EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(4), 57–66
https://doi.org/10.12912/27197050/149956
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.05.01
Accepted: 2022.05.18
Published: 2022.06.01

Estimation of Groundwater Recharge Using APLIS Method – Case Study of Bokoya Massif (Central Rif, Morocco)

Ali Errahmouni[1*], Jamal Eddine Stitou El Messari[1], Morad Taher[2]

[1] Department of Geology, Faculty of Sciences, Abdelmalek Essaadi University, Avenue Khenifra, Tetouan 93003, Morocco

[2] Department of Earth and Environmental Sciences, Faculty of Sciences and Technique of Al-Hoceima, Abdelmalek Essaadi University, Avenue Khenifra, Morocco

* Corresponding author's e-mail: errahmouniali@gmail.com

ABSTRACT

Considering the low annual precipitation of AL-Hoceima province, the groundwater resources, especially in Bokoya, are one of the most critical water resources. Therefore, this study aims to estimate the amount of groundwater recharge into the Bokoya massif. For this purpose, the APLIS method is used in a geographical information environment for mapping the spatial distribution of groundwater recharge rates by combining five parameters: altitude, slope, lithology, infiltration, and soil. This study revealed that the recharge rate ranges between 9 and 76%, and the high rates (61–79%) are the most represented in the study area; this means that the region needs good groundwater management.

Keywords: APLIS, Bokoya, Central Rif, groundwater, recharge, GIS.

INTRODUCTION

Groundwater recharge is an essential process for sustainable groundwater management. The volume rate abstracted from an aquifer in the long term should be less than or equal to the recharged volume rate. Karst aquifers' water supplies have grown more significant worldwide, with roughly 25% of the world's population relying on them for their water, notably in Asia, the Mediterranean area, and the United States [1, 2]. The complexity of recharge computing in karst aquifers is influenced by the heterogeneity of hydrological properties, which directly results from the recharge duality [3].

In measuring groundwater recharge rate, the numerical methods used encounter limitations such as the lack of different important data that make these methods unreliable. The Geographic Information Systems (GIS) method is the key to solving this challenge. The APLIS method developed by IGME [4] is a tool designed to work with databases that are readily accessible to public bodies. It estimates the mean annual recharge of carbonate aquifers by combining different variables relating to the aquifer (Altitude, Slope, Lithology, Infiltration, and Soils) [5]. The acronym of these variables is APLIS. This approach uses geological and geomorphological features to explain the spatiotemporal distribution of karst recharging [4–6].

The APLIS method was used by Kirn et al. [7] to examine the aquifer recharge in both wet and dry years in the karst area of Andalusia, Spain. Alem et al. [8] studied the northern Khorasan aquifer, with the lowest level of water recharge (42%) correlating with common altitude areas and the highest of 72% representing the upper karst limestone and dolostone. Espinoza et al. [9] concluded that the APLIS method used to estimate the recharge of karst aquifers is suitable for the Mediterranean region.

The main objective of this study is to estimate the recharge rate in the Bokoya massif using the

APLIS method as an essential part of hydrogeological research. Therefore, this study's importance is mainly for managing and providing water resources for different uses, such as drinking and agriculture. However, it is necessary to mention that in the context of this paper, the recharge rate value obtained by the used method has not yet been compared to recharge estimations by other methods. Thus, the method's validation is the next step, which will occur shortly.

STUDY AREA SETTING

The Bokoya massif (Fig. 1a) is located in Al-Hoceima province (Fig. 1b), which is located in northern Morocco (Fig. 1c). It spreads out with around 40 km in length and 10 km in width and stretches from north latitude 35.26 to 35.11 west longitude 4.36 to 3.91. It is a karstified system with a general absence of permanent streams, the presence of tiny caves, and the occurrence of small springs in the area's southern corner. The Aghbar spring, which drains the karstic system and has a discharge rate of around 6 L/s, is the most significant in the area. The Bokoya massif topography is characterized in the east by relatively low altitudes of no more than 600 m and gradually rises to 700 m in the west. This topography is mainly due to recent and active tectonic movements [10]. Sector morphology shows two form types, summits having approximately the same altitude separated by deep valleys with steep slopes [11]. This undulated morphology type is related to the rigid facies nature of the limestone ridge that dominates the massif [12]. The morphological units of this area roughly in the east-west direction outcrop elongated and can be subdivided into four different regions from the north to south [13].

The Bokoya massif is subjected to a dry Mediterranean climate [14]. The calculation of the aridity index (I) [15] of the Al-Hoceima station between the 1979/80 and 2008/09 periods showed a value of $10 < I = 10.99 < 20$, which means that it belongs to a semi-arid area bioclimatic. The said study area is characterized by two distinguished seasons; the dry season (May to October) and the wet season (November to April). It is the driest area of the Rif coast, where average annual precipitation does not exceed 450 mm. The average temperature is ranged between 5 and 29 °C. The evaporation rate varies from 1200 to 1900 mm, with the lowest recorded values during January, whereas the highest is in July and August.

From the geological and structural point of view (Fig. 2), the Bokoya massif is a piece of the internal domain [16] that is well individualized in the northern central part of the Rif belt. It is marked

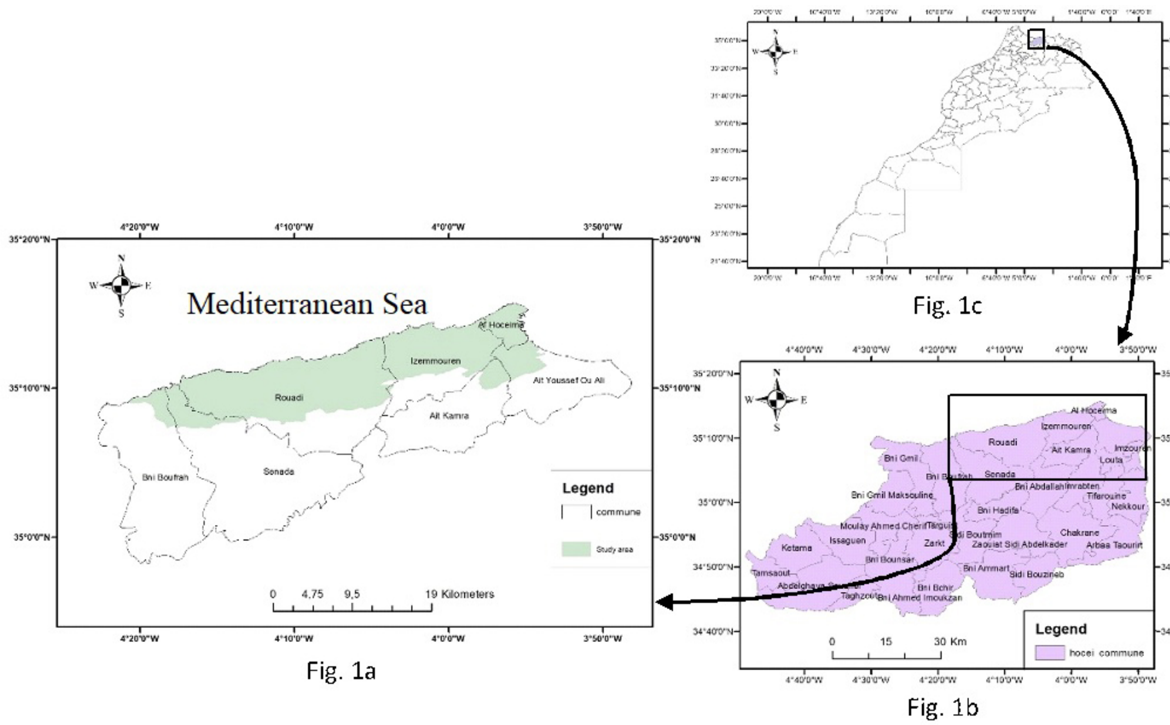

Figure 1. The location of the study area

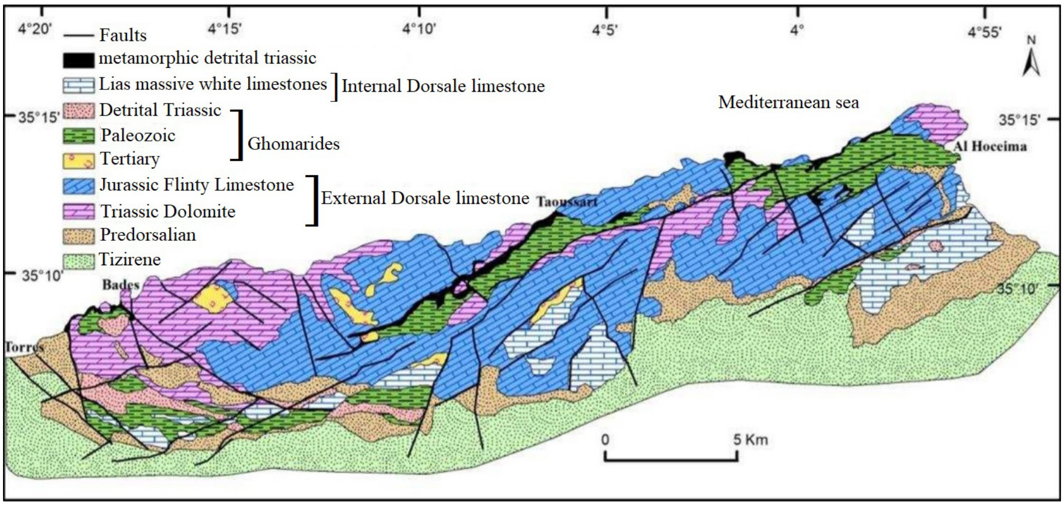

Figure 2. Structural map of the Bokoya massif

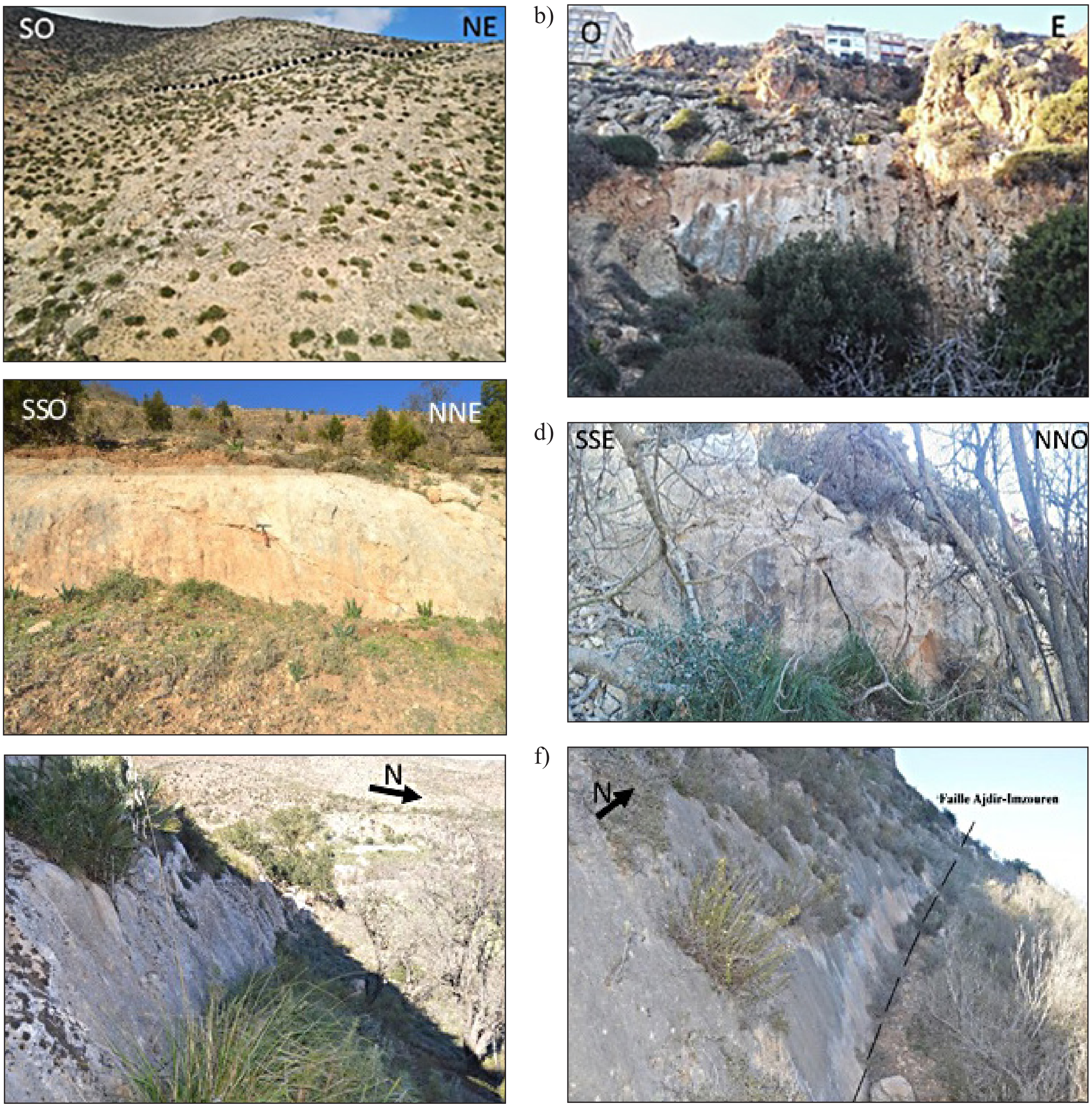

Figure 3. Images of active faults in the Bokoya massif; a) Bousekour fault; b) Quemado fault; c) Rouadi fault; d) Boujibar fault; e) Aghbar fault; f) Ajdir fault

by the stack of several structural units separated by abnormal contacts from each other [17]. It is dominated by carbonate formation of external dorsal, on which rest as tectonic klippes lands belonging to the internal limestone dorsal and those of Ghomaride Paleozoic layers. The whole massif overlaps towards the south on a series of sandstone flysch of Tizirene by the Predorsalian marly layer (tertiary sole), which is carried on the extern Rif units to the south [11, 16, 18–20]. The quaternary presents in consolidated dune sands form, which can reach more than 100 m in some places. Sliding tectonics animated by left-lateral strike-slip faulting N70, N55, and N40 and right-lateral strike-slip faulting N115, N130, and N160 intersect the whole of Bokoya [10]. The study area is characterized by presenting many active faults such as the Bousekour fault (Fig. 3a), Quemado fault (Fig. 3b), Rouadi fault (Fig. 3c), Boujibar fault (Fig. 3d), Aghbar fault (Fig. 3e), and Ajdir fault (Fig. 3f) [21].

METHODOLOGY

The APLIS method was used for estimating the groundwater recharge rate of massif Bokoya, expressed as a percentage of precipitation by combining five factors (Eq. 1). The methodology adopted in the study is shown in Figure 4.

Altitude factor (A)

The elevation map (Fig. 5) was extracted from the earth explorer's digital elevation model (DEM). The results obtained show that the highest height is 739 m, and the lowest is -8 m. based on Table 1, the elevation class is divided into nine classes. The areas with the highest altitude scored the highest, while those with the lowest height received the lowest score.

Slope factor (P)

The slope map (Fig. 6) was also extracted from the same DEM mentioned above. The results show that the highest slope degree is 74%, characterized by sea cliffs. Based on Table 2, the slope class is divided into nine classes. The highest value was assigned to the areas with the lowest slope degree, while the lowest was given to those with the highest slope degree.

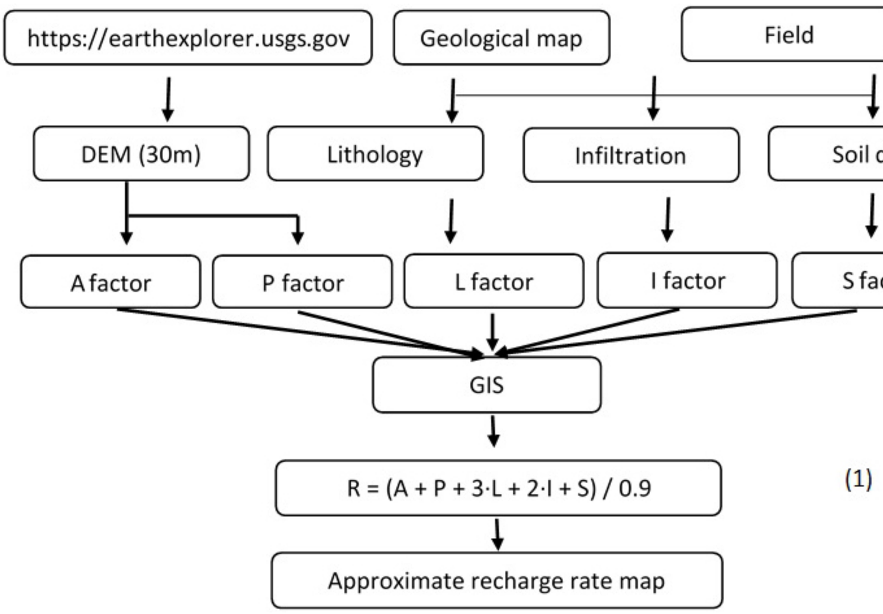

Figure 4. Flowchart of the methodology; where: R - Recharge (expressed in %); A - Altitude; P - Slope; L - Lithology; I - Infiltration; S - Soil. Recharge rates obtained range from 8.88 to 88.8% of the precipitation that falls onto the surface of the aquifer [3, 6]

Table 1. The altitude variable and class

Altitude (m)	-8–93	93–173	173–244	244–306	306–366	366–432	432–505	505–584	584–739
class	1	2	3	4	5	6	7	8	9

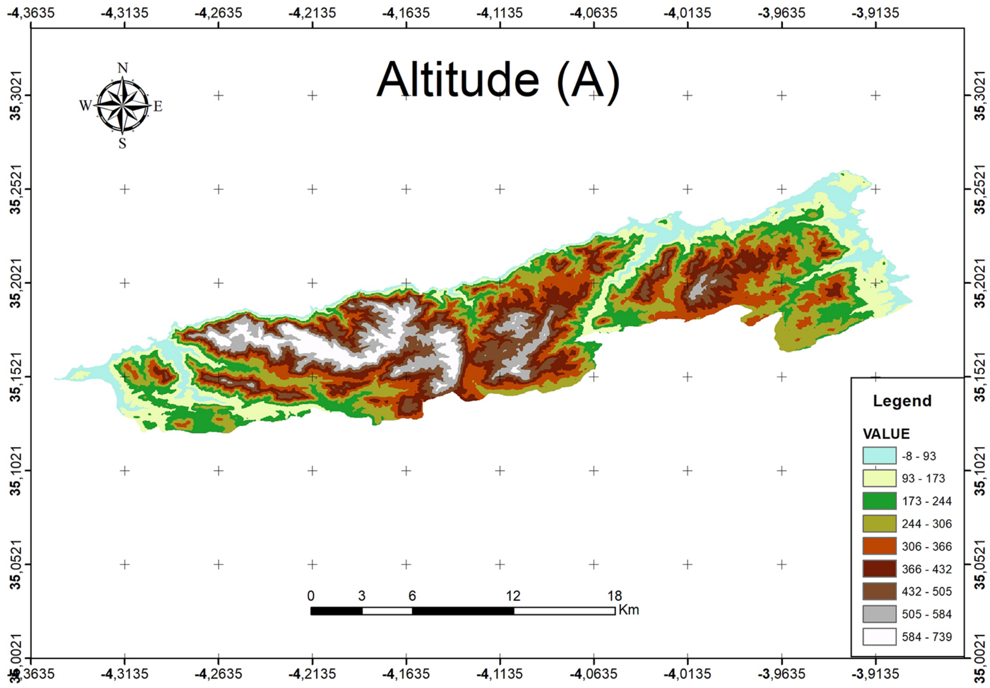

Figure 5. The altitude map of the Bokoya massif

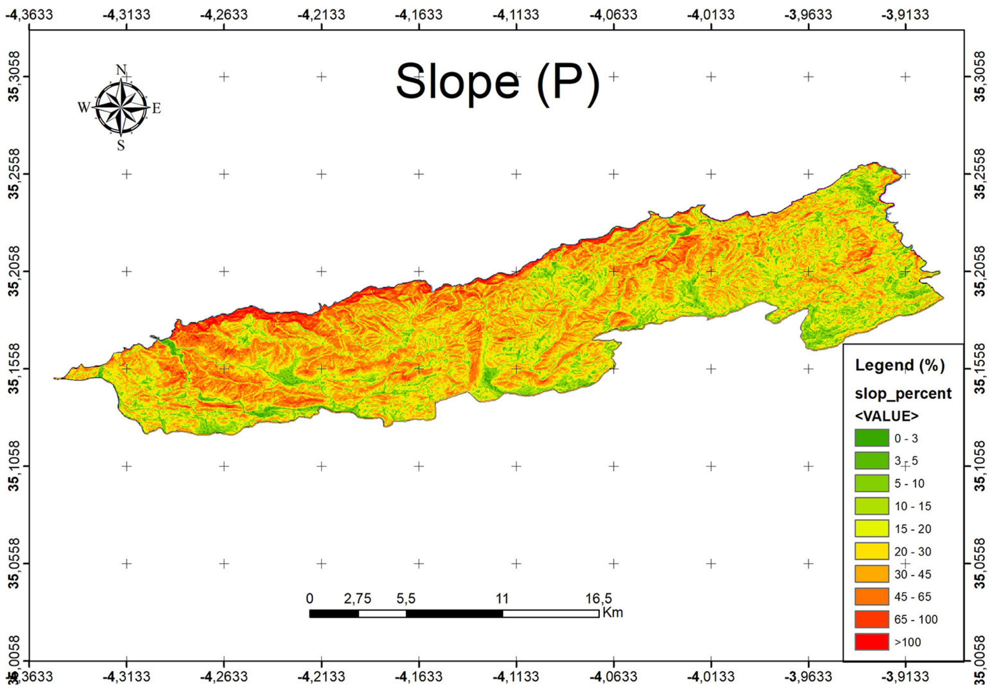

Figure 6. The slope map of the Bokoya massif

Table 2. The slope variable and class

Slope %	0–3	3–8	8–16	16–21	21–31	31–46	46–76	76–100	>100
Class	10	9	8	7	5	4	3	2	1

Table 3. The lithology variable and class

Lithology	Limestone	Marl	Shale	Clay
class	10	1	1	1

Lithology factor (L)

In this area, four rocks unite limestone, marl, clay, and shale (Fig. 7). Limestone rock is the most represented. Table 3 shows the class of the rock units.

Infiltration factor (I)

The parameter I (Eq. 2) results from the combination of the slope (S) (Fig. 6) with the lithological (C) (Fig. 7) and the distance from the faults (F) (Fig. 8) [2, 6]. Figure 9 shows that the

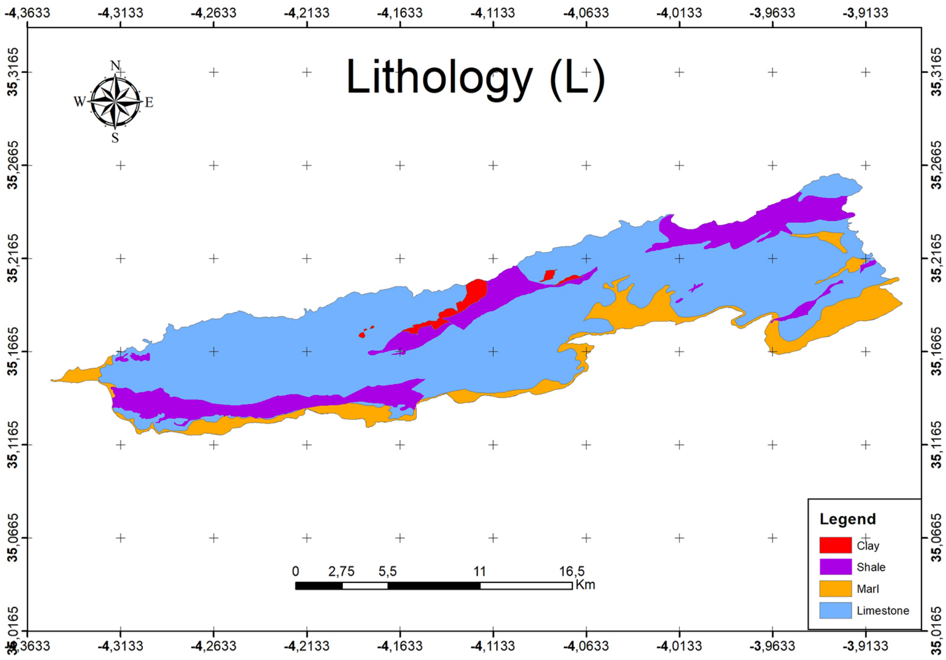

Figure 7. The lithology map of the Bokoya massif

Table 4. The infiltration variable and class

Infiltration %	4–10	10–14	14–18	18–22	22–29
Class	2	4	6	8	10

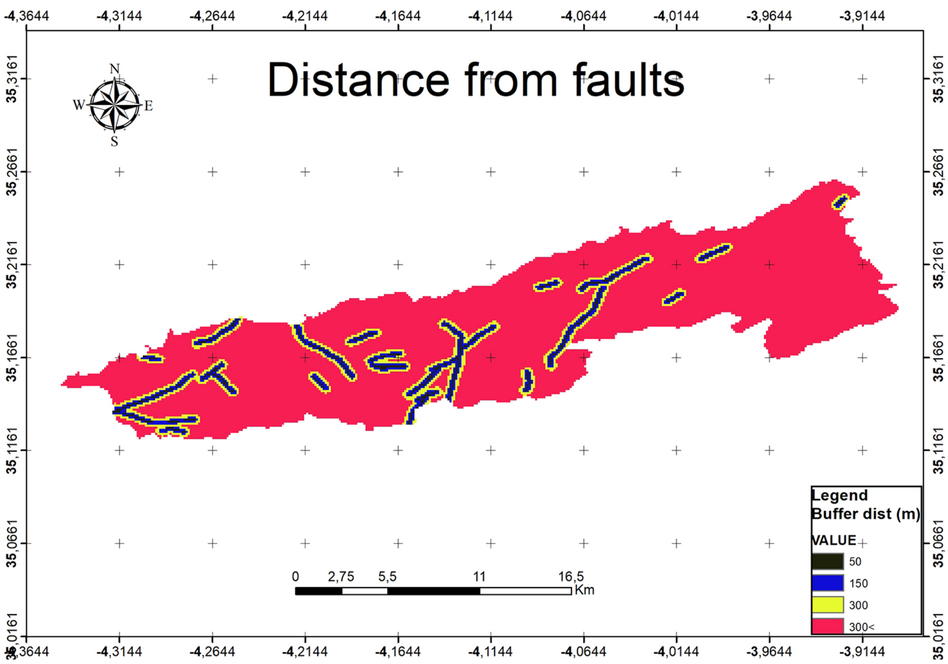

Figure 8. The distance from faults map of the study area

infiltration is decreased by increasing the distance from the faults.

$$I = C + F + S \qquad (2)$$

Based on Table 4, the infiltration class is divided into five classes. The highest score was assigned to the areas with the highest infiltration percentage, while the lowest score was assigned to the areas with the lowest infiltration percentage.

Soil factor (S)

The soil map (Fig. 10) was obtained from a geological map 1/100000 of Beni Boufrah [22] and confirmed by fieldwork. The classification of

Table 5. The soil variable and class

Soil	Arenosols	Calcareous
Class	1	6

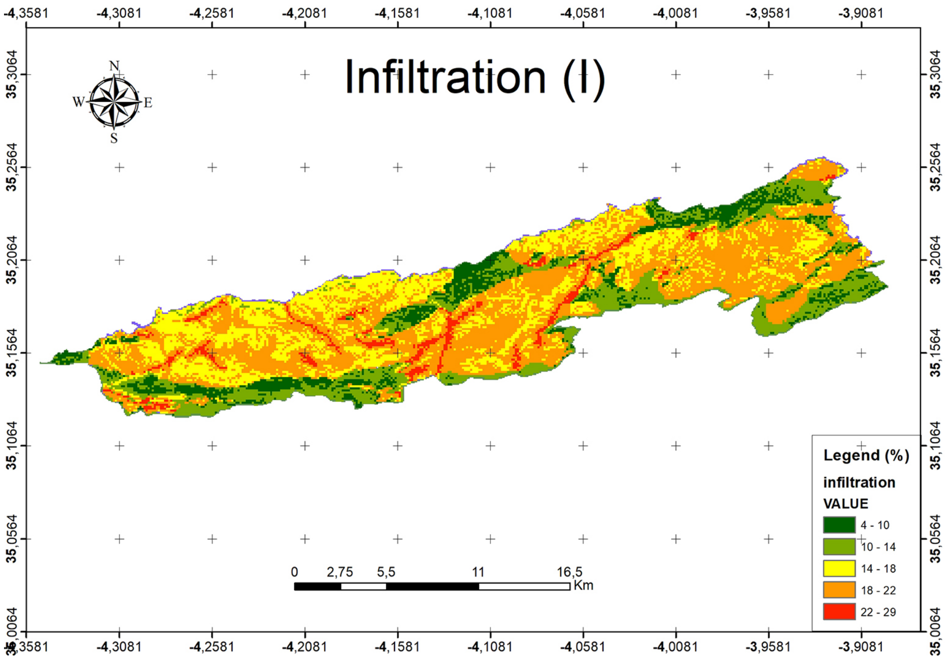

Figure 9. The infiltration map of the study area

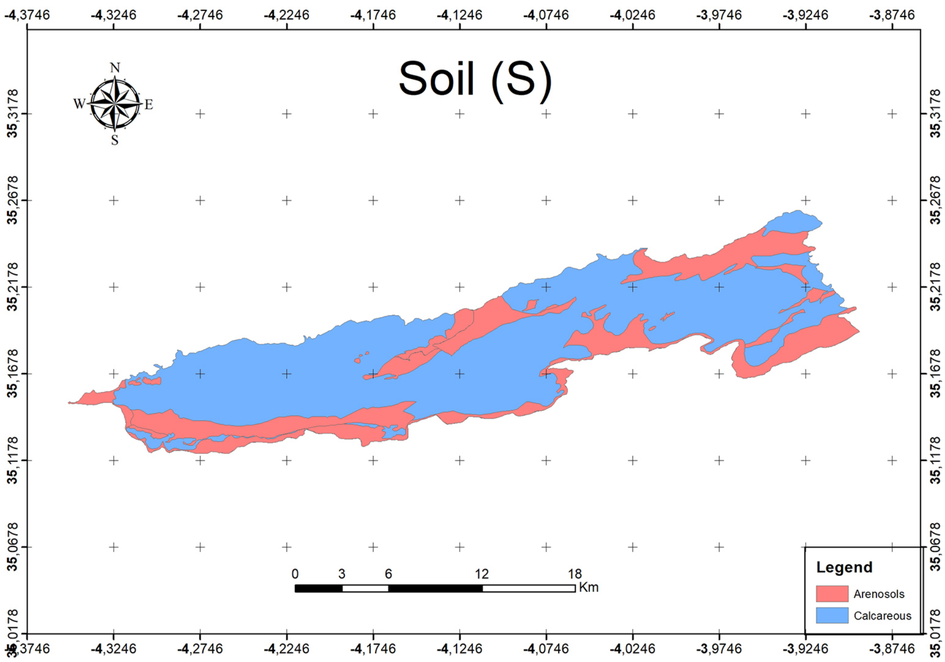

Figure 10. The soil map of the study area

different soil types and scoring for the arenosols and calcareous soil are presented in Table 5.

RESULTS

The APLIS model was prepared in the GIS environment by combining the five parameters: altitude (A), slope (P), lithology (L), infiltration (I), and soil (S), according to the APLIS equation (Eq 1). The map obtained (Fig. 11) represents an aquifer's recharge rate (percentage) in the limestone Bokoya massif. High recharges rates (61–79%) are the most described in the study area. They are associated with lineaments

Table 6. The recharge percentage and the vulnerability class and precipitation

Recharge (%)	9–21	21–34	34–61	61–79
Vulnerability	Very low	Low	Moderate	High
Precipitation mm/year	200–250	250–300	300–350	350–450

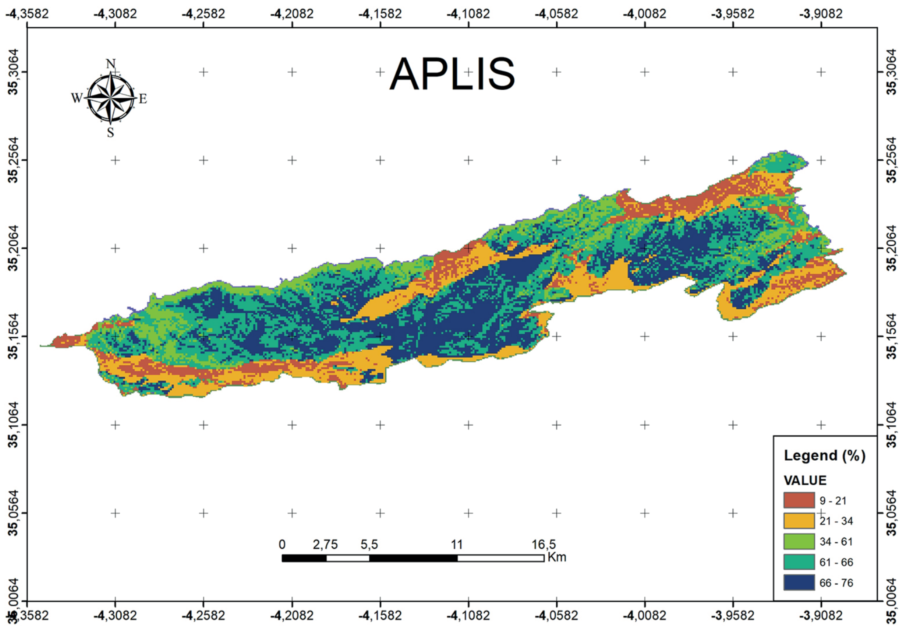

Figure 11. Recharge rate map of the study area

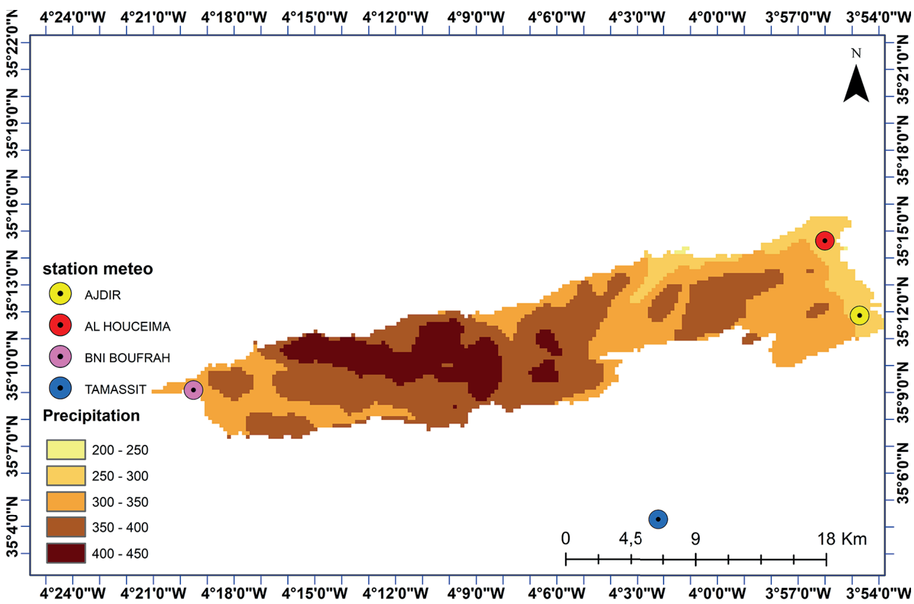

Figure 12. Precipitation map of the study area

and limestones. According to the presented calculations, our study's minimum and maximum recharge rates are 9 and 79%, respectively.

Based on Table 6, the groundwater recharge rate class is divided into four classes: very low, low, moderate, and high. The areas of highest recharge are in the centre part of the study area, surrounded by the regions of the lowest recharge rate. These results are acceptable, considering the precipitation map of the study area (Fig. 12), presenting the areas of highest annual precipitation (350 – 450 mm/year) in almost the same regions with the highest recharge rate. In this context, the conservation and management of water resource consumption are essential, and the rate of recharge of precipitation will strictly control the use of water resources in the area.

CONCLUSION

In this study, the APLIS model is achieved to quantify the spatial distribution of groundwater recharge in Bokoya massif. Furthermore, the use of the GIS environment proves its efficacy in calculating the groundwater recharge by combining layers of altitude, slope, lithology, infiltration, and soil. The results indicate the highest recharge percentage in the recharge map situated in the limestone rock of the study area, except for the limestone located on the sea cliffs owing to high slope degree. While the lowest recharge percentage is situated in clay, schist, and marl rock layers and the areas with the highest slope degree. The recharge map was compared with the annual precipitation map, which showed a relative similarity between the two maps to validate the results obtained.

REFERENCES

1. van Beynen P., Brinkmann R., van Beynen K. 2012. A sustain ability index for karst environments. Journal of Cave and Karst Studies, 74(2), 221–234. https://doi.org/10.4311/2011SS0217
2. Entezari M., Karimi H., Gholam Heidari H., Jafari Aghdam M. 2020. Estimation of groundwater recharge level in karstic aquifers using modified APLIS model. Arabian Journal of Geosciences, 13(4). https://doi.org/10.1007/s12517-020-5173-7
3. Farfán H., Corvea J.L., De Bustamante I. 2010. Sensitivity analysis of APLIS method to compute spatial variability of karst aquifers recharge at the national park of viñales (Cuba). Environmental Earth Sciences, 19–24. https://doi.org/10.1007/978-3-642-12486-0_3
4. IGME-GHUMA Q. 2003. Estudios metodológicos para la estimación de la recarga en diferentes tipos de acuíferos carbonáticos: Aplicación a la cordillera Bética. Instituto Geológico y Minero de España y Grupo de Hidrogeología de La Universidad de Málaga. Informe Inédito, 1.
5. Andreo B., Durán J., Vías J., López-Geta J.A., Carrasco F., Jiménez P. 2004. Métodos para la estimación de la recarga en acuíferos carbonáticos: Aplicación en acuíferos de la Cordillera Bética (Sur de España). Investigaciones En Sistemas Kársticos Españoles, 12(July 2019), 185–203.
6. Bakalowicz M. 2005. Karst groundwater: a challenge for new resources. Hydrogeology Journal, 13(1), 148–160. https://doi.org/10.1007/s10040-004-0402-9
7. Kirn L., Mudarra M., Marín A., Andreo B., Hartmann A. 2017. Improved assessment of groundwater recharge in a Mediterranean karst region: Andalusia, Spain. In EuroKarst 2016, Neuchâtel Springer, 117–125. https://doi.org/10.1007/978-3-319-45465-8_13
8. Alem H., Soudejani A.E., Farmanieh S.N. 2017. Groundwater recharge assessment in the karst aquifers of North Khorasan, Iran using APLIS method. Acta Carsologica, 46(2–3), 283–294. https://doi.org/10.3986/ac.v46i2-3.4740
9. Espinoza K., Marina M., Fortuna J.H., Altamirano F. 2015. Comparison of the APLIS and modified-APLIS methods to estimate the recharge in fractured karst aquifer, Amazonas, Peru. In Hydrogeological and Environmental Investigations in Karst Systems. Springer, 83–90. https://doi.org/10.1007/978-3-642-17435-3_10
10. Azzouz O. 2007. Les dolomies triasiques de la dorsale externe (Bokoya, Rif interne, Maroc): Un complexe tectono-sédimentaire du Rift oblique alboran-iberie.
11. Mourier T. 1982. Étude géologique et structurale du Massif des Bokkoya. Univ. Paris XI.
12. El Fellah B., Azzouz O., Asebriy L. 1996. Sikha Asfalou: exemple de glissement sur la côte méditerranéenne des Bokoya entre Torrès et Badis, (Rif septentrional, Maroc). Bulletin-Réseau Erosion, 16, 222–231.
13. Margaa K., Abdelgader A. 1998. Une méthodologie de cartographie des zones potentiellement instables Application à la région d'Al Hoceima (Maroc). Canadian Geotechnical Journal, 35(3), 460–470.
14. Deil U., Hammoumi M. 1997. Contribution à l'étude des groupements rupicoles des Bokkoya (Littoral du Rif Central, Maroc).

15. Martonne E.de. 1926. L'indice d'aridité. Bulletin de l'Association de Géographes Français, 3(9), 3–5.
16. Andrieux J. 1971. La structure du Rif central: étude des relations entre la tectonique de compression et les nappes de glissement dans un tronçon de la chaîne alpine.
17. Blumenthal M.M., Figuerola J.C. 1936. Esbozo geológico del Rif en la región de Bokoya. Instituto geológico y minero de España.
18. Chalouan A., Benmakhlouf M., Mouhir L., Ouazani-Touhami A., Saji R., Zaghloul M.N. 1995. Les étapes tectoniques de la structuration alpine du Rif interne (Maroc). IVème Colloque International Sobre El Enlace Fijo Del Estrecho de Gibraltar, Sevilla, 163–191.
19. Azzouz O. 1992. Lithostratigraphie et tectonique hercynienne des terrains paléozoques ghomarides du Massif des Bokoya (Rif Interne, Maroc). These 3eme Cycle, Faculté Des Sciences, 208.
20. Michard A., Chalouan A., Feinberg H., Goffé B., Montigny R. 2002. How does the Alpine belt end between Spain and Morocco? Bulletin de La Société Géologique de France, 173(1), 3–15.
21. Morad T. 2021. sismotectonique du bassin inférieur du Neckor (Rif central) - Maroc - : Apport de la télédétection, du SIG et de la topométrie. These 3eme Cycle, Univ. Abdelmalek Essaadi.
22. Andrieux J., Mégard F. 1973. Carte géologique: Feuille de Béni Boufrah (Maroc) à 1/100 000. Direction Des Mines et de La.