factor in ensuring the sustainability of water resources and their efficient use. Future research in this area may include more detailed considerations of hydrogeological conditions and their impact on groundwater recharge in the region, as well as an analysis of the impact of climate change on the groundwater regime. Such studies will help to develop more effective water management strategies and ensure their sustainable use in the future. The study also requires analysis of a large amount of climatic and other hydrological data, which can serve as a continuation of the development of current research.

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None.

Conflict of Interest

None.

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Аналіз живлення підземних вод у Надвірнянському районі методом Коркмаза

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Анотація. Визначення джерел живлення підземних вод і прогноз можливих коливань рівня води є актуальним питанням, адже дослідження даних показників має велике значення для розуміння поновлення водних ресурсів та їх ефективного використання в конкретних територіальних умовах. Метою даного дослідження було встановити джерела живлення підземних вод на території с. Микуличин та оцінити їх зміну протягом періоду з 2016 по 2022 роки. Дослідження базувалося на методі Коркмаза та аналізі даних про рівень води в колодязі та рівень опадів на території дослідження. Проведено структурний аналіз живлення підземних вод на території с. Микуличин у Надвірнянському районі за допомогою методу Коркмаза. Встановлено, що живлення підземних вод у с. Микуличин відбувається за рахунок атмосферних опадів. Також показано кореляційну залежність між дебітом води з джерела та рівнем води в колодязі, що дало можливість проектувати результати дослідження на обидва об'єкти. Середньорічна кількість опадів на території становила 1 055,7 мм. Результати лінійного регресійного аналізу показали зв'язок між рівнем води та сумарною кількістю опадів. В результаті аналізу коливань рівня води в колодязі було виявлено, що щорічне поповнення рівня води варіюється від 782 мм у 2017 році до -254 мм у 2022 році. Це свідчить про можливе пересихання деяких менших за об'ємом водоносних пластів у 2022 році. Середньорічне поповнення за період із 2017 по 2022 роки становить 347 мм, що складає близько 32,88 % від середньорічної кількості опадів. Отримані результати дослідження можуть бути корисні на практиці для керування та планування водних ресурсів на території с. Микуличин, а також у схожих географічних умовах

Ключові слова: опади; поновлення джерела; коливання рівнів; колодязі; сезонність