GEOPERSIA

Accepted Manuscript

Application of Hydrological Balance Approach to Estimate Karstic Groundwater Discharge to the Sea: Nekarood Karst Basin, Iran

Narges Nabizadeh Chamazcoti, Gholam Hossein Karami, Azizollah Taheri, Ramazan Ramazani omali

DOI: 10.22059/geope.2025.390468.648808

Receive Date: 13 February 2025
Revise Date: 30 April 2025
Accept Date: 31 May 2025

Application of Hydrological Balance Approach to Estimate Karstic Groundwater Discharge to the Sea: Nekarood Karst Basin, Iran

Narges Nabizadeh Chamazcoti [1], Gholam Hossein Karami [2, *], Azizollah Taheri [1], Ramazan Ramazani omali [1]

[1] Department of Geology, Shahrood University of Technology, Shahrood, Iran
[2] Department of Geology, University of Kharazmi, Tehran, Iran

Received: 13 February 2025, Revised: 30 April 2025, Accepted: 31 May 2025

Abstract
Nekarood karst basin (NRKB) is located near the southern coast of the Caspian Sea, in Mazandaran province, Iran. The recharge potential map of this karst basin was prepared by considering lithology, slope, aspect, density of streams, precipitation, density of fractures, epikarst and karst features using GIS. These factors have been weighted using information obtained from geological maps, satellite images and field investigations. The results show that the values of recharge in NRKB varies from 12 to 45%. Based on this, the total amount of annual recharge in this basin is estimated to be about 243 million cubic meters. To estimate the annual discharge of karst springs in this basin, the hydrograph of all springs has been prepared. Based on the obtained results, the annual discharge of groundwater in the area is estimated about 71 million cubic meters. Due to the fact that there is no important consumer in the NRKB, the discharges of the springs in this basin form the base flow of the river. The evaluation of the annual volume of the base flow of Nekarood River shows that it is in good agreement with the annual discharge of the springs in the area. The water budget studies in NRKB indicate that the recharge volume is significantly higher compared to its discharge. In addition, the investigations show that there are no discharge zones in adjacent areas. Due to the existence of an important fault zone in this karst basin which extends towards the sea, most likely a significant part of the recharge water in this karst basin is discharged into the sea.

Keywords: Karst, Recharge, Water Budget, Nekarood River.

Introduction

Karst groundwater (KGW) is one of the most important groundwater sources around the world. Due to the expansion and diversity of carbonate formations, more than 25% of the world's population get their drinking water from karst aquifers (Ford & Williams, 2007; Hao et al., 2021; Liu et al., 2019). Assessing the percentage of annual recharge in karst zones is very important for water management and protection, but it is a complex issue. Failure to accurately estimate the amount of recharge in many aquifers in Iran and discharge more than the amount of recharge has caused a sharp drop in the groundwater water level. Estimating the amount of recharge in karst aquifers, due to heterogeneity, requires numerous information and statistics and accurate knowledge of factors affecting recharge (Bakalowicz, 2005; Freeze & Cherry, 1979; Todd & Mays, 2005, Karami et al., 2016). Knowledge of the subsurface discharge is also important in karst areas. Karst features create different conditions on the surface, so the subsurface discharge mechanism created in karst areas are very different from other areas and

* Corresponding author e-mail: g.karami@khu.ac.ir

it is a complex phenomenon. Also, determining the amount of rainfall, the karstification coefficient, and the area of the karst catchment area is not accurate and reliable enough (Bonacci, 2001). To determine the infiltration rate in karst areas, it is necessary to know the various factors that are effective on the infiltration in these areas. On the other hand, spatial and temporal changes of hydrogeological and hydrodynamic parameters are characteristics of karst regions (Jemcov & Petric, 2009). Recharge conditions in karst systems are different from other systems. The recharge of karst aquifers is much more than aquifers located in other geological zones. Infiltration takes place directly through ponor, estavelle, and by diffused infiltration from the surface, and by direct infiltration of rainfall and snowmelt water through joint (Milanovic, 1981).

The remote sensing (RS) and geographic information system (GIS) methods have been used in many areas due to the consideration of several variables, low cost and applicability on a large and regional scale in areas where field and laboratory operations are not possible (Milewski et al., 2009; Shaban et al., 2006; Zhu et al., 2013). Factors such as geology, slope, aspect, vegetation, precipitation, type of precipitation, density of streams, density of fractures, karst features, epikarst, etc. are factors affecting the amount of recharge in a karst aquifer (Ford & Willams, 2007; Ayalon et al., 1998; Singhal & Goyal, 2012). However, the complex effects of geologic factors on subsurface discharge characteristics have not been well quantified in karst catchments' areas.

The characteristics of subsurface discharge depend on factors such as climate, factors and characteristics of the catchment area (vegetation, topography, geology and shape of the basin) (Merz & Bloschl, 2009; Zhang et al., 2014; You et al., 2021; Zheng et al., 2018). Geological factors with direct and indirect effects on vegetation, soil, topography and other factors have the greatest impact on subsurface discharge characteristics (Hou et al., 2020; McGuire et al., 2005; Sang et al., 2022; Tromp-van Meerveld & McDonnell, 2006). Radulovic et al., (2012) used GIS to assess the spatial distribution of recharge in the karst region of Montenegro. The amount of recharge in this area is estimated between 60 and 80% of the annual rainfall. Karami et al., (2016) evaluated the recharge potential in Chaldoran region in western Iran using GIS and remote sensing and estimated the percentage of recharge in this region to be around 80% and 63% on average. Changan et al., (2023) concluded that climate change and land use change are the two main factors affecting water in the region. Subsurface discharge response of the several Chinese karst catchments are evaluated considering the climate and land-use change scenarios with hydrological models (ASD, FLUS, and SWAT). Zhang et al. investigated the factors affecting the characteristics of subsurface discharge. Geochemical, hydrogeological, and geological structure factors all have key effects on subsurface discharge characteristics, among which hydrogeological factors had the greatest impact. Also, among the studied hydrogeological factors, sinkhole density had a great effect on subsurface discharge characteristics (Yingzhong et al., 2023).

The NRKB, as a coastal aquifer, can discharge to the Caspian sea through alluvium, faults and deep dissolution channels. The aim of this papre is the identification of the complex recharge-discharge mechanism of the coastal NRKB, where the amount of recharge is way higher than the observed discharge. Our hypothesis is the availability of the potential discharge from the deep system to the Caspian sea. To do so, we used (i) GIS, (ii) remote sensing, and (iii) hydrogeological budget.

Materials and methods

Study area

The NRKB with an area of 2275 square kilometers is located in the eastern part of Caspian province and northeast of the central Alborz mountain range. In terms of geographic coordinates, this range is located at latitude 30 ˚ 36 to 37 ˚ 15 and longitude 53 ˚ 00 to 54 ˚ 45 (Figure 1). The maximum and minimum height of this basin is 3836 and -52 meters above sea level. The average annual rainfall in this basin is 430 mm and the average annual temperature is 14 °C. According to De Martonne method, this area is located in the Mediterranean climate in terms of climate. Geologically, part of its northern part is the Alpine-Himalayan orogenic belt in west Asia, based on structural geological divisions in the Alborz zone (Stöcklin, 1968; Alavi, 1991; Nogole-Sadat, 1993), Alborz- Azerbaijan Zone (Nabavi, 1976). Also, structurally, there is the Caspian fault in the north of this basin, and the north Alborz fault is in the south border, and there is another fault in the center of this basin, where the Nekarood river flows on this fault. The geological map shows the study area of NRKB (Figure 1). According to the sedimentary-structural divisions, it is located in central Iran (Agha-nabati, 2004). Most of the rocks are Mesozoic and Cenozoic deposits. Carbonate rocks such as limestone, dolomite, and sandy limestone are widely scattered, and even calcareous clastic rocks are observed (Figure 2).

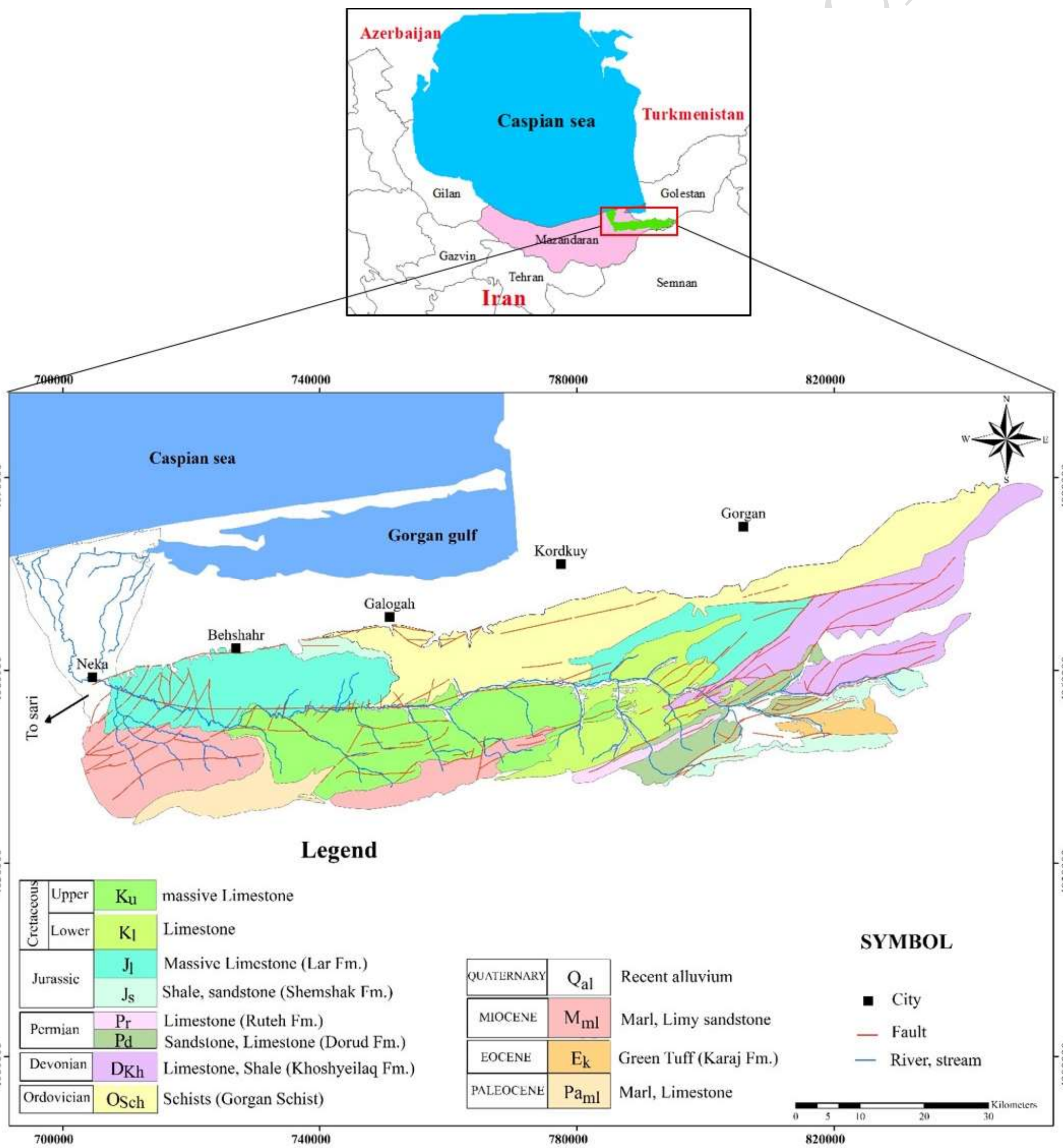

Figure 1. Geological map of the study area

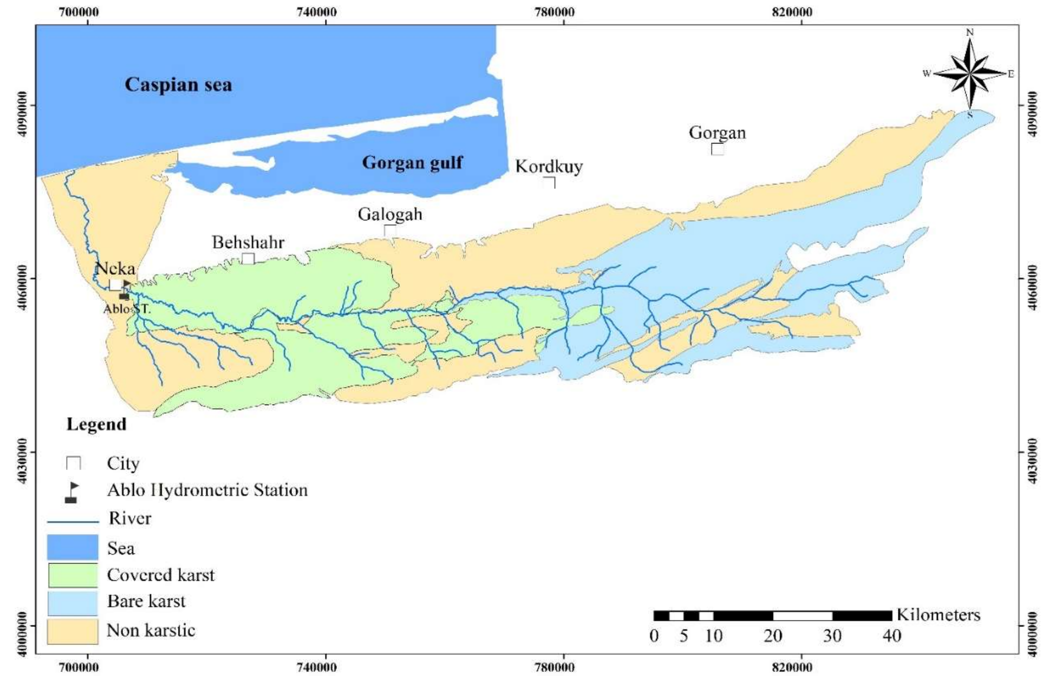

Figure 2. Hydrogeological and the location of the last hydrometric station map of the studied area

Methods of study

In order to estimate the amount of subsurface discharge of this karst basin towards the sea, hydrological balance have been evaluated in this karst basin. Using geological maps and field survey, the spread of rock units and their hydrogeological conditions were determined. Then using aerial photos, Landsat ETM satellite data and digital elevation model (DEM), the zoning map of recharge potential using information layers including lithology, amount of slope, direction of slope, density of streams, precipitation, density of fractures and epikarst (soil cover) and karst features were prepared after weighting by expert method and integrating information in GIS environment. Geological maps, satellite images and field visits have been used to weigh the factors affecting recharge. Due to the fact that there is no important consumer in the NRKB, the discharges of the springs in this basin form the base flow of the river. To estimate the annual discharge of karst springs in this basin, the hydrograph of all springs has been prepared. In order to validate the hydrological balance in the NRKB, the flood discharge information of Nekarood in basin outlet hydrometric station has been and compared with hydrograph of springs. After weighting, these information layers have been prepared using GIS and zoning map of recharge potential, and then according to the amount of recharge, precipitation and discharge, the water budget of the karst basin has been estimated. By weighting and overlapping the information layers of factors affecting recharge in the GIS environment, the uncertainty of hydrogeological information can be significantly reduced and this information can be used for the groundwater budget (Tweed et al., 2007).

Discussion

In order to estimate the annual recharge percentage in NRKB, the weight values of each 8 influencing factors in groundwater recharge were estimated from aerial photos, geological maps and specific field visits, and the categories of factors affecting the recharge potential, such as the influence values and weight of each unit, in the NRKB were tabulated Table 1. The highest degree of influence was given a number of 8 and the lowest degree of influence was given a number of 2. For example, the recharge index of areas with a slope of less than 10 degrees due to high recharge was given a score of 8 and for areas with a slope of more than 30 degrees, a score of 2 was considered.

Lithology: lithological characteristics play a decisive role in the amount of recharge, water storage capacity and karst development (Shaban, 2006). The most important exposed rock units include limestone, dolomite, marl limestone, shale, volcanic rocks and alluvial sediments, which are classified into 5 groups in terms of permeability potential (Figure 3). In the recharge index, carbonate rocks got the highest score due to their high permeability, and shales and marls got the lowest score due to their low permeability.

Slope: The topographic slope is one of the most important factors affecting infiltration, in hydrological balance. In areas with a high slope value, due to the creation of runoff, the amount of infiltration decreases, and in low slopes, the amount of infiltration increases due to the existence of sufficient time for infiltration. The map of the slope value has been prepared using the DEM of the area (Figure 4). The studied area was divided into 4 groups based on the slope value.

Slope direction: The sun's radiation angle is different on slopes facing north and northeast compared to south. In the northern hemisphere, the amount of sunlight is higher in the southern slopes, so the amount of evaporation is higher in the southern slopes and the amount of recharge is less. Therefore, the most points are assigned to the northern slopes. The slope direction map was prepared using the DEM of the area (Figure 5).

Density of faults and fractures: Faults and fractures have caused the transfer of water into the aquifers, increased karst development and water storage. Normal faults, which are formed in tensional conditions, have a greater role in groundwater transport than reverse and thrust faults that are formed in compressive structures. Using satellite images and geological maps and ground control, a map of fractures and faults in the region was drawn and scored based on the density of fractures. Areas with a high density of fractures and faults were given more points in recharge. The map of faults and fractures in the NRKB is shown in Figure (6).

Table 1. The value of different layers to calculate the recharge index and the weight of each category based on the expert method

Effective factors	Agent classification	Value	Weight	Effective factors	Agent classification	Value	Weight
Lithology	Limestone	8	15%	Soil cover	No covers	8	25%
	Marbly Dolomitic Limestone andesite ‹Dolomite ‹ Limestone	6			Low	6	
	Conglomerate Sandstone,	5			Moderately	4	
	Alluvium and Tuff	3			Highly	3	
	Marl and Shale	2			Very highly	2	
Slope	0-10	8	5%	Density of streams	0-25%	8	5%
	10-20	6			25-50%	6	
	20-30	4			50-75%	4	
	>30	2			>75%	2	
Fracture density	60-80%	8	10%	Karst features	Important complications of Karst (Karren)	8	15%
	40-60%	6			Bare karst (low epikarst)	6	
	20-40%	4			Covered karst (lots of epi-karst)	4	
	<20%	2			Non-karst rock formations	2	
Precipitation	>700	8	15%	Aspect	N-NE	8	10%
	600-700	6			E	6	
	500-600	5			SE-E	4	
	400-500	3			FLAT	3	
	<400	2			SW-S- W-NW	2	

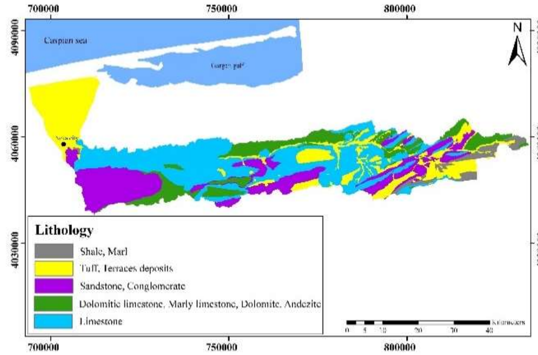

Figure 3. Geology of the study area

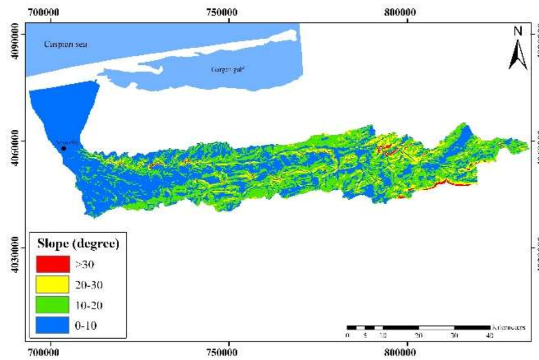

Figure 4. Slope value map

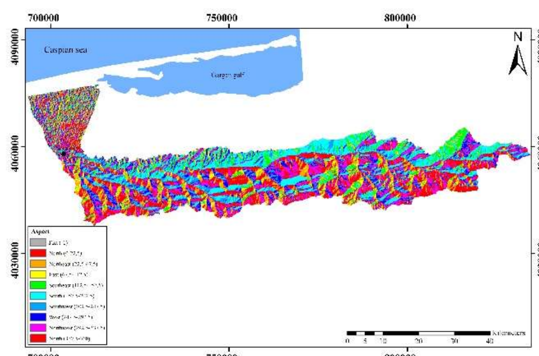

Figure 5. Slope direction map

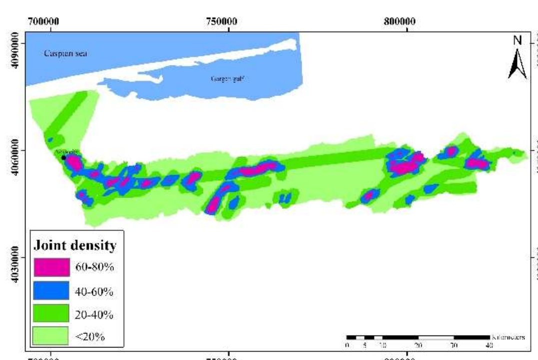

Figure 6. Density map of fractures and faults

Precipitation: Rainfall is one of the most important factors which influence the recharge rate into karstic formations. The amount and type of precipitation change depending the climate conditions and altitude in karst basins. The type and intensity of precipitation has a direct effect on the rate of recharge potential. So that torrential and sudden rains have less opportunity to penetrate and the amount of recharge from these rains is low, while snow and low intensity rains have more opportunity to penetrate and the amount of infiltration is more than that. Areas with more rainfall received more points. Figure (7) also shows the precipitation map of NRKB.

Drainage density: Streams generally reflect the structures, lithology, and permeability of the underlying rocks. Stream density is inversely related to permeability. The more streams in an area, the greater the amount of runoff, and therefore the lower the recharge. The stream network map was prepared using the DEM of the area and scored using GIS software. Areas with higher stream densities were assigned lower scores and areas with lower stream densities were assigned higher scores. Figure (8) shows the stream density map in the NRKB, with the highest density of streams on the north-facing slope.

Soil cover: Soil cover plays an important role in infiltration. The soil cover layer is considered as an information layer that in areas with extensive and relatively thick soil cover, the amount of precipitation retention is higher and the amount of effective infiltration is lower. In the areas where the rocks are bare, the accumulation of precipitation is greater and the amount of infiltration through features is greater. High slope and low rainfall have caused a large part of this area to be bare of soil and rocks. Due to its location in the north of the country, the studied area is covered with plants and soil in most areas. Figure (9) shows the soil cover map of NRKB.

Karst features: Considering that most of the precipitation in the region occurs as rain, this problem has caused the degree of development of karsts in the region to be relatively small. The most important karst features in the area include bare rocks and karrens. Karst features in the region were mapped using satellite images and field visits. Based on this, karst features were divided into 4 groups, including important karst features (karrens), bare karst (low epikarst), covered karst (high epikarst) and non-karst rock units. Figure (10) shows the map of karst features of NRKB.

To determine the recharge potential in the study area, influential factors were scored between 2 and 8 based on the researcher's experience (Table 1). Evaluating each factor alone on recharge potential is not effective and cannot obtain a true value of recharge value. Weighted overlay is a tool for different values and inputs to create a single analysis with a common measurement scale. The obtained maps are considered as a single layer for each factor. When these layers are superimposed according to their weight in GIS, they create ranges, which have different recharge characteristics. In order to obtain the weight and score of each region, the effective factors were superimposed and a recharge potential map (Figure 11) was prepared.

Based on the final recharge potential map (Figure 11) and the average annual recharge percentage of 5 recharge zones (Table 2), the average percentage of recharge in NKB is estimated at 27% (Equation 1).

Table 2. recharge percentage and area of each region

Annual recharge percentage	**Area (km^2)**
45	50
36	332
28	945
20	684
12	98

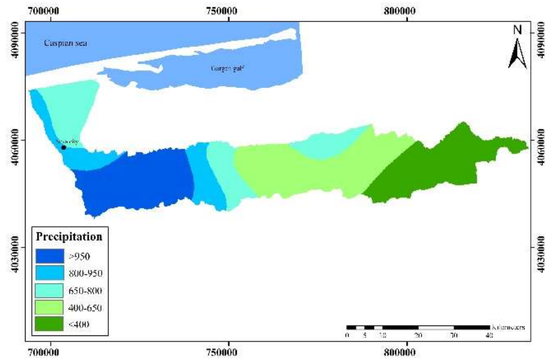

Figure 7. Rainfall map

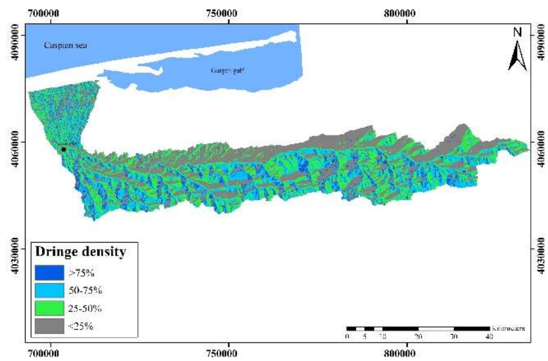

Figure 8. Drainage density map

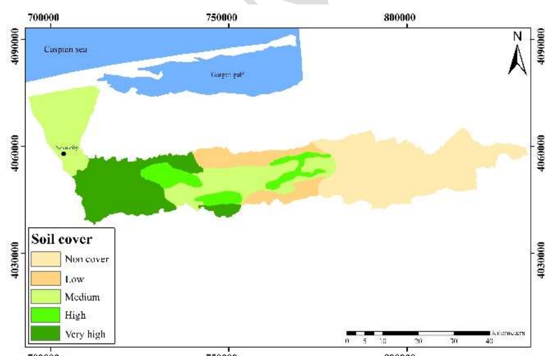

Figure 9. Map of soil cover and epikarst

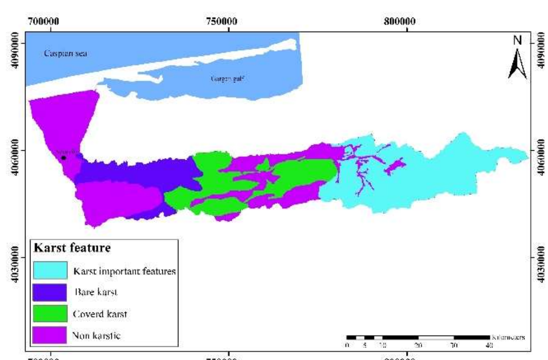

Figure 10. Map of karst features

$$R = \frac{\sum_{i=1}^{5}(A_i \times R_i)}{A_t} \qquad (1)\ Eq$$

$$R = \frac{98 \times 12\% + 684 \times 20\% + 945 \times 28\% + 332 \times 36\% + 50 \times 45\%}{2109} \cong 27\%$$

where, R is the average annual recharge in the entire basin, R_i is the average annual recharge percentage in the Ai subbasin, and A_t is the total area (in km) of the NKB.

Also, the hydrograph of the basin outlet hydrometric station was compared with the hydrograph of the basin springs (Figure 12 and 13). Analyzing the statistical results of precipitation and flow of Nekarood in the five water years of 2016-2021 in these station shows that, for example, the years 2017 to 2018 were drought periods, comparing the amount of precipitation in these years and the amount of flow in the respective stations shows that the runoff at the level of the basin has not been formed. The reason for this is probably due to the drought of the land and also the role of the karst phenomenon in this basin (Figure 2). In April 2019, significant rainfall was recorded in NRKB, which caused floods. In order to validate the basin outlet in the NRKB, the flood discharge information of Nekarood in hydrometric station has been separated from the total discharge (observed flood) and compared with the volume of subsurface discharge calculated from the basin outlet (calculated flood). The obtained results indicate that the flood discharge estimated from the hydrograph is about 2.8 m^3/s and the base flow is about 0.6 m^3/s. The outlet flow of the basin's springs is also about 0.45 m^3/s.

Water budget is the changes in water storage in the aquifer. The area of rock outcrop of NRKB is 2100 square kilometers. According to the calculated amount of recharge of 27% and the average annual rainfall of 430 mm, the total volume of annual recharge is estimated to be 243 million cubic meters. Based on the obtained results, the annual discharge of groundwater in the area is estimated about 71 million cubic meters. According to Figure 13, the output of the high-water springs in this area is about 12 million cubic meters per year.

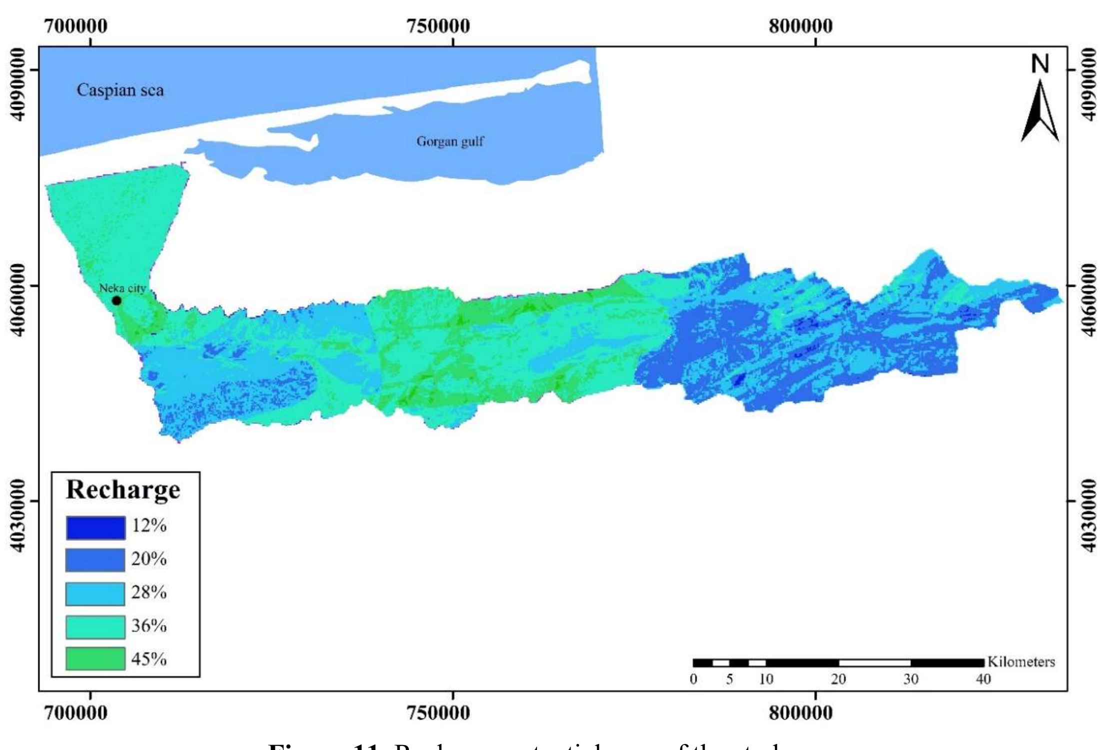

Figure 11. Recharge potential map of the study area

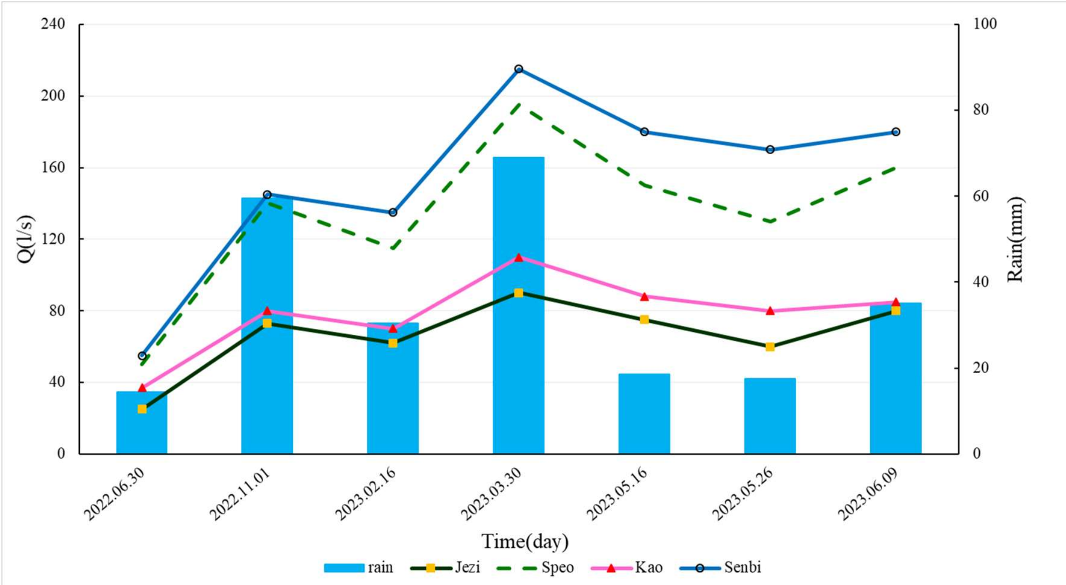

Figure 12. Hydrograph of the springs of NRKB with precipitation

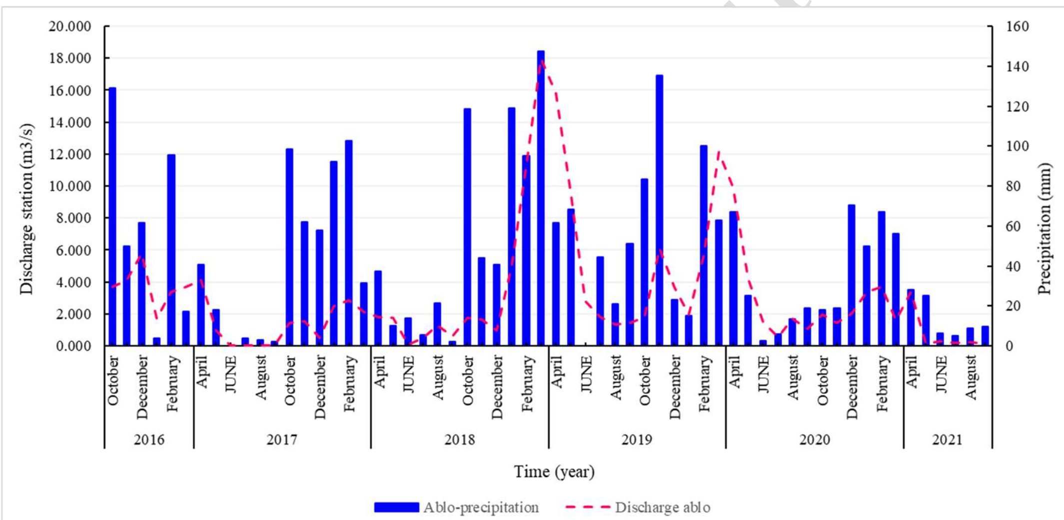

Figure 13. Hydrograph of hydrometric Ablo station

Also, the base flow of the Nekarood River, based on the last hydrometric station at the outlet of the basin, is about 32 million cubic meters. It should be noted that there are about 716 springs with low flowrate in this area and a significant part of the base flow of the river is supplied from the springs in the area, and the 4 springs mentioned in this area have the highest flow. According to the only input of the area that was rain and the amount of recharge in this basin as well as the output of the springs, the amount of 172 million cubic meters, causes the recharge of the nearby aquifers or enters the path of bedrock faults and finally discharges into the sea.

Conclusion

Determining the amount of recharge is the first step in hydrogeological budget studies. The recharge potential map of NKB shows that 50 km2 has 45% recharge, 332 km2has 36% recharge, 945 km2 has an average recharge of 28%, 684 km2 has an average recharge of 20% and 98 km2 has an average recharge of 12%. Examining the relationship between precipitation and hydrograph of hydrometric station and their relationship with the final map of recharge prepared in the basin shows that in station, according to the outcrop and tectonics that govern it, the development of Upper Cretaceous karsts in this hydrometric station confirms. In order to calculate and estimate the hydrogeological budget of this region, the outcrop area of karst limestone formations, the average rainfall and the percentage of recharge were determined. The amount of annual recharge in this area was about 243 million cubic meters. The annual volume of the base flow of the entire Nekarood river (as the total discharge of the karst basin in the river) is estimated to be about 68 million cubic meters, and the annual discharge volume of the wells is about 3 million cubic meters per year, and the difference between the amount of recharge and discharge is about 179 million cubic meters. An examination of the relationship between precipitation and the hydrograph of the hydrometric station and their relationship with the final recharge map prepared in the basin shows that at the Ablo station, considering the outcrop and tectonics prevailing there, it confirms the development of Upper Cretaceous karsts at this hydrometric station. Due to the fact that there is no important consumer in the NRKB, the discharges of the springs in this basin form the base flow of the river. The evaluation of the annual volume of the base flow of Nekarood River shows that it is in good agreement with the annual discharge of the springs in the area. The water budget studies in NRKB indicate that the recharge volume is significantly higher compared to its discharge. Considering that the groundwater tends to move towards the surface of the base of erosion and due to the shape of the basin as well as the existence of large faults (two faults north of Alborz and Khazar) and bedrock in the region, it is likely that part of the water fed to the alluvium and the Caspian Sea In addition, the investigations show that there are no discharge zones in adjacent areas. Therefore, it can be stated that the mountains of the region have more reserves in addition to providing water from the springs, which is a confirmation of the existence of the submarine groundwater discharge to the Caspian Sea. Although estimating the amount of recharge due to factors affecting recharge is associated with uncertainty; But despite this uncertainty, research should be done in this regard. It is also possible to reduce this uncertainty by using isotopic and hydrogeochemical samples in the area of water output from the basin and achieve a favorable result. Therefore, the presented method can be used to determine the amount of recharge and reduce uncertainty and reach more accurate information.

Conflicts of interest

The authors declare that they have no known conflicts of interest or personal relationships that might influence the work of this research.

Author Contributions

Narges Nabizadeh Chamazcoti: Investigation, Methodology, Data Analysis, Writing the original draft, Visualization, Data collection- Gholam Hossein Karami: Project Administration, Review and Editing, Methodology, Conceptualization- Azizollah Taheri: Review and Editing. Ramazan Ramazani Omali: Review and Editing.

References

Ayalon, A., Bar- Matthews, M., Sassb, E., 1998. Rainfall-recharge relationships within a karstic terrain in the Eastern Mediterranean semi-arid region, Israel: 18O and D characteristics. Journal of Hydrol, 207:18-31.

Agha- Nabati, A., 2004. Geology of Iran. Geological Survey of Iran. (In Persian)

Alavi, M., 1991. Sedimentary and Structural Characteristics of the Paleo-Tethys Remnants in Northeastern Iran. Geology Society of American, 103: 983.

Bonacci, O., 2001. Monthly and annual effective infiltration coefficients in Dinaric karst: example of the Gradole karst spring catchment. Hydrological Science-Journal-des Sciences Hydrologiques, 46: 287-299.

Chongxun, M., Mengxiang, B., Shufeng, L., Juan, D., Peiyu T., Zhenxiang, X., Gang, T., Lingguang, L., 2023. Impact of Future Climate and Land Use Changes on Runoff in a Typical Karst Basin, Southwest China, Journal of Water, 15:2240.

Ford, D.C., Williams, P.W., 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester.

Freeze, R. A., Cherry, J. A., 1979. Groundwater. Prentice-Hall, Englewood Cliffs, 604 pp

Jemcov, I., Petric, M., 2009. Measured precipitation vs. effective infiltration and their influence on the assessment of karst systems based on results of the time series analysis. Journal of Hydrology, 379 (3): 304-314

Hao, Z., Gao, Y., Green, S.M., Wen, X.F., Yang, J., Xiong, B.L., Quine, T.A., He, N.P., 2021. Chemical Characteristics of Flow Driven by Rainfall and Associated Impacts on Shallow Groundwater Quality in a Karst Watershed, Southwest China. Environ. Prog, 8: 615-636.

Hou, G., Bi, H., Huo, Y., Wei, X., Zhu, Y., Wang, X., Liao, W., 2020. Determining the optimal vegetation coverage for controlling soil erosion in Cynodon dactylon grassland in North China. Journal of Cleaner Production, 244.

Karami, G. H., Bagheri, R., Rahimi, F., 2016. Determining the groundwater potential recharge zone and karst springs catchment area: Saldoran region, western Iran. Hydrogeology Journal, 24(8): 1981-1992.

Kastning, E. H., 1977. Faults as positive and negative influence on groundwater flow and conduit enlargement, In: hydrologic problem in karst regions, ed. by Dilamarter, R. r., & Csallany, S. C., Western Kentucky University. Bowling Green Kentucky.

McGuire, K.J., McDonnell, J.J., Weiler, M., Kendall, C., McGlynn, B.L., Welker, J.M., Seibert, J., 2005. The role of topography on catchment-scale water residence time. Water Resour Research, 41 (5):1-14.

Merz, R., Bloschl, G., 2009. A regional analysis of event runoff coefficients with respect to climate and catchment characteristics in Austria. Water Resour. Res, 45 (1): 1-19.

Milanovic, P. T., 1981. Karst hydrogeology .Water Resources Publications .434 pp.

Milewski, A., Sultan, M., Yan, E., Becker, R., Abdeldayem, A., Soliman, F., Gelil, K. A., 2009. A remote sensing solution for estimating runoff and recharge in arid environments. Journal of Hydrology, 373(1): 1- 14.

Nabavi, M.H., 1976. An introduction to the geology of Iran, Geological survey of Iran. (in Persian)

Nogole-Sadat, M.A.A., Almasian, M., 1993. Tectonic Map of Iran in 1:1000000 Scale. Geological Survey of Iran, Tehran.

Radulovic, M., Stevanovic, Z., Radulovic, M., 2012. A new approach in assessing recharge of highly karstified terrains-Montenegro case studies. Environmental Earth Sciences, 65(8): 2221-2230.

Singhal, V., Goyal, R., 2012. A methodology based on spatial distribution of parameters for understanding affect of rainfall and vegetation density on groundwater recharge. European Journal of Sustainable Development, 1 (2): 85- 96.

22. Stocklin, J., 1968. Structural history and tectonics of Iran: a review. American Association of Petroleum Geologists Bulletin, 52: 1229-1258.

Tweed, S. O., Leblanc, M., Webb, J. A., Lubczynski, M. W., 2007. Remote sensing and GIS for mapping groundwater recharge and discharge areas in salinity prone catchments. southeastern Australia, Journal of Hydrology, 15:75- 96.

Liu, F., Wang, S., Wang, L.S., Shi, L.M., Song, X.F., Yeh, T.C., Zhen, P.N., 2019. Coupling hydrochemistry and stable isotopes to identify the major factors affecting groundwater geochemical evolution in the Heilongdong Spring Basin, North China. Journal of Geochem. Explor, 205: 106352.

Sang, L., Zhu, G., Qiu, D., Zhang, Z., Liu, Y., Zhao, K., Sun, Z., 2022. Spatial variability of runoff recharge sources and influence mechanisms in an arid mountain flowproducing zone. Hydrological Processes, 36 (8): e14642.

Tromp-van Meerveld, H.J., McDonnell, J.J., 2006. Threshold relations in subsurface stormflow: 2. The fill and spill hypothesis. Water Resour Research, 42 (2):1-11.

Yingzhong, L., Qiuwen, Z., Dawei, P., Weihong, Y., Mantong. Z., 2023. Key influence of

hydrogeological, geochemical, and geological structure factors on runoff characteristics in karst catchments. Journal of Hydrology, 623: 129852.
You, Y., Liu, J., Zhang, Y., Beck, H.E., Gu, X., Kong, D., 2021. Impacts of El Nino˜ -southern oscillation on global runoff: Characteristic signatures and potential mechanisms. Hydrological Processes, 35 (10): e14367
Zhang, Z., Chen, X., Huang, Y., Zhang, Y., 2014. Effect of catchment properties on runoff coefficient in a karst area of southwest China. Hydrological Processes, 28 (11): 3691-3702.
Zheng, Y., Huang, Y., Zhou, S., Wang, K., Wang, G., 2018. Effect partition of climate and catchment changes on runoff variation at the headwater region of the Yellow River based on the Budyko complementary relationship. Science of The Total Environment, 643: 1166-1177.
Zhu, Q., Liang, R., Jin, H., Wang, X.Z., 2013. Runoff simulation in the Arashi River Basin based on SWAT model. Water Resour, 31: 25-27.
Yingzhong, L., Qiuwen, Z., Dawei, P., Weihong, Y., Mantong. Z., 2023. Key influence of hydrogeological, geochemical, and geological structure factors on runoff characteristics in karst catchments. Journal of Hydrology, 623: 129852.