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Abstract: *El-Bayadh region, situated in southwestern Algeria, is marked by a semi-arid climate with scarce and irregular precipitation, making groundwater the primary source to satisfy growing water demands. Rapid economic development and population growth have further intensified the pressure on these limited resources, creating a significant deficit. This study seeks to evaluate the current status of water resources in the region, project future requirements, and anticipate the main challenges for sustainable water management. To achieve this, Geographic Information Systems (GIS) were employed to develop thematic and spatial databases, facilitating the assessment of both surface and groundwater resources. Furthermore, the hydrochemical properties of key aquifers—namely the Albian, Infra-Cretaceous, Bajo-Bathonian, and Continental Intercalary systems—were examined through Piper diagram analyses. The findings underscore the urgent necessity of adopting integrated water resource management strategies that combine conservation measures with the mobilization of non-conventional resources to secure water availability in El Bayadh.*

Keywords: *El Bayadh, Water Resources, Water Balance, GIS, Hydrochemistry, Semi-Arid Region*

1. Introduction

Water resources constitute a fundamental component of natural systems and human development [1, 2]. Globally, increasing demographic growth, rapid urbanization, and agricultural intensification have generated unprecedented pressure on water availability and quality [3, 4]. This situation is particularly critical in arid and semi-arid regions, where rainfall is scarce, irregular, and insufficient to meet the growing demand [5]. Groundwater therefore represents a strategic resource, yet its overexploitation and vulnerability to contamination pose significant risks to sustainability [6, 7]. Algeria, located in the southern Mediterranean basin, is among the countries most affected by water stress [8]. The imbalance between limited

renewable water resources and rising consumption highlights the urgent need for integrated management strategies[9, 10]. El Bayadh region, in southwestern Algeria, is characterized by an arid to semi-arid climate with low precipitation and high evapotranspiration. As a result, the population and economic activities rely predominantly on groundwater, which is increasingly threatened by both quantitative depletion and qualitative degradation[11].

Scientific approaches based on Geographic Information Systems (GIS)[12] and hydrochemical analysis provide powerful tools to evaluate the spatial distribution of water resources and to identify the processes affecting groundwater quality. Such methods are essential to establish a reliable water balance, anticipate future needs, and guide decision-making in resource management[13, 14]. The present study aims to assess the state of water resources in the El Bayadh region through a combined analysis of hydrological, hydrogeological, and hydrochemical data. Specifically, it (i) evaluates water availability and demand, (ii) characterizes the main aquifers and their quality, and (iii) explores perspectives for sustainable management under conditions of increasing water stress.

2. Materials and Methods

2.1. Study Area

El-Bayadh region is situated on the High Plateaus of southwestern Algeria, approximately 520 km southwest of the capital, Algiers. Geographically, it extends between latitudes 30°42' and 34°28' N and longitudes 0°24' and 2°16' E, covering an area of nearly 71,697 km², which accounts for about 3% of the national territory[15]. It shares boundaries with Saida and Tiaret to the north, Laghouat and Ghardaïa to the east, Timimoun and El Meniaa to the southeast, Nâama and Sidi Bel Abbès to the west, and Béchar to the southwest. Climatically, the region falls within the semi-arid to arid zone[16, 17], with an average annual temperature of 15,56 °C and mean precipitation of 277,86 mm. Rainfall is both spatially and temporally irregular, often marked by sporadic episodes of intense flooding[18]. The topography is shaped by a succession of mountain ranges, including Djebel Ksel, Djebel Oustani, Bouderga, Roundjaia, and Arif, interspersed with wide plains. Elevations generally range between 1000 and 2000 m above sea level.

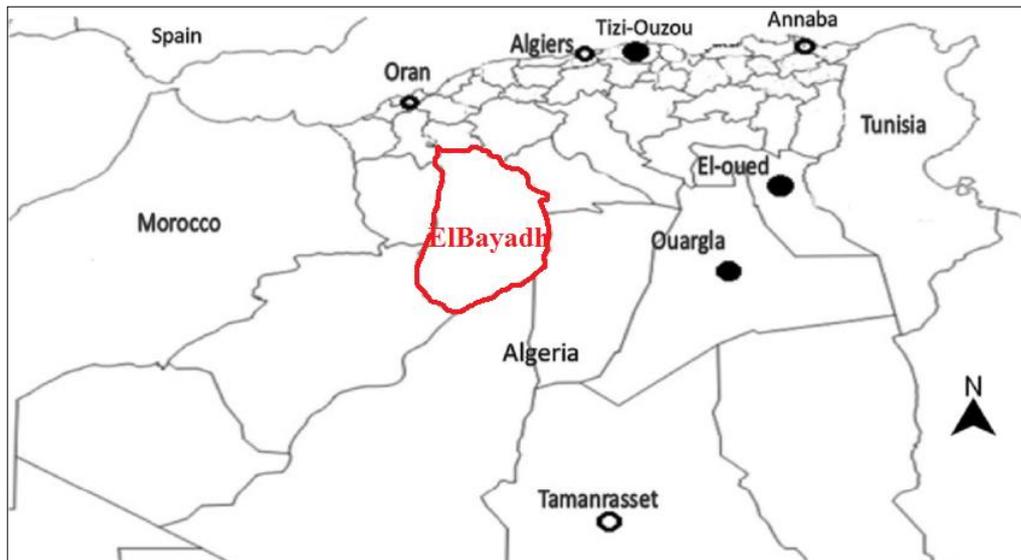


Figure 1. Area study

2.2. Data Collection

Meteorological records, including temperature, precipitation, humidity, and wind speed, were obtained from the National Office of Meteorology (ONM) for the period 1986–2017. Hydrological information related to surface water such as discharge volumes from the Brezina Dam and groundwater, including aquifer characteristics, well productivity, and groundwater table levels, was provided by the Directorate of Water Resources (DRE) of El Bayadh and the National Agency for Water Resources (ANRH).

2.3. GIS Analysis

A spatial and thematic database was developed using Geographic Information System (GIS) software. This database incorporated multiple datasets, including administrative boundaries, hydrographic networks, aquifer extents, water abstraction points (wells, boreholes, and springs)[19], and population distribution. GIS-based tools were applied to map water resource availability, assess the spatial distribution of deficits, and examine the relationship between water demand and supply across the study area.

2.4. Hydrochemical Analysis

Groundwater samples were collected from the main aquifer systems of the region, namely the Albian, Infra-Cretaceous, Bajo-Bathonian, and Continental Intercalary aquifers, in order to determine their physico-chemical properties[20]. The analyses included measurements of pH, electrical conductivity, major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+) and anions (Cl^- , SO_4^{2-} , HCO_3^- , NO_3^-), as well as total dissolved solids

(TDS). Hydrochemical facies were identified through Piper diagrams generated using specialized hydrochemical analysis software.

The evaluation of water demand included the estimation of current and future needs for drinking water, agriculture, and industrial activities, based on population growth projections and existing water usage data. Comparative analyses were carried out between available resources and forecasted demands for the years 2022 and 2032 to identify potential deficits and propose management strategies.

3. Results

3.1. Water Resources Assessment

El-Bayadh region exhibits a strong reliance on groundwater resources, largely driven by its semi-arid climatic conditions and the limited reliability of surface water supplies. Surface water is mainly provided by the Brezina Dam, which has a total storage capacity of 123 million m³. However, this capacity remains insufficient to satisfy the increasing water demand. Consequently, groundwater extracted from the Infra-Cretaceous, Bajo-Bathonian, and Continental Intercalary aquifers constitutes the principal source for both domestic consumption and agricultural irrigation. The assessment indicates a progressive decline in groundwater levels across several parts of the region, primarily linked to overexploitation. In certain areas, water tables have dropped markedly, while numerous springs-such as Ain Mahboula and Ain Agrouba have completely dried up. Future projections suggest that the demand for drinking water and irrigation will continue to increase substantially by 2032, thereby intensifying pressure on these already vulnerable resources.

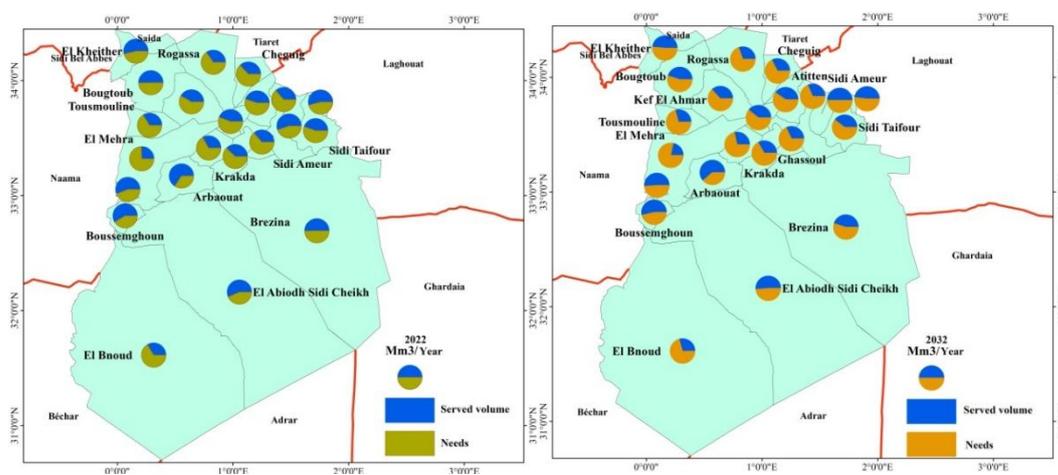


Figure 2. Spatial distribution of water needs and availability in 2022-2032 m³/year

3.2. Spatial Analysis of Water Deficit

The GIS-based spatial assessment revealed that the mismatch between water supply and demand is unevenly distributed across the El Bayadh region. Municipalities such as El Bayadh city and Brezina are already facing pronounced deficits, whereas less populated areas show comparatively lower levels of stress. Projections for 2032 indicate that, in the absence of timely management measures, the majority of the region is likely to be subjected to moderate to severe water shortages.

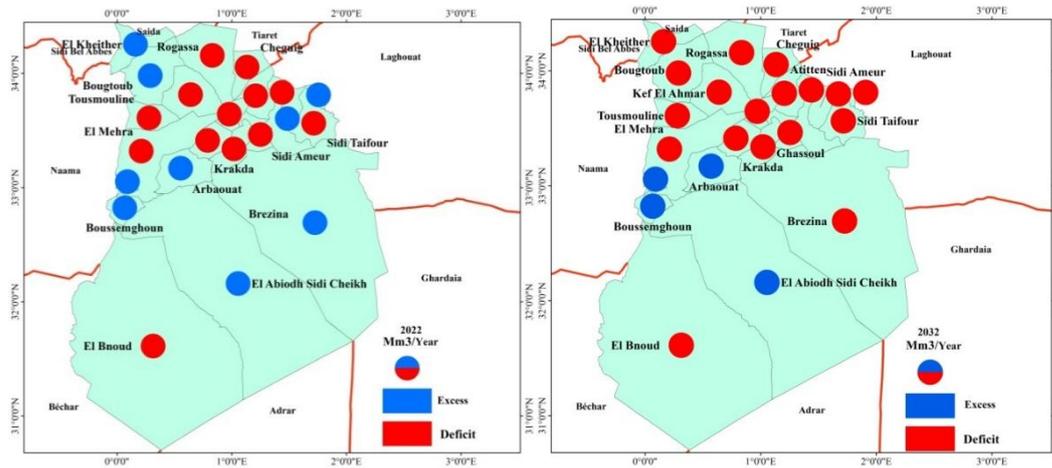


Figure 3. Spatial Distribution of Water Surplus and Deficit in 2022 and 2032

3.3. Hydrochemical Characterization

Hydrochemical analyses revealed that groundwater quality varies significantly across aquifers. Electrical conductivity (EC) and total dissolved solids (TDS) values indicated moderate to high mineralization, particularly in areas influenced by evaporitic formations and agricultural activities. The dominant ions were calcium, magnesium, chloride, and sulfate, with hydrochemical facies largely belonging to the Ca-Mg-Cl-SO₄ and Ca-Mg-HCO₃ types[21]. Elevated nitrate concentrations in some wells reflected localized contamination from agricultural practices, underscoring the anthropogenic pressures on groundwater quality[12].

Most groundwater samples complied with World Health Organization (WHO) [10] standards for drinking water, although isolated cases of high nitrate concentrations were observed, indicating possible agricultural pollution from fertilizers [11,12].

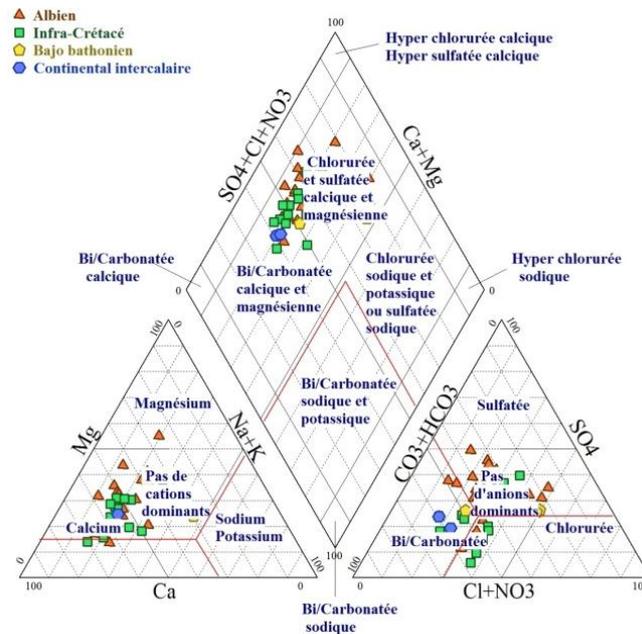


Figure 4. Piper Diagram of Groundwater in the Aquifer System of the El Bayadh Region

3.4. Implications for Water Management

The combined hydrogeological, spatial, and hydrochemical assessments highlight both the quantitative and qualitative vulnerability of groundwater resources in El Bayadh. Increasing demand, coupled with irregular recharge and localized contamination, poses serious challenges for sustainable water supply. Effective management will require the integration of hydrochemical monitoring, demand forecasting, and GIS-based spatial planning to optimize water allocation and protect aquifers from overexploitation and degradation.

4. Discussion

The findings of this study highlight the critical dependence of the El Bayadh region on groundwater resources, a situation common to many arid and semi-arid regions. The progressive decline in water levels, coupled with the drying up of springs, reflects the imbalance between recharge and exploitation rates[22]. Similar patterns have been reported in other regions of Algeria and North Africa, where increasing demand, limited recharge, and weak regulatory frameworks exacerbate water stress[23]. The spatial analysis confirmed that water scarcity is not uniformly distributed, but rather concentrated in urban and agricultural centers such as El Bayadh city and Brezina. This uneven distribution reflects both demographic pressures and land-use practices, illustrating the need for spatially targeted interventions. By integrating population data, hydrographic networks, and aquifer

extents, GIS proved to be a valuable tool for identifying priority areas for management[24]. Hydrochemical analyses further demonstrated that groundwater quality is influenced by both natural and anthropogenic factors. The dominance of Ca-Mg-Cl-SO₄ and Ca-Mg-HCO₃ facies suggests that water-rock interaction and evaporite dissolution are the main natural processes controlling water chemistry. However, the elevated nitrate concentrations observed in certain wells indicate agricultural contamination, confirming that human activity is an increasingly significant factor in groundwater degradation. Such findings are consistent with regional studies that emphasize the dual role of geology and human pressure in shaping groundwater quality.

From a management perspective, the projected increase in water demand by 2032 represents a major challenge. Without immediate action, the region is likely to face widespread water stress, threatening both domestic supply and agricultural productivity. This underlines the necessity of adopting integrated water resources management (IWRM) approaches, combining hydrogeological monitoring, demand-side management, and the promotion of more sustainable agricultural practices. Overall, the results demonstrate that addressing the water crisis in El Bayadh requires a multidimensional strategy, integrating quantitative assessments, spatial analysis, and hydrochemical monitoring. Such an approach would provide decision-makers with the scientific basis needed to balance resource availability with growing socio-economic demands, while safeguarding the sustainability of groundwater systems.

5. Conclusion

This study provided an integrated assessment of water resources in the El Bayadh region through hydrogeological evaluation, GIS-based spatial analysis, and hydrochemical characterization. The results revealed that groundwater is the main source of supply for domestic and agricultural needs due to the semi-arid climate and the limited reliability of surface water. However, declining groundwater levels, the drying of springs, and increasing demand indicate that the resource is under significant quantitative stress. The spatial analysis highlighted uneven distribution of water deficits, with urban and agricultural areas such as El Bayadh city and Brezina being the most affected. Projections for 2032 suggest that, without immediate intervention, the majority of the region will face moderate to severe

shortages. Hydrochemical investigations showed that groundwater quality is generally controlled by natural processes such as water-rock interaction and evaporite dissolution, leading to facies dominated by Ca-Mg-Cl-SO₄ and Ca-Mg-HCO₃ types. However, elevated nitrate concentrations in certain areas point to localized anthropogenic contamination, particularly from agricultural practices.

Taken together, these findings underscore the urgent need for integrated and sustainable water management strategies. Such strategies should combine continuous hydrochemical monitoring, GIS-based spatial planning, optimization of water allocation, and the adoption of sustainable agricultural techniques. Only through proactive measures can the El Bayadh region secure its water resources, ensure their equitable distribution, and preserve their quality for future generations.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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