

Water resources in Algeria and Poland in the light of adaptation to climate change

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How to cite:

Kubiak-Wójcicka, K., Messis, M.-S., Mebarki, A., & Merabti, A. (2026). Water resources in Algeria and Poland in the light of adaptation to climate change. *Bulletin of Geography. Socio-economic Series*, 73(73): 81-100. <http://doi.org/10.12775/bgss-2026-0027>

Abstract. The pressure on water resources that the world is facing results from water shortages and the increasing demand for water by various sectors of activity. Depending on the region, the impact of climate change and population growth have different consequences, which largely depend on the management of water resources. The aim of the study is to estimate the size of available renewable water resources in Algeria and Poland in the years 1991–2020 and the degrees of their use by individual sectors of the national economy. In the 30-year study period, an upward trend in the total amount of water withdrawn in Algeria was observed, while for Poland a downward trend was observed that mainly resulted from changes in population size. There is a significant differentiation in the breakdown of uses for which water is extracted, i.e., industrial purposes predominate in Poland and agricultural purposes in Algeria. In both countries, water withdrawal for agricultural purposes has increased in recent years due to greater demand for irrigation water. This problem is compounded by various state subsidies for agricultural purposes, which calls into question the appropriateness of practices and strategies used at both local and national levels.

Article details:

Received: 26 June 2025
Revised: 22 July 2026
Accepted: 07 September 2026

Key words:

water resources
management,
climate change,
water stress,
population,
geography, planning &
development,
Algeria,

Contents:

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1. Introduction

Water has always been foundational to human existence, as human life depends on access to water. With the development of civilization and the growing population worldwide, the demand for clean water by various sectors of the economy has increased significantly (Biswas & Tortajda, 2018; Van Vliet et al., 2021). Water is a renewable resource, the amount of which varies both in time and by region (Cheng & Hu, 2012). In recent years, there has been a growing demand for water, which has reduced global freshwater resources. This pressure has several main sources, including population growth and the concomitant need for increased food production, greater industrialization, pollution caused by human activities, and the effects of climate change (Kundzewicz et al., 2007).

Recent reports and scientific publications indicate that the impact of climate change has increased over the past few decades, leading to increasingly frequent extreme events, including floods and droughts (IPCC, 2022). Climate change will affect the availability of water resources in river basins (Heyi et al., 2022; Abbas, 2023), thereby aggravating water problems, especially in areas with relatively few resources (Jankovic-Rankovic et al., 2024). Therefore, the problem of freshwater scarcity has become one of the key problems facing humanity. Water crisis is considered one of the greatest global threats in terms of impact on society and the environment (Nkiaka et al., 2021; Ingrao et al., 2023; Amparo-Salcedo et al., 2025). Both economic development and water security are threatened by poor water resources management, which should primarily focus on the dynamic relationship between people and water (Cook & Bakker, 2012; Cosgrove & Lucks, 2015; Zeitoun et al., 2016; Ahopelto et al., 2024).

Water is becoming an increasingly high-priority political issue at the international level. Sustainable management of water resources has therefore become a central topic of debate at the United Nations. One of the most important global agreements was the United Nations' (UN) adoption of the Sustainable Development Goals (SDGs) in 2015. This is a call to action for all countries to promote prosperity while protecting the planet (<https://www.un.org/sustainabledevelopment/>). One of the 17 Sustainable Development Goals adopted was SDG6 on water and sanitation (*The Sustainable Development Goals*, 2025). SDG 6 aims to ensure safe drinking water and sanitation for all, focusing on the sustainable management of water resources, wastewater and ecosystems and recognizing the importance of an enabling

environment. In the 2030 Agenda for Sustainable Development, countries committed to systematically monitor and review progress towards the goals and targets, using a set of global indicators (<https://www.sdg6data.org/en>) (Marcal et al., 2021). More than 150 different indicators are used to assess water stress (Damkjaer & Taylor, 2017; Bouchentouf & Benabdeli, 2021). Eleven global indicators have been adopted to track progress towards SDG 6. Global estimates are based on national data collected and verified by the responsible UN agencies and sometimes supplemented with data from other sources. For some indicators, insufficiency of national data hampers global estimates (<https://www.sdg6data.org/en>). It should be noted that each region differs in its water sensitivity and therefore requires different adaptation measures. There is therefore a need to assess the vulnerability of water resources systems for improved management strategies, including robust adaptation measures for future sustainable water use (Mohammed & Al-Amin, 2018; Ciampittello et al., 2024; El Boute et al., 2024; Su et al., 2024). Vulnerability assessment can explain the capacity of water resources to meet regional water demands under pressure (Wei et al., 2022).

This study reviews water resources management for two regions: Algeria and Poland. Despite their distinct environmental conditions, both countries face similar challenges in finding sustainable solutions to water problems.

In this article, we conducted an analysis of water resources and their use for the needs of different sectors of the national economy in order to better plan and manage water resources in Algeria and Poland. The study aimed to meet four main objectives: identify the main freshwater resources, assess levels of water use in economic sectors, review the management framework, and compare existing policies. We hope that presenting the current state of knowledge on water resources and their use will give an impetus to decision-makers and other stakeholders to take action to improve the use of water resources in the future.

2. Materials and methods

2.1. Study area

Poland. According to data from Statistics Poland (*Generalny Urząd Statystyczny*) for 2021, the total area of the country was 322,719 km², and the population of Poland at the end of December 2020 was 38.265 million (Statistics Poland, 2021) (Table 1). Among the 27 member states of the European

Union, Poland ranks sixth in terms of area and fifth in terms of population. Since 2010, there has been a significant decline in the population of Poland. The population fell from 38.538 million at the end of 2011 to 37.637 million at the end of 2023. In administrative terms, Poland is divided into 16 voivodeships (Fig. 1). The largest by population are the Mazowieckie and Śląskie voivodeships, while the smallest is the Opolskie voivodeship. The average population density in Poland at the end of 2020 was 122 people per 1 km². The highest average population density in Poland at the end of 2020 was recorded in the Silesian Voivodeship (364 people·km⁻²), Lesser Poland Voivodeship (225 people·km⁻²) and Masovian Voivodeship (153 people·km⁻²). The voivodeships with the lowest population density are Podlaskie Voivodeship (58 people·km⁻²) and Warmian-Masurian Voivodeship (59 people·km⁻²) (*Demographic Yearbook*, Statistics Poland, 2021). The highest population density is recorded in cities. The cities with the largest populations outside Warsaw are (in descending order) Kraków, Łódź, Wrocław, Poznań, Gdańsk, Szczecin, Bydgoszcz, Lublin and Katowice (Kubiak-Wójcicka, 2021). There are 37 cities in Poland with a population of over

100,000 inhabitants, the most populous of which is the capital, Warsaw (1.8 million) (Statistics Poland, 2021). The majority of the Polish population lives in cities or towns (59.86%), while 40.14% of the total population of Poland lives in rural areas.

Poland is a lowland country, with almost 50% of the country's surface being at altitudes of 100 to 200 m above sea level. Mountainous areas (>500 m a.s.l.) constitute only 3% of the country's surface. The topography of Poland is characterized by a belt-like relief system – a young-glacial landscape (with a belt of coastlines and lake districts) in the northern part of the country, an old-glacial landscape in the central part, and a belt of uplands and mountains in the south (<https://www.gov.pl/web/gdos/polska-w-liczbach>).

Algeria. Algeria covers an area of 2,381,741 km² and has a population of 43.85 million. In terms of area, Algeria is the largest country in Africa. The territory of Algeria stretches from the south-western shores of the Mediterranean Sea to the Ahaggar massif in the Saharan interior (Fig. 2). Administratively, Algeria is divided into 58 wilayas (i.e., provinces; note that this increased to 69 in late 2025), three national

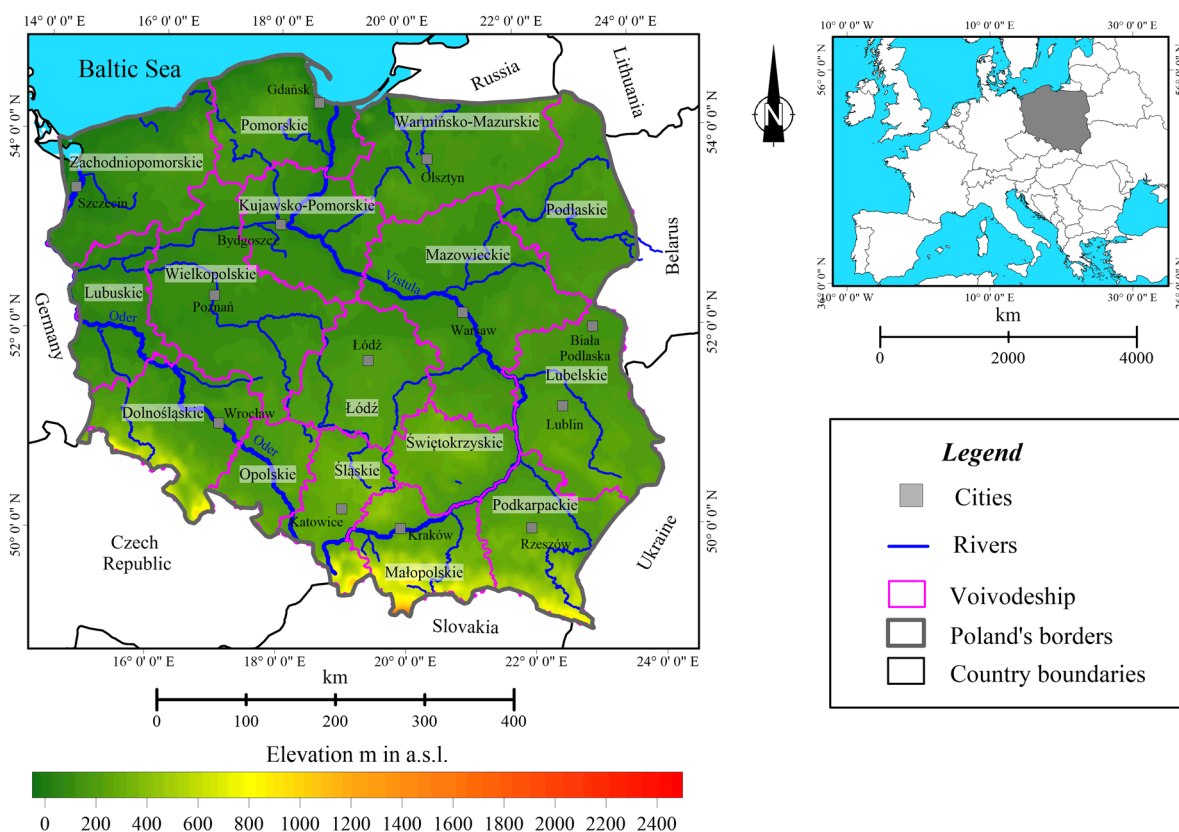


Fig. 1. Map of Poland based on DEM data, showing the largest cities and administrative division
Source: own study based on www.geoportal.gov.pl

metropolises (Oran, Constantine, Annaba) and one international metropolis – the capital, Algiers. In Algeria, the territorial division is presented in three successive levels – wilaya, daïra and municipality. Based on the criterion for designation as a city being the number of inhabitants (defined in the law on the orientation of cities 06-06 of February 20, 2006), we noted three main sizes: Large city: more than 100,000 inhabitants; Medium city: 50,000–100,000 inhabitants; and Small city: 20,000–50,000 inhabitants (Aibeche et al., 2023). Most of the population of Algeria lives in cities (73.7% of the population), while a much smaller number lives in the countryside (26.3%). The cities with the largest populations are (in descending order) the capital Algiers (2.2 million people), Oran, Constantine, Batina, and Djelfa. The average population density is 18.41 people·km⁻². According to estimates, the population of Algeria is growing and could reach about 51 million inhabitants by 2030 (Kherbache, 2014). Algeria is characterized by a mountain/steppe zone with high plateaus (9% of the country) dominated by a continental climate and extending into the vast Saharan regions (87% of the country's territory).

Unfavorable environmental conditions (arid areas with little rainfall) mean that only 17% of Algeria's territory is used for agriculture. In addition to these large disparities in the natural environment, there are similar disparities in population density. The coastal zone concentrates more than 63% of the total population, while the high plateau regions are home to 26% of the country's total population, and only 11% of the population inhabits the Saharan regions (Kherbache, 2020).

The presented conditions of Algeria and Poland indicate that the two countries are characterized by different conditions, not only environmental, but also social and economic. Gross domestic product *per capita* in Poland is over six times that of Algeria (Table 1). Data show that protected areas constitute only a small part of Algeria (0.036%) but ~32.2% of Poland.

2.2. Data and methods

This study compared water resources and the degree of their use in Algeria and Poland. Due to the limited

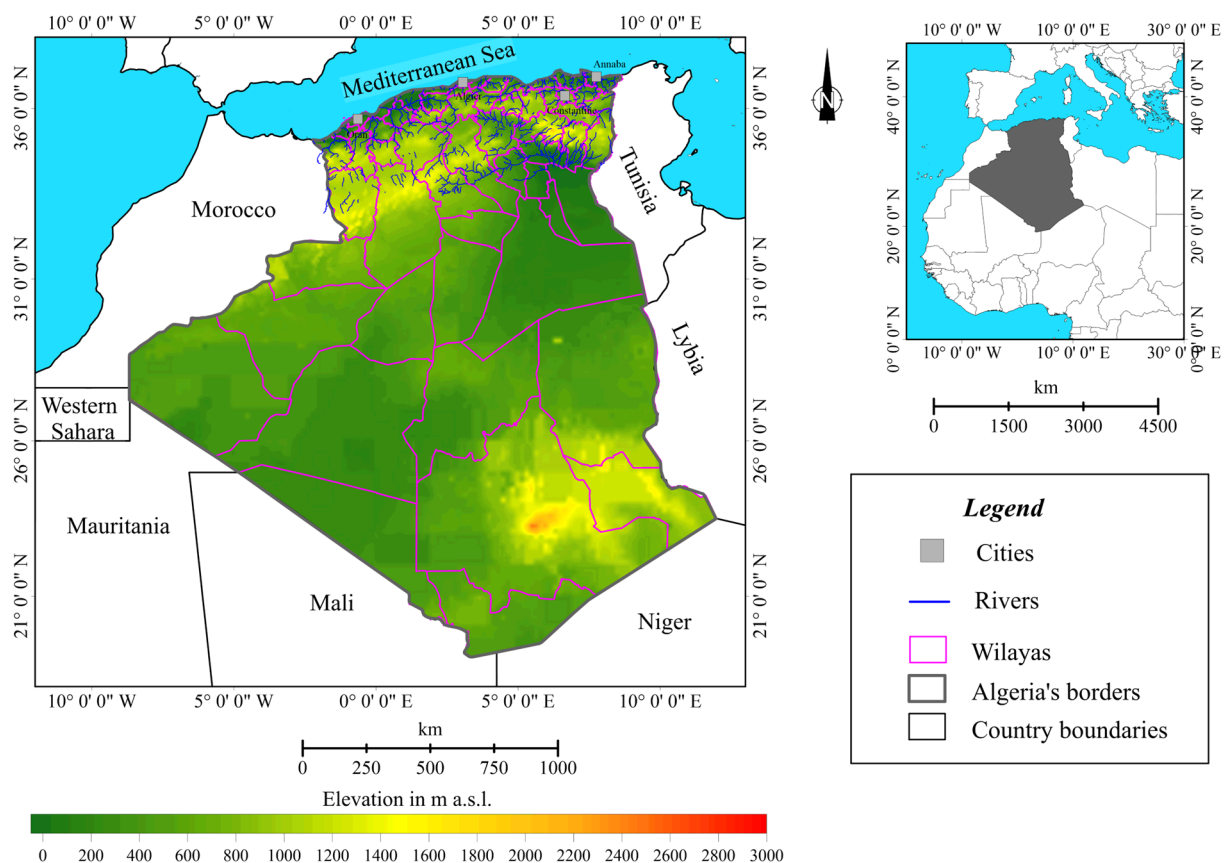


Fig. 2. Map of Algeria based on DEM data, showing the largest cities and administrative division

Source: own study based on <https://geoalgeria.com/>

Table 1. Area, population and land use characteristics of Algeria and Poland, 2020

Indicator	Algeria (2020)	Poland (2020)
Country area (km ²)	2,381,741	322,719
Population (million people)	43.851	38.265
Urban	32.318 (73.7%)	22.905 (59.86%)
Rural	11.533 (26.3%)	15.360 (40.14%)
Elevation differences (m)	2,957	2,500.8
Lowest terrain (m a.s.l.)	−39	−1.8
Highest terrain (m a.s.l.)	2,918	2,499
Land use by sector		
Agriculture	17%	47%
Forest	1%	31%
Other (2018)	82%	22%
Area of legally protected areas (% of country's area)	0.036%	32.2%
Gross Domestic Product (GDP) per capita	USD 5,285	USD 32,690

Source: CSO, JORA, *UN Water: <https://www.sdg6data.org/en/country-or-area/Algeria>

scope of available statistical data for Algeria, data from official national and international statistics were adopted for the study. The adoption of data from the same years allowed for a comparison of some parameters and indicators characterizing general conditions, including area, population, and land use for both countries. Data came from the Office National des Statistiques in Algeria (<https://www.ons.dz/spip.php?rubrique378>) and Statistics Poland (<https://stat.gov.pl/>), as well as from United Nations Water (UN Water: <https://www.sdg6data.org/en/data-lab>). Annual precipitation and annual runoff in 2020 were used to assess water resources and determine water shortages. The data come from reanalysis data from ERA5 models (Hersbach et al., 2020). The reanalysis data used in the above studies brings together a large amount of high-resolution data from satellite and conventional observational sources (Qiu et al., 2023). These data are available as a 0.25° spatial resolution grid (<https://cds.climate.copernicus.eu/>), which we transformed into a 0.01° resolution grid using the kriging method. This method is based on the validation of the variogram model (spherical model) using the Root Mean Square Error (RMSE) parameter by choosing the lowest value (Willmott & Matsuura, 2006). The final maps are realized using SURFER® software (Golden Software, 2024). This model is widely used in the field of water resources management (Aschale et al., 2024; Bodjrenou et al., 2024; Tripathy & Mishra, 2024).

The following indicators were adopted from the global indicators used to track the SDG 6 goals: water resources in total km³, water resources *per*

capita (m³ *per capita*), water abstraction structure for industrial, agricultural and municipal purposes as % of renewable water resources, and the water stress indicator calculated as water abstraction in relation to water resources (%). These indicators are among the most popular indicators assessing the size of water resources and the degree of their use (Damkjaer & Taylor, 2017). These indicators were selected due to the long observation period (1991–2020), which allowed for the analysis of trends in changes. These indicators were adopted based on data available on the Our World Data website (<https://ourworldindata.org/water-use-stress>) and United Nation Water (UN Water) (2025) <https://www.sdg6data.org/en/country-or-area>.

The Mann–Kendall test was used to detect trends for the adopted indicators in the years 1991–2020. A correlation was made between the population size and the annual FreshWater Abstraction (AFW), and then the share of Municipal Water in the total water abstraction (MW). The correlation between the indicators was implemented based on the “gg-corrplot” package in R software.

2.3. Water resources management

In terms of hydrographics, almost the entire area of Poland is located in the Baltic Sea catchment area. More than half of Poland's area – as much as 54% – lies in the Vistula River basin, 33.9% lies in the Oder River basin, and 11% belongs to the catchment areas of the Baltic Sea coastal rivers. The administrative

borders of Poland coincide with the hydrographic borders, which is important from the point of view of water management (Kubiak-Wójcicka, 2021). The terrain and climatic conditions are conducive to agricultural use, with as much as 47% of the country being used for agricultural purposes. Forest areas constitute 31% of the country's area (Table 1). The main entity responsible for national water management in Poland is the State Water Management Polish Waters. Polish Waters operate under the provisions of the *Act of 20 July 2017 - Water Law* (Journal of Laws, items 1566 and 2180). Water resources management is carried out by the National Water Management Authority with its seat in Warsaw (the central unit) and 11 Regional Water Management Authorities (RZGW) with their seats in Białystok, Bydgoszcz, Gdańsk, Gliwice, Kraków, Lublin, Poznań, Rzeszów, Szczecin, Warsaw and Wrocław. The division into RZGWs is hydrographic and includes individual catchments and river basins. Polish Waters exercise ownership rights in relation to waters that are the property of the State Treasury (Fig. 3).

Algeria is divided into 17 watersheds, only seven of which have an outflow that reaches the ocean (the Mediterranean Sea) (Fig. 4). The remaining basins are endorheic, meaning that their outlets do not reach the sea but are lost in closed areas such as sebkhas (salt flats or salt marshes) (Sebkha of Oran, Sebkha of El Golea, Sebkha of Ouargla), chotts (salt lakes) (Chott Melghir, Chott Ech Chergui and Chott Zahrez) or depressions. The Cheliff wadi (river) is the longest wadi in Algeria that rises from the Djbel Amour and flows for about 700 km before reaching the Mediterranean Sea (Messis et al., 2024, 2025). It drains an area of 43,750 km², or 1.83% of Algeria's total area. These watersheds are characterized by low runoff, with a runoff coefficient (E_c) ranging from 2.3 to 38.4%, resulting in a very significant runoff deficit (Mebarki et al., 2013). These unfavorable conditions are the reason for the low proportion of land used for forestry (1%) and agriculture (17%) (Table 1). Since 1996, the 17 watersheds have been managed by five hydrographical basin agencies (ABH) created by Executive Orders 96-279, 96-280, 96-281, 96-282 and 96-283 of 26 August establishing the ABH Algerois-Hodna-Soummam, ABH Constantinois-Seybousse-Mellegue, ABH Oranie-Chott-Chergui,



Fig. 3. Map of the hydrographic division of Poland

Source: own study based on www.geoportal.gov.pl

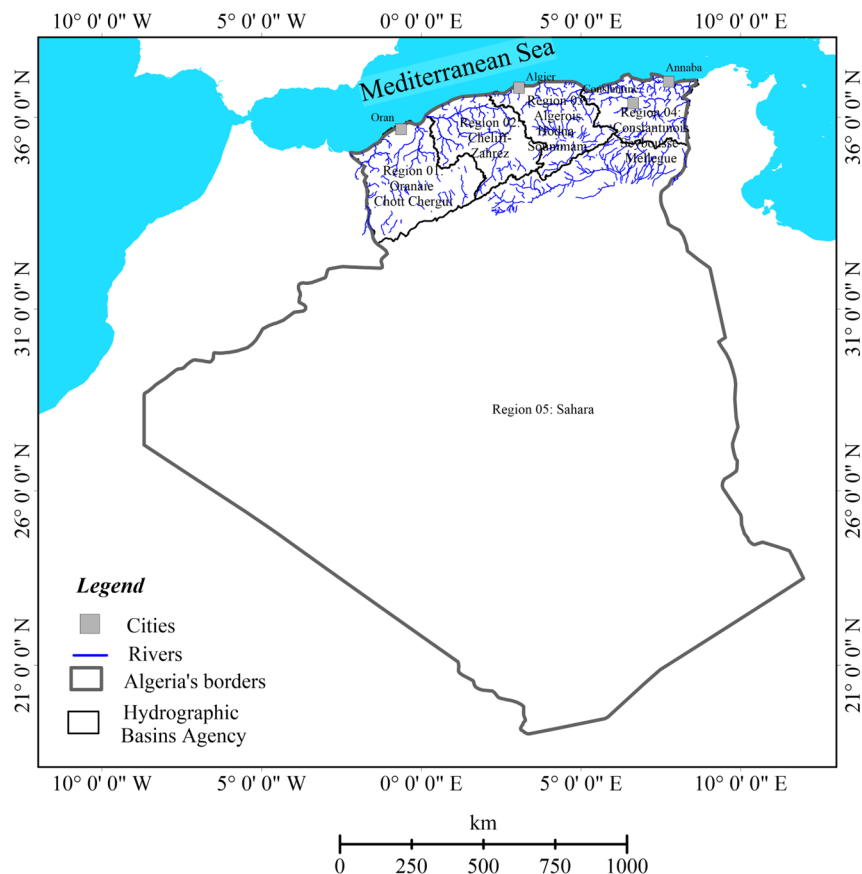


Fig. 4. Map of the hydrographic division of Algeria

Source: own study based on <https://geoalgeria.com/>

ABH Cheliff-Zahrez and ABH Sahara (JORA, 1996). These agencies have been under the supervision of AGIRE (National Agency for Integrated Water Resources Management) since 2011, the year AGIRE was officially established by Executive Decree 11-262 of 30 July 2011 and placed under the supervision of the Ministry of Water Resources (JORA, 2011).

3. Results

3.1. Precipitation in Poland and Algeria

The main source of water resources in Algeria and Poland is atmospheric precipitation, which is characterized by high spatial and temporal variability. The variability of annual precipitation totals, which determines the size of water resources, is very large, and the multi-year average values depend on the adopted research period. The spatial distribution of atmospheric precipitation in Algeria and Poland is presented using the example of 2020. In the case

of Algeria, the average annual atmospheric precipitation in 2020 was 53.8 mm, while in Poland it was 776.5 mm. As Figure 5 shows, the distribution of atmospheric precipitation in both countries is spatially diversified and is related to altitude and distance from the sea. In Algeria, the highest precipitation totals are recorded in the northern part of the country, in the immediate vicinity of the Mediterranean Sea and in mountainous areas (>400 mm). In the central and southern parts of Algeria (desert and semi-desert areas), rainfall is low and amounts to less than 100 mm. The land is poor due to unfavorable climatic conditions, with only an estimated 100,000 hectares of usable agricultural land (FAO, 2005). In terms of precipitation, Algeria can be divided into four characteristic zones, which run parallel from the highest in the north to the lowest in the centre and south. These are: the coast, with rainfall ranging from 600 to 1000 mm per year; the highlands, with rainfall ranging from 400 to 600 mm; the steppes, with rainfall ranging from 100 to 400 mm; and the Sahara, with rainfall below 100 mm. The coastal and mountainous regions together form the Tellian region (Drouiche et al., 2012).

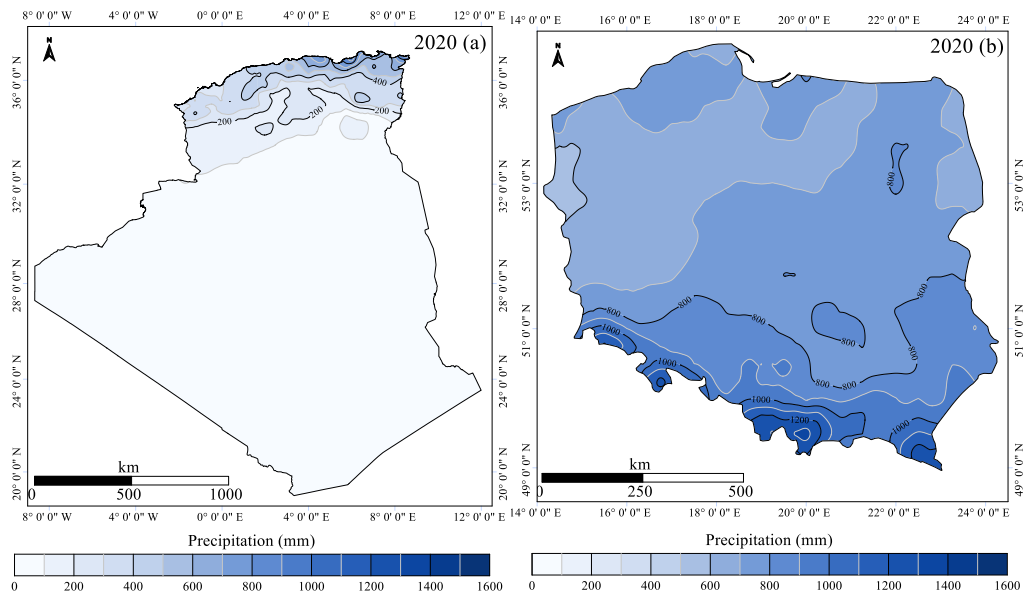


Fig. 5. Distribution of annual precipitation totals in selected calendar years in Poland and Algeria in 2020

Source: own study based on <https://cds.climate.copernicus.eu/>

In Poland, precipitation totals are highest in the south, in mountainous areas, at 1000 to 1600 mm. In upland areas, annual precipitation totals reach values from 800 to 1000 mm. In the central part of the country, precipitation is the lowest, not exceeding 600 mm. Slightly higher precipitation values (above average) are recorded in the northern part of Poland in the lake districts (~800 mm).

The regions of Algeria most affected by rainfall deficits are, apart from the Sahara, the High Plateaus and the Steppes. They are transition zones between the north and the south of the country and cover ~70% of the fertile land in the north. They have real agricultural potential and ensure the country's food security (Dali, 2021). In Poland, the areas of least precipitation in 2020 were central and western Poland. Central Poland is used for agriculture, with exceptionally good soils, but is experiencing water deficits. Therefore, climate change, which is characterized by high variability of precipitation, will have an impact on the volume of agricultural production.

3.2. Water resources

Renewable water resources depend on meteorological conditions, including precipitation. The average amount of renewable resources for Poland calculated based on river runoff from the country is ~60 km³ per year. In recent decades, river runoff has shown large fluctuations from 37.6 km³ (1954) to almost 87 km³ (2010) (Kubiak-Wójcicka & Machula, 2020;

Kubiak-Wójcicka & Kielik, 2021). This gives an average annual *per capita* water resource of ~1600 m³, while in most European countries, freshwater resources are above 5,000 m³ *per capita* (CSO, 2023). Among the 27 European Union countries, only Cyprus (500 m³ *per capita*) and Malta (200 m³ *per capita*) have lower water resources *per capita*. According to the UN, the limit below which a country is considered to be at risk of water shortage is 1,700 m³ *per capita*. This means that Poland is in the group of countries classified as below the level of water security. However, the amount of water resources *per capita* is variable. The resources of flowing water in Poland *per capita* during the year were 1,061 m³ in 2015, 1,095 m³ in 2020 and 2,255 m³ (2010) (Fig. 6). The average value in the years 1999–2018 was 1,566 m³ *per capita*, which means that Poland is in the group of countries with low water resources exposed to water stress (Kubiak-Wójcicka & Machula, 2020). Renewable water resources in Algeria are estimated to be ~12.2 billion m³/year (23% for groundwater, which is 2.8 billion m³, of which 800 million m³ in the south of the country, and 77% for surface water, i.e. 9.4 billion m³) (Drouiche et al., 2012; Hamiche et al., 2015; Oulmane et al., 2022). In addition, in the south of the country there are large amounts of groundwater (from the intercalary continental and terminal complex) estimated at over 50,000 billion m³. In recent years, the potential of water resources *per capita* and per year has significantly decreased. Water availability *per capita* has decreased from an average of

1,500 m³/year in 1962 to 630 m³/year in 1998 and 292 m³/year in 2014 (FAOSTAT, 2015). This ratio is low compared to other Mediterranean countries such as Morocco (879 m³/year) and Tunisia (420 m³/year) in 2013 (FAOSTAT, 2015). This situation places Algeria among the countries that live under water stress, with an average resource *per capita* well below the World Bank's scarcity threshold of 1,000 m³/year (Touitou & Al-Amin, 2018)). To cope with this situation, the use of non-conventional water has recently gained interest from public authorities, as it can provide Algeria with significant water potential. It consists in the production of freshwater by desalination of seawater or by demineralization of salt water, artificial recharge of groundwater and wastewater treatment (Hamiche et al., 2015). These options offer the possibility of reducing or at least preserving conventional water resources by increasing the availability of water in the agricultural sector. One of the most important indicators of water security is the amount of renewable water resources *per capita*. Renewable resources *per capita* depend on two factors: the total amount of renewable flows and the size of the population. As Table 2 shows, renewable resources *per capita* in Algeria are decreasing, mainly due to population growth, while in Poland they are slightly increasing due to population decline. In order to maintain a sustainable level of water resources, the rate of water withdrawal must be lower than the rate of freshwater replenishment.

It should be noted, however, that the data presented include average values and do not take into account the variability of seasonal water resources; nor do they present the variability associated with the spatial differentiation of water resources depending on the region. In addition to renewable water resources, some water comes from groundwater intakes, drainage of mine areas and water desalination.

3.3. Water needs

Providing water for the needs of the national economy and population is an important element of the socio-economic development of each country. Table 2 presents the total annual withdrawals of fresh water, which exclude evaporation losses from storage reservoirs. Total water withdrawals are the sum of withdrawals for agriculture, industry and municipal economy (domestic use). Withdrawals for Algeria also include water from desalination plants.

As can be seen in Figure 6, there is a downward trend in water withdrawals in Poland over the period 1991–2020, while in Algeria there is an upward trend. The years 2017–2018 are worth noting, when water withdrawals in both countries amounted to ~10 km³ per year.

From the point of view of water security of the society living in a given country, an important indicator is the amount of freshwater per inhabitant. This indicator is called the Water Stress Index and is the most commonly used indicator because it allows for a comparison of water availability in individual countries. It was proposed by Falkenmark (1989). According to this indicator, a country is defined as affected by water shortage when its *per capita* water supply decreases below 1700 m³/year, water shortage when water supply falls below 1000 m³/year, and absolute water shortage occurs when water supply falls below 500 m³/year (Damkjaer & Taylor, 2017; Khan & Khan, 2022). In light of these thresholds, Poland is classified as a country with water shortage, because its freshwater resources are below 1700 m³/capita/year, while Algeria is a country affected by absolute water shortage, with freshwater resources below 500 m³/capita/year (Fig. 7). Over the 30 years analyzed, a slight upward trend in Poland's water resources is

Table 2. Water resources and water withdrawal in 2015

Indicator	Algeria	Poland
Total water resources (km ³)	19.4	40.8
Renewable freshwater resources (dam ³ per capita)	0.488	1.061
Total water withdrawals (km ³)	10.30 (100%)	10.502 (100%)
Surface waters (%)	31.00	83.5
Underground waters (%)	52.14	16.0
Other waters (%) ¹	16.86	0.5
Freshwater withdrawals by use (km ³)	9.41 (100%)	10.502 (100%)
Industry (%)	1.60	74.3
Irrigation in agriculture (%)	65.46	9.9
Public water-supply network (%)	32.94	15.9
Total water consumption (m ³ /capita/year)	236.86	271.9

Source: <https://ourworldindata.org/water-use-stress>

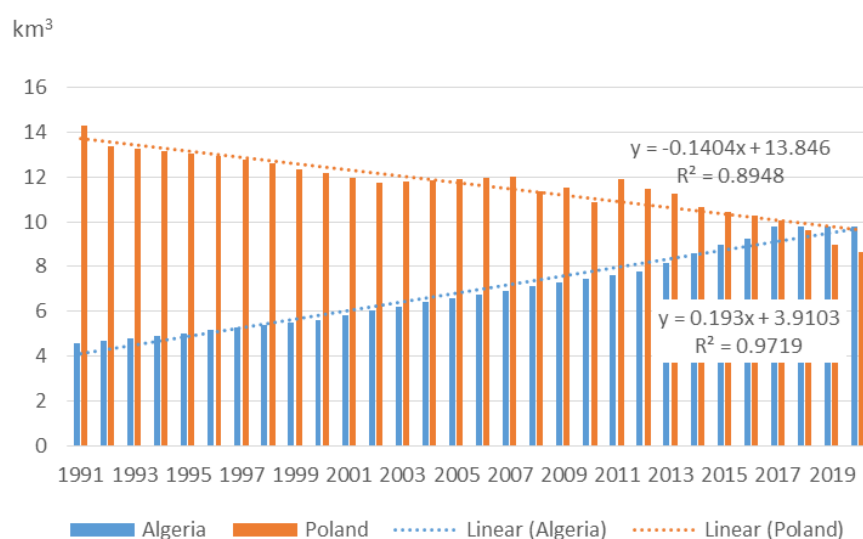


Fig. 6. Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins, measured in cubic metres (m^3) per year
Source: own study based on <https://ourworldindata.org/water-use-stress>

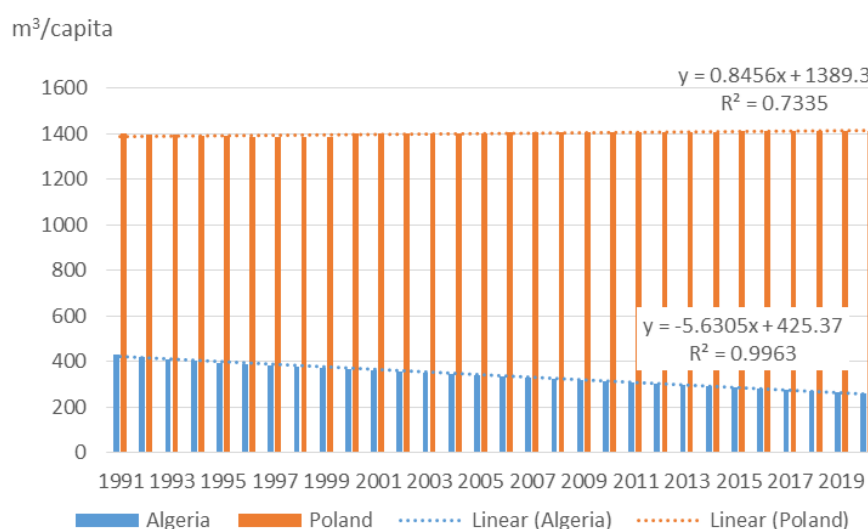


Fig. 7. Renewable freshwater resources per person
Source: own study based on <https://ourworldindata.org/water-use-stress>

visible, which is a positive phenomenon. The size of *per capita* water resources in Poland remained at 1386–1414 m^3/year . In Algeria, a clear downward trend in water resources was noted, which means a decrease in water resources *per capita*. The decrease or increase in water resources in this case should be mainly associated with the changing population size. Intensive population growth in Algeria led to a decrease in water resources *per capita* from 430 to 259 m^3/year in the period 1991–2020. Another

indicator of water stress is the percentage of freshwater withdrawn for industry, agriculture and population needs relative to renewable water resources (Fig. 8). If the value exceeds 100%, it means that part of the water withdrawn for various purposes of the national economy comes from other sources, e.g. from seawater desalination, or is collected from groundwater intakes.

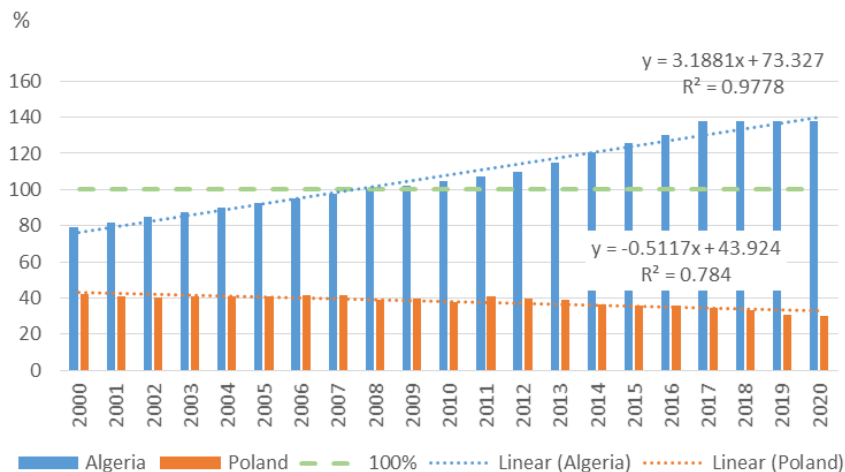


Fig. 8. Freshwater withdrawal refers to the total water withdrawal from agriculture, industry and municipal/domestic uses. Withdrawal may exceed 100% of the total renewable resources if extraction from non-renewable aquifers or desalination plants is significant
Source: own study based on <https://ourworldindata.org/water-use-stress>

3.4. Water withdrawal structure

In addition to the amount of water withdrawn in the national context, the structure of water withdrawal (i.e., the economic purposes for which water is withdrawn) is an extremely important element. From the point of view of water withdrawal, national statistics most often divide water into use for industry, for agriculture (including irrigation) and for the supply of drinking water to the population (municipal purposes, operation of the water supply network). The structure of water withdrawal differs greatly between the two countries.

In Poland, the main source of supply for the national economy is surface water. Its collection in 2020 covered 79.6% of needs (mainly production in industry), while groundwater collection amounted to 19.8%. In total, 8.7 km³ of water was used in 2020. Groundwater collection amounted to 1.7 km³. Being much better quality water, this was mainly used to supply the population with drinking water. The exploitable resources of domestic groundwater in Poland are estimated at >18 km³, with ~2 km³ currently being exploited (*Environmental Protection Yearbook*, 2023). In the 1991–2020 study period, water collection for industrial needs decreased relative to total water collected, in both Poland and Algeria (Fig. 9). However, the scale of water collection for industrial needs in both countries is definitely different. The percentage of water taken for industrial purposes ranged from 1.29% to 14.34% in Algeria, compared to 63.7% to 74.53% in Poland. The

decrease in percentage of water taken for industrial purposes in recent years has various causes. The low percentage of water taken for industrial purposes in Algeria results from the lack of investment in the industrial sector, and the decrease in the percentage in recent years results from the increase in the total amount of water taken for agricultural and municipal purposes combined. In Poland, the percentage of water taken for industrial purposes is several times higher than in Algeria. The decrease in the percentage of water for industrial purposes in Poland results from the increase in water-saving installations and the possibility of reusing water that has already been extracted and used and then subjected to treatment processes. The economizing/recycling activities of industrial plants were forced by the increasing costs of water and requirements related to water reclamation.

In the case of water withdrawal for agricultural purposes, a systematic increase in the amount of water withdrawn is noted in both countries (Fig. 10). Agricultural water is defined as the annual amount of water withdrawn from domestic resources for irrigation, animal husbandry and aquaculture. In Algeria, the amount of water withdrawn for agricultural purposes is from 59.2% to 65.8% of total water withdrawn, while in Poland it is from 8.5% to 15.1%. The increase in water withdrawal is particularly visible in 2018–2020 in Poland and in 2013–20 in Algeria.

The water supply network operation accounted for 17.6% to 21.6% of the total water used in Poland

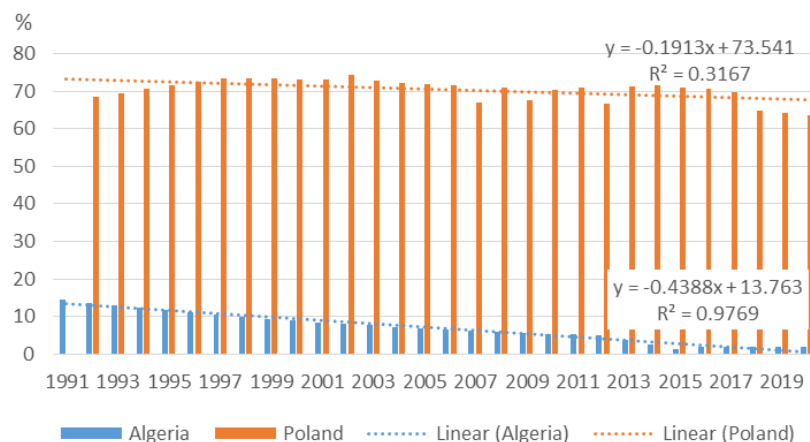


Fig. 9. Industrial water as a share of total water withdrawals (%)

Source: own study based on <https://ourworldindata.org/water-use-stress>

(Fig. 11). In Algeria, these values ranged from 25.6% to 35.8%.

The Mann–Kendall Test was applied to the five indices for the period 1990–2020 based on the 5% confidence level (Table 3). The results in Algeria show a significant negative trend for the industrial water as a share of total water withdrawals (IW) and Renewable FreshWater resources per person (RFW), and a significant positive trend for the Municipal Water as a share of total water withdrawals (MW), population, and Annual FreshWater withdrawals (AFW). However, in Poland, the results show a significant negative trend for Agricultural Water as a share

of total withdrawals (AW), IW, RFW, population and AFW.

The structure of water abstraction in Algeria and Poland is best reflected in the graph prepared for 2020 (Fig. 12). It shows that the largest amount of water abstracted is for agricultural purposes in Algeria (63.8%), while in Poland it is for industrial purposes (63.7%). The large share of water abstracted for agricultural purposes in Algeria results from environmental conditions (dry areas with low rainfall).

The plot correlation, realized basing on the “ggcorplot” package in R software, is presented in Figure 13. In Algeria (A), the results show a strong positive

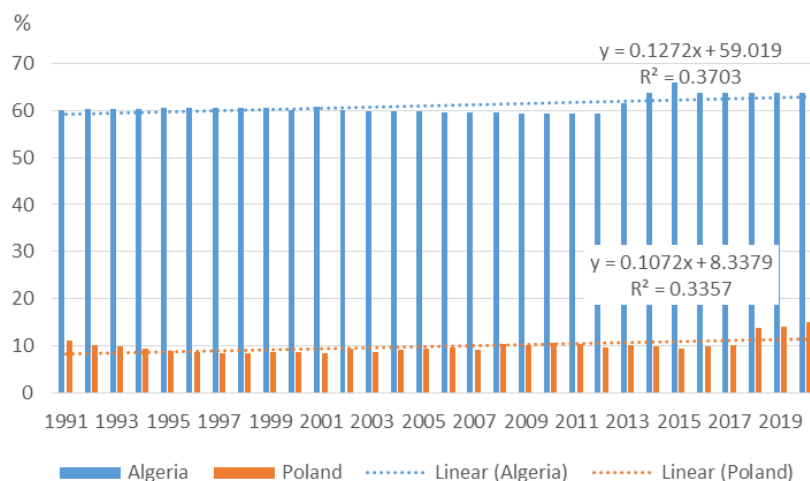


Fig. 10. Agricultural water as a share of total withdrawals

Source: own study based on <https://ourworldindata.org/water-use-stress>

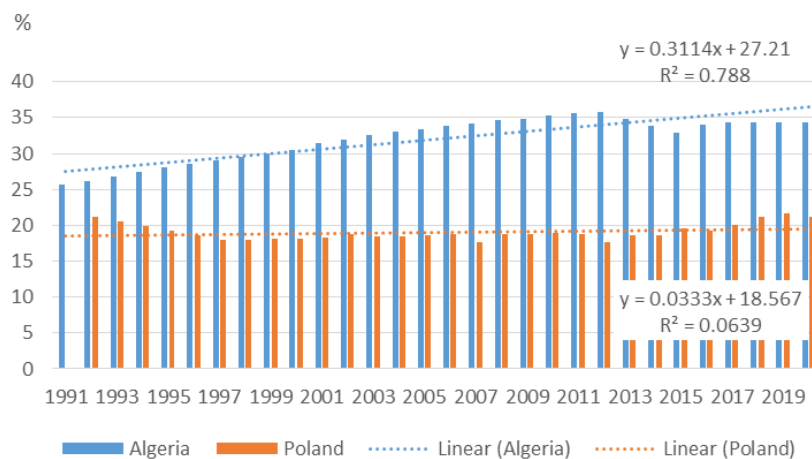


Fig. 11. Municipal water as a share of total water withdrawals
Source: own study based on <https://ourworldindata.org/water-use-stress>

Table 3. Trends for the five indicators from 1990 to 2020

Indices	Algeria		Poland	
	Sen's slope	P.value	Sen's slope	P.value
AW	0.05	0.53	-0.13**	5.89×10^{-11} **
IW	-0.43**	2.71×10^{-13} **	-0.17**	0.001**
RFW	-5.5**	3.03×10^{-14} **	0.71**	7.03×10^{-10} **
MW	0.37*	4.1×10^{-08} *	0.05	0.05
Population	621677*	3.03×10^{-14} *	-9022.22**	0.02**
AFW	0.18*	6.5810^{-14} *	-0.13**	5.89×10^{-11} **

* significant positive trend

** significant negative trend

Source: own study

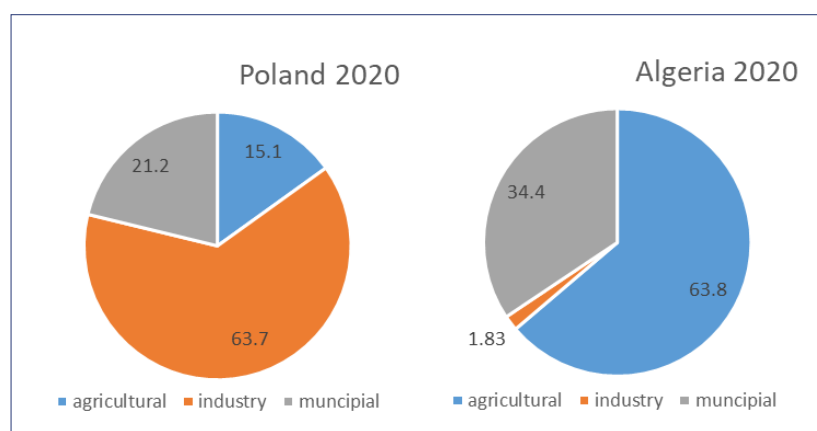


Fig. 12. Structure of water withdrawals for different purposes of the national economy in Algeria and Poland in 2020

Source: own study based on <https://ourworldindata.org/water-use-stress>

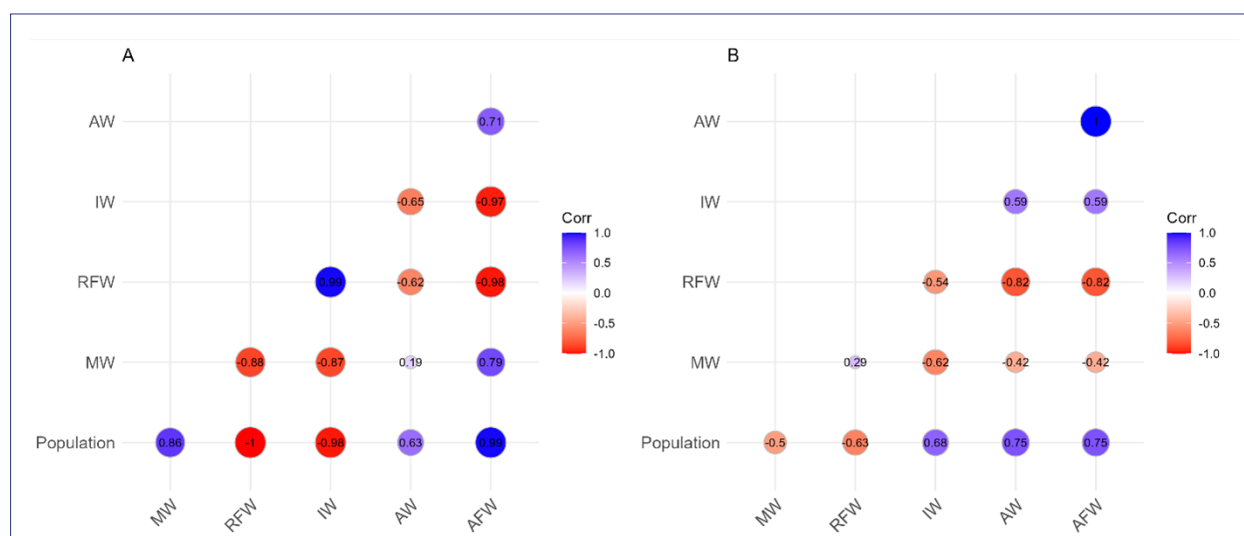


Fig. 13. Correlation between population and selected indicators in Algeria (A) and Poland (B)

Source: own study

correlation between population and AFW, followed by a slightly less strong correlation between population and MW. Strong negative correlations were observed between RFW and population and between IW and population. In Poland (B), a strong positive correlation was observed between AW and AFW, and strong negative correlations were observed between RFW and AW and between RFW and AFW.

4. Discussion and conclusions

Water stress and the risk of water scarcity are common problems today, which results from the growth of the world population and increase in demand for water, which exerts particular pressure in countries with smaller water resources. Water stress does not mean that a country has water shortages, but it gives an indication of how close it may be to exceeding renewable water resources. If water withdrawals exceed 100% of available resources, then the country is either extracting water faster than aquifers can be replenished or has a very high level of water production from seawater desalination (<https://ourworldindata.org/water-use-stress>). Algeria and Poland differ in their water resources. Regardless of the water stress indicators used for the analysis, Poland is clearly in the group of countries with water stress, while Algeria belongs to the countries affected

by absolute freshwater shortage. Both countries use freshwater to different extents for various purposes. Despite these discrepancies, it has been established that in the last few years there has been an increase in the extraction of water for agricultural purposes and for the supply of drinking water to populations. The problem of supplying drinking water to the population will intensify in Algeria due to population growth but also to the uneven demand for water among regions. The demographic increase will significantly worsen the population indicator, since the country is forecasted to reach 51 million inhabitants by 2030, leading to a significant decrease in the availability of water resources (Kherbache, 2014; Hamiche et al., 2015). The uneven population distribution is the result of migration from the countryside to cities, which should be associated with the unstable nature of employment in agriculture (Mostefei, 2024). In Algeria, the population is being concentrated coastally, where the most important cities are located, causing significant pressure on national water resources; in addition, most of the groundwater is overexploited (Kherbache, 2020). Studies conducted by Fertas et al. (2024) in the peri-urban zone of Setif (north-eastern Algeria) showed that this region has experienced significant transformations in the last twenty years (2000–2020), the most visible of which is the significant population growth rate. Their number changed from 447,529 in 2000 to 671,132 in 2020, an increase of

~49%. The population growth has led to an increase in the supply of drinking water, the establishment of industrial complexes and increased food security (Bouchareb & Morad, 2023). Ensuring food security for a larger number of inhabitants has led to a change in agricultural patterns through the introduction of intensive agriculture. Irrigated agricultural areas increased by 44.19% between 2000 and 2020, leading to an increase in vegetable production of 212.4% in the same period (Fertas et al., 2024). In Poland, there has been a slight decrease in the total freshwater intake and in the percentage share of collected water relative to renewable water resources, which is the result of the population decline. Changes are visible in the structure of water intake. In the years 2017–2020, there was a slight increase in the intake of water for municipal needs, but this is not such a worrying phenomenon, because the values are similar to those in the early 1990s. According to Szymańska (2008), the end of the 20th century and the beginning of the 21st century has been a period of socio-economic and political transformation. In many cities in Poland, population is decreasing and, in some, depopulation and suburbanization are beginning (partly manifesting as emigration from cities to outer zones – outskirts). People are moving out of the city to single-family houses with gardens. Tap water is used to water home gardens, which is visible in the summer. The main problem of Poland and Algeria is increasing water abstraction for agricultural purposes, including irrigation. In Poland, the area of agricultural land subject to irrigation has doubled in recent years. According to data published in the Statistical Yearbook of Agriculture (2021), the area of irrigated land in Poland in 2010 was 85,000 ha, which constituted 0.6% of agricultural land. In 2020, irrigated land already covered 271,000 ha, i.e. 1.9% of agricultural land (Statistical Yearbook of Agriculture, 2021). This increase may be the result of the introduction of subsidies at the national level by the Agency for Restructuring and Modernization of Agriculture for the improvement of existing irrigation installations or expanding the area of irrigation (as part of the aid under the Rural Development Program 2014–2020) (<https://modr.pl/prow-2014-2020/strona/nowy-program-pomocy-z-prow-2014-2020-dotacje-na-inwestycje-w-nawadnianie>). An increase in irrigated areas was also recorded in Algeria.

According to Belaidi and Benmehaia (2023), the total irrigated area of Algeria has increased more than fourfold over the last 20 years, from 350,000 hectares in 2001 to 1,424,262 hectares in 2020. The increase in irrigated agricultural areas is the result of an irrigation subsidy program implemented to

stimulate the agricultural irrigation sector since 2000. Various agricultural development plans have been launched in Algeria to promote the use of water-saving irrigation techniques. Despite the irrigation subsidy programs, the overall water consumption in Algeria continues to increase in the irrigated sector (rebound effect). The introduction of efficient irrigation technologies has encouraged farmers to expand irrigated areas or to grow water-intensive crops (Belaidi & Benmehaia, 2023). Therefore, it is important to conduct spatial-temporal monitoring of changes in land use and land cover patterns, which is needed to inform policy and planning support for sustainable catchment management (Ramli et al., 2023).

As a result of the increase in irrigated areas, the use of good quality groundwater has increased. This is a worrying phenomenon that is diminishing the quantity and quality of groundwater resources, which have a lower capacity to recharge. In many cases, the amount of water abstracted for agricultural purposes is not controlled, which can lead to over-use of water resources and thus lower water levels. Over-exploitation of groundwater can exacerbate conflicts between the needs of different users, especially in areas that are already experiencing water stress, which will in turn be exacerbated by climate-change-related disruptions to the regularity of annual and seasonal distribution of rainfall (and thus of water resources). Therefore, the rapid increase in water demand with limited water resources requires rational water management at national, regional and local levels (Hu et al., 2018). In Poland, water shortages mostly affect the central part of the country, while in Algeria they concern the north. For both countries, these are agricultural areas that are a strategic element of food security. A particular challenge for Algeria in the coming decades will be to adapt to the decline in renewable water resources. The country will have to manage these resources carefully. Mobilization of non-conventional water resources (desalination and wastewater reuse) will be a strategic element of the future water policy (Hamiche et al., 2015).

In this context, effective water management policies play a key role in mitigating water shortages (Touitou & Al-Amin, 2018; Bouchentouf & Benabdeli, 2021). Many researchers emphasize that good water management requires cooperation and harmonization between all relevant government stakeholders in order to achieve more common and coordinated actions that can better adapt to uncertainty (Julio et al., 2021; Houar et al., 2024).

Considering that water scarcity will intensify, it is necessary to consider the use of recycled, treated

water for irrigation purposes. Therefore, long-term financing of activities consisting in the development of new treatment technologies, as well as the augmentation of existing water treatment systems with reclamation facilities for processing wastewater into agriculture-safe output, seems to be a future-proof solution (Kubiak-Wójcicka et al., 2022). The proposed solution can be implemented through various forms of subsidies that incentivize farmers to use treated wastewater for agricultural purposes, while using less groundwater. Water recovery from wastewater can be used not only in agriculture, but also in water-intensive sectors of the economy characterized by significant water consumption at various stages of production, e.g. the fruit and vegetable processing industry (Woźniak, 2025). The investment effort in the design, financing of wastewater treatment activities combined with reforms of legal regulations in this area will be a source of improvement of the discussed water indicators. The circular economy model can be one of the driving forces behind accelerating the use of reclaimed water, but it requires the development of regulations promoting water recycling and cross-sectoral cooperation (Szoldrowska & Smol, 2025). Ongoing climate change and an unpredictable future for food security will make water management more difficult. Taking immediate action to adapt the sector to climate change will be much less costly than the damages resulting from this phenomenon (Abbas et al., 2023). Among other proposed solutions often used by water managers is the economic approach. Some authors argue that price is the main incentive for proper water use, helping producers deliver water at optimal levels, which requires the establishment of a gradual, fair, transparent and appropriate pricing system. The proposed solution is one of the few solutions that will effectively contribute to the implementation of the Sustainable Development Goals on water and sanitation.

The presented conditions of Algeria and Poland indicate that the two countries are characterized by different conditions, not only environmentally, but also socially and economically. From the point of view of water resources, both countries face water shortages, which are occurring increasingly as a result of climate change. Based on the analysis of selected indicators, it was shown that, in recent years, water withdrawal has increased at the national level in Algeria while it has decreased slightly in Poland. However, the structure of water withdrawal shows an increasing share of extraction for municipal and agricultural needs. Increased water withdrawal for the operation of the water supply network results from population growth, which is particularly visible in Algeria. In turn, the increased amounts of

water taken for agricultural purposes result from a significant increase in the area of irrigated land, which is noticeable in both Algeria and Poland. The global indicators adopted only partially show the problem of water resources within individual countries, because they do not take into account the diversity of water resources in regional terms. The problem of water availability, both in terms of quantity and quality, may be much more serious. In order to cope with population growth and economic development, constant monitoring of the amount of water withdrawn for various economic purposes is required not only at the local level but also at the regional level. A quick response to increased water demand in many regions will help avoid water shortages in the future while avoiding conflicts between individual users. In the light of available information, the effectiveness of the policy regarding subsidizing irrigation of agricultural land should be reassessed, especially in those areas that use large amounts of groundwater. This process requires comprehensive and effective action, including an approach to realistically assessing water consumption in agriculture. On the one hand, greater financial outlays on sewage treatment installations and technologies should be considered, which leads to improved water quality and its reuse for irrigation. On the other hand, proposing a form of incentive for farmers through subsidies for using reclaimed water at the expense of groundwater and for investments in sewage treatment technologies on their own farms. Therefore, further research is needed to assess the short-term and long-term effects of the policies and strategies being implemented, while acknowledging which new actions at the farming community level would effectively address the problem of over-utilization of groundwater and ensure water security.

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