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Significance of Groundwater Resources for Provision of Water Consumption in Varna District

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***Abstract*— This study highlights the significance of the groundwater resources in present state of water use in Varna District in the context of provision of essential needs and demands of the society and economic development. The household water supply in the Varna region sourced from groundwater over an eight-year period (2016–2023) is analysed. A primary trend identified in water consumption is the decrease in the volume of used groundwater. Household consumption represents a significant portion of the total water usage, predominantly concentrated in the city of Varna. Public water supply dominates, accounting for over 99% of the total water volume during the period under review. The overall reduction in water consumption is approximately 22.4%. Industrial water usage remains stable throughout the study period, with an upward trend observed in specific sectors such as the chemical and food processing industries. Agricultural consumption of freshwater from groundwater sources is also notable, particularly in cases of private water supply for irrigation of agricultural crops. The water use from private water supply in this sector fluctuate considerably, ranging from 1,367,245 m³ in 2016 to 2,040,130 m³ in 2023. Water consumption in Varna region shows significant seasonal variation. A general trend of water consumption indicates pronounced seasonal irregularities, with a sharp increase during the summer months, especially in resort areas and settlements with tourism development potential. The expansion of settlements, including the incorporation of new territories into urban planning and the reclassification of agricultural lands, has not been accompanied by adequate water supply infrastructure in recent years. This has hindered the provision of reliable water services to consumers. Sustainable management of groundwater resources and the optimization of their utilization will be the key to ensuring long-term water security in the region.**

Keywords – Groundwater abstraction, Water supply, Private water supply, Water consumption

I. INTRODUCTION

On a global, national, and regional scale, the quality and quantity of groundwater resources are of critical importance [5], [11], [21], [22]. Groundwater is one of the most valuable natural resources, playing a crucial role in urban, rural and industrial development. It serves as a primary water source for industrial processes and plays significant role in sustaining ecosystems and biodiversity. The significance of groundwater is most evident in regions with limited surface water resources or during drought seasons. Groundwater serves as a primary source for drinking water supply, agriculture, industry, and energy production [2], [3], [4], [18], [19], [22]. Moreover, it plays a vital role in maintaining the water balance of ecosystems, providing moisture to rivers and wetlands even during periods of low precipitation. According to the latest report by the European Environment Agency (EEA), groundwater provides approximately 65% of the drinking water in the European Union and over 25% of the water used in agriculture. [1], [9].

Nevertheless, globally, and particularly in Europe groundwater is under considerable pressure from human activities, excessive water abstraction, leading to depletion, decrease in groundwater levels and a decline in water quality [1], [6], [9], [19], [25]. Past and present patterns of resource utilization have led to high levels of pollution, environmental degradation, and depletion of natural resources. Simultaneously, seasonal variations in surface water availability are becoming increasingly unpredictable, which inevitably affects the state of groundwater resources as well [2], [3].

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In the context of globalization, increasing human population, respectively constantly increasing water consumption, and climate change, sustainable management of groundwater is becoming a primary challenge for modern societies [6], [10], [11], [20].

Bulgaria and Varna region in particular is no exception to the broader global and European trends, e.g. 24% of all EU groundwater bodies are in poor chemical status, while 9% are in poor quantitative status, referring to years from 2016 to 2021. The combined assessment of chemical and quantitative status reveals that 29% of groundwater body areas lack sufficient capacity to meet the needs of ecosystems and society due to deterioration in quality or quantity [14]. In recent years, groundwater abstraction in Bulgaria has accounted for 47-55% of the total water abstracted for public water supply in the country [1], [9]. In Varna district the water consumption varies seasonally and increases significantly during the summer period mainly due to the large number of tourists and recreational users visiting the resort areas.

The present study aims to analyse groundwater consumption trends by different users for the period 2016–2023, with focus on groundwater abstraction and consumption analysis, and thus to highlight the groundwater resources importance in the context of water provisioning for Varna region.

II. MATERIALS AND METHODS

The Varna district is located in the North-Eastern part of Bulgaria. It covers area of 3 818 km², representing approximately 3.44% of the territory of Bulgaria. The region comprises of 158 settlements, gathered in 12 municipalities: Varna, Aksakovo, Avren, Beloslav, Byala, Vetrino, Valchi Dol, Devnya, Dolni Chiflik, Dalgopol, Provadia, and Suvorovo municipality [26].

The permanent residents of Varna district reach 434191 inhabitants in 2023, accounting for 6.7% of Bulgaria's population. Thus, the district of Varna ranks third in terms of population after the capital Sofia and the Plovdiv region [26]. During the summer tourist season, the population of Varna town increases significantly, reaching over a million.

Publicly available data on water abstraction and consumption from the National Statistical Institute of Bulgaria, Eurostat, as well as data from the Black Sea Basin Directorate were used to determine the significance of groundwater resources for meeting water needs in Varna region. Balance calculations are attached to the data. The data were obtained through comprehensive control and operational monitoring from points of groundwater bodies in independent karst basins, alluvial deposits, and high-flow springs with a discharge rate of no less than 1.0 l/s. Additionally, data were collected from facilities operated by "Water Supply and Sewerage" companies, "Irrigation Systems," boreholes from self-monitoring networks, and facilities constructed for groundwater observation (monitoring points).

The use of the withdrawn water quantities by the purpose of water abstraction has been analyzed. The distribution by production activities is grounded on reported data and balance calculations.

III. RESULTS AND DISCUSSION

Within the Varna district, 18 groundwater bodies have been identified, distributed across 5 aquifer horizons as follows: Quaternary Aquifer Horizon – 4 groundwater bodies, Neogene Aquifer Horizon – 7 groundwater bodies, Upper Cretaceous Aquifer Horizon – 2 groundwater bodies, Lower Cretaceous Aquifer Horizon – 3 groundwater bodies and Malm-Valanginian Aquifer Horizon – 2 groundwater bodies [24].

All groundwater bodies in Varna district are appointed in good quantitative state during the whole period from 2021 to 2023. Three underground water bodies are identified as being exposed to pressure from marine intrusion due to proximity to or less than 1 km from the Black Sea coastline: BG2G000000Q014 Pore waters in the Quaternary of the Dvojnitsa River: BG2G000000Q002 Pore waters in the Quaternary of the Batova River; BG2G00000PG026 Pore waters in the Paleogene-Eocene Varna-Shabla

Due to differenr factors - agricultural pressure, industrial pressure, pressure from urban wastewater and salt water penetration 27,77% of groundwater bodies in Varna district are assessed to be in poor chemical condition.

Water abstraction from all water bodies is carried out for different purposes – for drinking and domestic water supply, for agricultural purposes (irrigation), for industrial purposes, for cooling, for aquaculture and others. The available water quantities vary significantly by groundwater bodies: from 18 l/s (BG2G000000Q002 Pore waters in the Quaternary of the Batova River) to 2126 l/s at BG2G000000N018 Pore waters in the Neogene-Sarmatian Northeastern and Middle Dobrudzha.

The inner structure of abstracted freshwater is dominated by the surface water sources. The relative share of groundwater varies from 9.9% in 2016 to 11.06% in 2020 of total gross water abstraction. Surface waters are the main and highest source of total water abstraction and water supply. Their share remains relatively stable, with a single drop observed in 2020, attributed to industrial stagnation and the global health crisis.

In 2023, the share of groundwater is higher compared to 2016, which may indicate an increased need for alternative water sources or a reduction in the availability of surface water. The peak groundwater abstraction was observed in 2017 (581.75 million m³), while the lowest level was in 2021 (538.81 million m³). Groundwater abstraction in 2023 reached 546.48 million m³, demonstrating a slight recovery compared to 2021.

During the analyzed period, there is a general trend of declining water abstraction from both surface and groundwater sources for public water supply in the

country. In 2016, water abstraction from surface water sources was 421.29 million m³, reaching its lowest level in 2020 (360.05 million m³). After 2020, a slight recovery was observed, reaching 381.53 million m³ in 2022, but in 2023, there was another decline to 372.31 million m³.

Groundwater abstraction started at 454.07 million m³ in 2016 and reached its peak in 2017 with 467.90 million m³. Subsequently, a decrease followed, reaching 429.15 million m³ in 2022, followed by a slight increase to 433.55 million m³ in 2023. This indicates a greater reliance on groundwater sources for drinking water needs and highlights their significance in ensuring potable and domestic water supply security (Fig. 1).

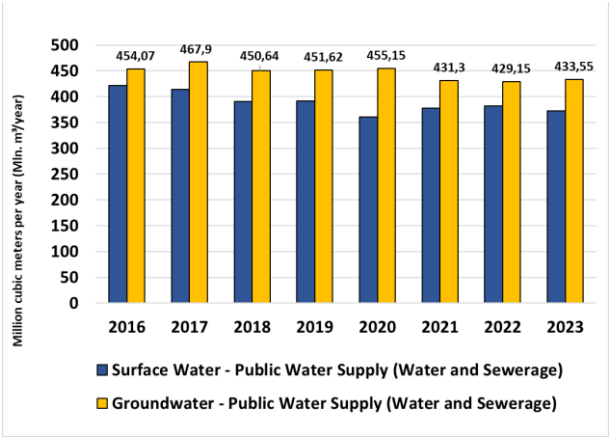

Fig. 1. Drinking water abstraction by sources, Bulgaria (2016-2023), Based on National Statistical Institute data.

The presented data show the annual volume of abstracted water (million m³) from Groundwater Bodies in the Varna district over an eight-year period (2016 –2023). Changes in water abstraction levels, as well as the overall trend, are influenced by natural (seasonal), socio-economic, and climatic factors specific to the region.

Within 2016 - 2021, a steady decline in the volume of abstracted water was observed. A slight recovery occurred in 2022, yet abstraction volumes remained below those recorded at the beginning of the period. Maximum water abstraction of 777.27 million m³ was recorded in 2016 and minimum – 601.60 million m³ in 2022. Total reduction of 175.67 million m³, corresponding to a 22.6% decrease was registered comparing 2016 in 2022 (Fig. 2) [16], [17].

Changes in water abstraction levels are due to decreasing precipitation and increasing droughts, exerting pressure on the region's water supply, particularly during the summer months [18]. Another reason might be the reduced water consumption in industry and agriculture, reflecting shifts in economic activities and resource efficiency. This trend underscores the need for adaptive water resource management to address challenges associated with climate variability and evolving water demands across different sectors.

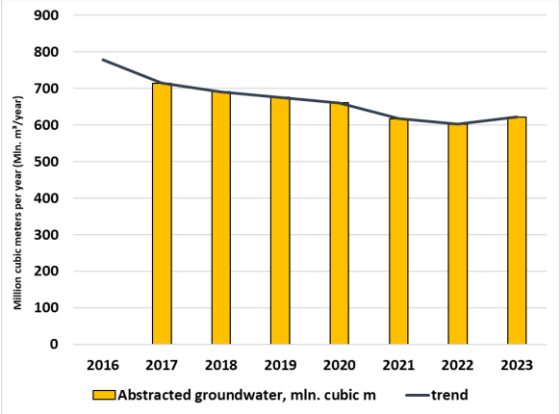

Fig. 2. Abstracted Water Volumes (Mln m³) from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD - Varna Data.

Regarding public drinking and household water supply from groundwater sources in the Varna Region, the volume of abstracted water has significantly declined over the years, from 70.41 million m³/year in 2016 to 54.65 million m³/year in 2023. Public water supply dominates, accounting for over 99% of the total water volume during this period. The overall reduction amounts to approximately 22.4% (Fig. 3).

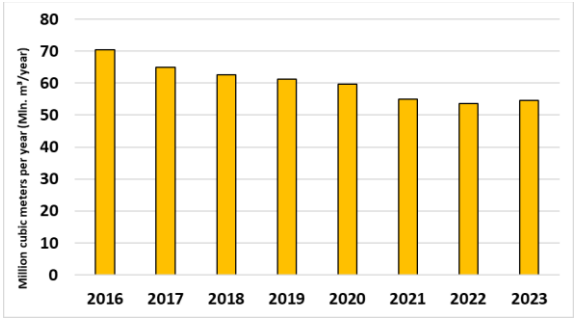

Fig. 3 Utilized Water by Type of Water Supply from Groundwater Bodies in the Varna Region (2016–2023).

In contrast, private drinking and household water supply, where abstracted water is used for domestic consumption, represents significantly lower volumes, fluctuating between 0.588 million m³/year (2021) and 0.758 million m³/year (2020). The minimum recorded volume was in 2016 (0.588 million m³/year), followed by an increase of approximately 28.8% until 2020, after which a decline was observed in 2021 (Fig. 4). While this type of water supply accounts for around 1% of total water use, it plays a crucial role in local and remote areas of the city and suburban zones. Although the volumes remain relatively low, they are highly sensitive to local variations in water sources within the region.

A detailed analysis of public drinking and household water supply reveals that water consumption is highest during the summer months, particularly in 2016, when a peak of 6.402 million m³ was recorded. The lowest consumption is observed during winter. In 2022, the most significant decline of water usage was recorded, dropping to 3.780 million m³, as illustrated in Fig. 5.

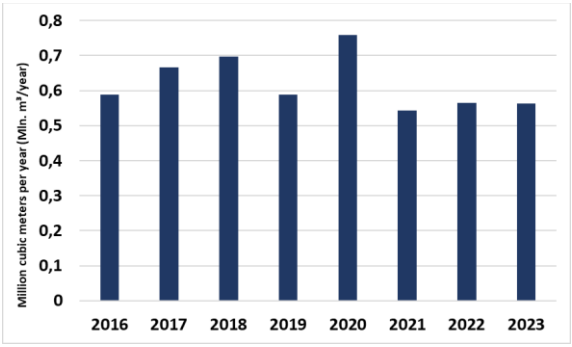

Fig. 4. Utilized Water by Type of Water Supply from Groundwater Bodies in the Varna Region (2016–2023).

A seasonal analysis of private drinking and household water supply reveals pronounced seasonal fluctuations, with increased water consumption during the summer months. (Fig. 6).

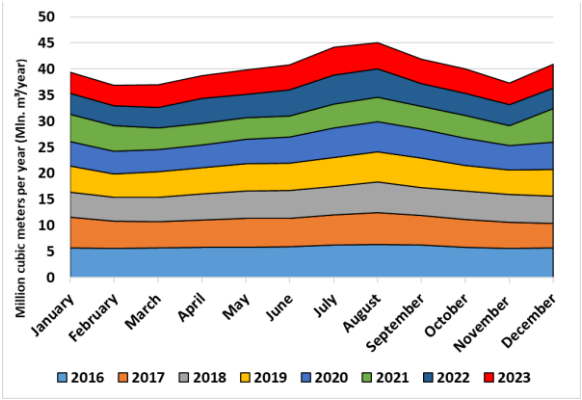

Fig. 5. Monthly Utilized Water for Public Drinking Water Supply from Groundwater Bodies in the Varna Region (2016–2023)

July and August consistently show the highest water consumption across all years, with a peak recorded in 2018 (0.0795 million m³). In August 2023, water consumption slightly decreased to 0.4905 million m³. Winter months also exhibit a trend of increased water usage, while spring and autumn remain relatively stable, with moderate growth in certain years. Despite being lower than summer consumption, winter water usage peaked at 0.0672 million m³ in 2020.

The main trend in water use for public irrigation of agricultural crops shows a significant decline of 85%, decreasing from 0.650 million m³ in 2016 to 0.096 million m³ in 2023. The data indicate a steady and continuous decrease in water use, with minor variations. This decline is primarily attributed to utilization of alternative water sources, reduction of agricultural land and irrigation needs (Fig. 7).

In contrast, private water supply for agricultural irrigation exhibits significant fluctuations, ranging from 1.367 million m³ in 2016 to 2.040 million m³ in 2023, marking an increase of 49.3% over the period. This growth reflects structural changes in groundwater use in the Varna Region, indicating a greater reliance on private water sources for irrigation. The volume of abstracted water for livestock farming varies between 0.856 million m³ (2022) and 1.092 million m³ (2019), showing moderate fluctuations over the years. Water use for aquaculture remains insignificant compared to other sectors in agriculture, forestry, and fisheries. The recorded volumes range from 0.0008 million m³ (2016) to 0.004 million m³ (2023). Although small in scale, the most recent data indicate a decline in water use for aquaculture activities.

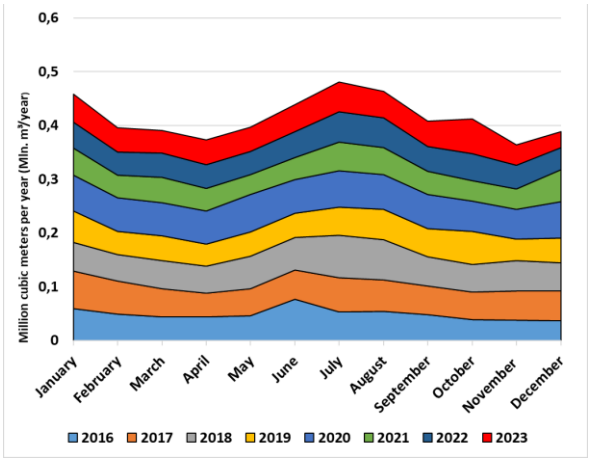

Fig. 6. Seasonal Variation in Private Drinking and Household Water Supply from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

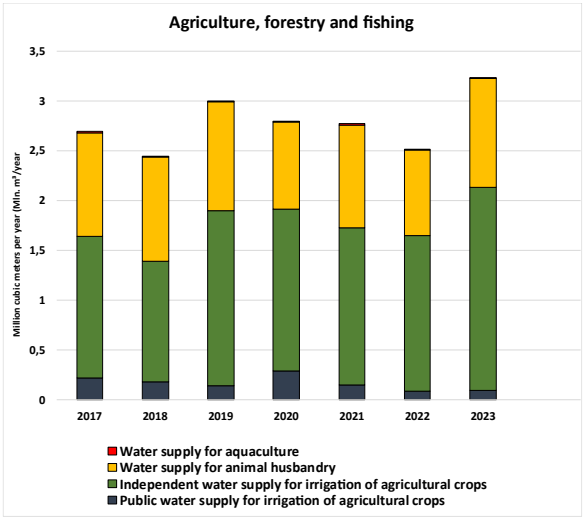

Fig. 7. Water Consumption from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

A significant seasonal pattern in irrigation water use is observed, with high volumes recorded during the summer months of June, July, and August (Fig. 8 and 9). This trend is directly related to the need for crop growth maintenance during the hottest months of the year, highlighting the importance of proper resource allocation and integrated water management.

The observed trends necessitate a seasonal strategy for water resource management. Climate change, rising temperatures, and irregular precipitation patterns may further increase irrigation demands. Spring and summer are the most vulnerable seasons in terms of climatic anomalies, requiring adaptive measures to ensure water availability. High water consumption during these months

exerts significant pressure on available water resources, particularly in regions of the Varna area with limited access to water. Implementing integrated water management strategies is essential to mitigate the impacts of seasonal fluctuations and ensure sustainable agricultural production.

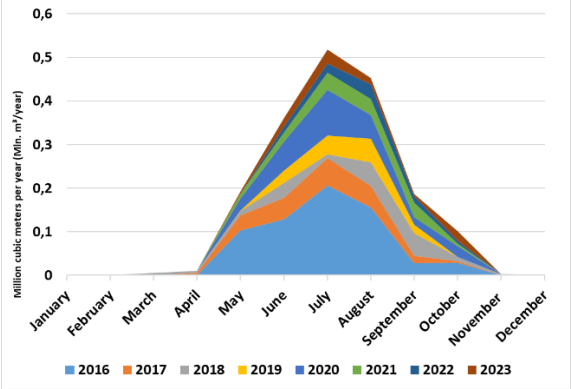

Fig. 8. Monthly Utilized Water for Irrigation from Public Water Supply from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

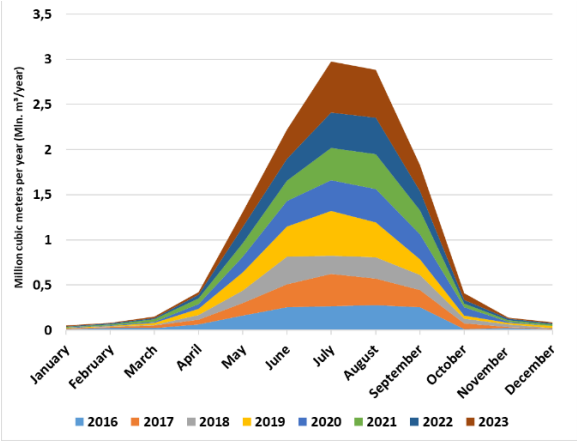

Fig. 9. Monthly Utilized Water for Irrigation from Private Water Supply from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

A steady increase in water consumption for livestock farming is observed during March, April, and May, coinciding with increased agricultural and breeding activities in this period. July and August show the highest water consumption, with peaks recorded in 2023 (0.0185 million m³) and 2018 (0.100 million m³). Winter months (December, January, February) have the lowest water usage, with values ranging between 0.0016 million m³ and 0.022 million m³. This pattern highlights the seasonal variations in water demand, with higher requirements during spring and summer and reduced consumption in winter.

An analysis of water usage for aquaculture reveals that the highest values were recorded in December 2017 (0.065 million m³), where consumption significantly exceeded that of other months. A similar peak was observed in December 2021 (0.0029 million m³), indicating periodic increases in water demand for aquaculture activities.

The lowest consumption levels were recorded in 2016 and 2020, with minimal monthly water use for aquaculture. This variability suggests that aquaculture water consumption is highly dependent on specific operational cycles and external factors such as seasonal production and environmental conditions.

An analysis of water abstraction for cooling reveals two distinct phases during the study period (2016–2020). A 54.8% decrease in water use for cooling was observed, reaching an absolute minimum of 0.942 million m³ in 2020. This decline is attributed to technological advancements, reduced industrial production, and shifts in the economic structure of the Varna region- Recovery Phase (2021–2023). Following 2020, water abstraction volumes began to recover, reaching 1.735 million m³ in 2023, approaching the 2016 level of 2.084 million m³ (Fig. 10). This revitalization of industrial activity in the region places significant pressure on groundwater bodies, which remain the primary source of drinking and household water supply. The growing demand highlights the need for integrated water resource management strategies to ensure sustainable groundwater use amid increasing industrial recovery.

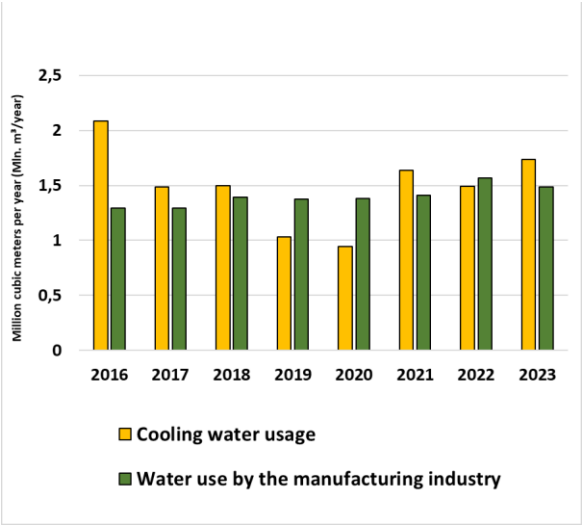

Fig. 10. Water Abstraction for Cooling and Manufacturing Industry from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

A peak in water consumption for cooling is observed during the summer months (July and August), particularly in 2021, when volumes exceeded – 0.290 million m³ in August, 0.221 million m³ in July. The lowest consumption is recorded in February and December, with the minimum value of 0.457 million m³ in November 2021 (Fig. 11). During the winter months (December–February), a general decline in water consumption is observed, except for December 2023, when volumes reached 0.165 million m³. This seasonal variation highlights increased cooling demands during the hottest months, emphasizing the

importance of resource planning and efficiency measures to optimize water use in industrial processes.

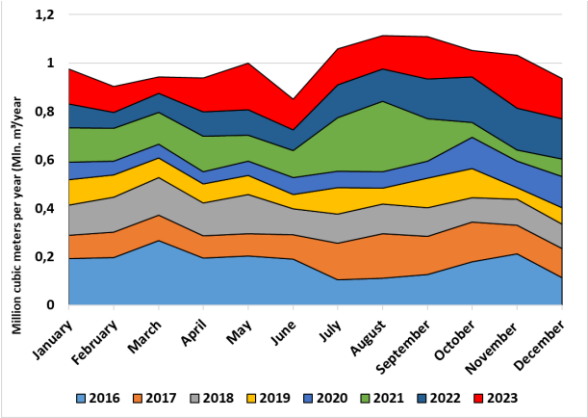

Fig. 11. Seasonal Water Consumption for Cooling from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

A significant shift is observed in the trend of water use for industrial water supply, including self-sufficient drinking and household water supply, particularly in cases where abstracted water is utilized for the production of food, pharmaceuticals, or cosmetic products. In 2022 was recorded the highest water consumption at 0.1567 million m³, marking a 20.9% increase compared to 2016. The lowest consumption was in 2016 (0.131 million m³), with the most significant growth occurring between 2021 and 2022. Stabilization was observed in 2023, but water abstraction volumes remained high. This trend reflects growth in the industrial sector, as well as substantial changes in production processes that require increased water consumption. These findings emphasize the need for efficient water management strategies to support industrial expansion while ensuring sustainable water resource use.

The highest water consumption levels are observed during the summer months (June, July, and August), with July 2022 recording the peak consumption at 0.157 million m³. Spring months (April and May) also exhibit high consumption, particularly in 2022. The lowest consumption levels occur during winter months, especially December and January, with the minimum recorded at 0.076 million m³ in December 2016. December 2021, however, shows a significant increase, reaching 0.211 million m³, indicating variations in industrial demand (Fig. 12). These seasonal fluctuations highlight the dynamic nature of water demand in the manufacturing sector, influenced by seasonal production cycles, economic activity, and industrial processes requiring water-intensive operations.

Water consumption for other purposes experienced the largest decline from 460 644 m³ in 2016 to 281 945 m³ in 2017, representing a 38.8% decrease. After 2018, the data indicate a steady increase, with volumes reaching 502 651 m³ in 2023, marking a 78.3% rise compared to 2017 (Fig. 13). Despite the upward trend, significant fluctuations and dynamic variations in water use for other purposes remain evident, highlighting the variable demand influenced by multiple factors.

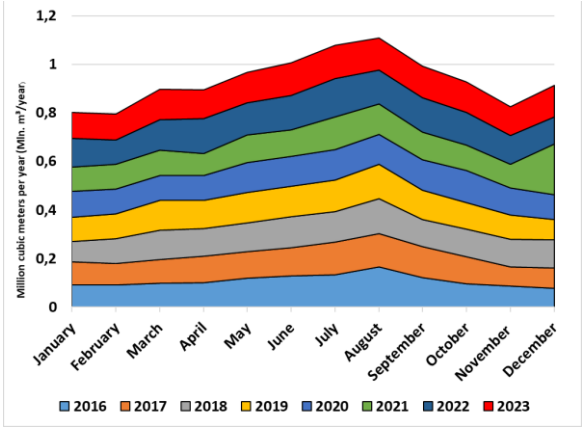

Fig. 12 . Monthly Utilized Water for the Manufacturing Industry from Groundwater Bodies in the Varna Region (2016–2023), Based on BSRBD – Varna Data.

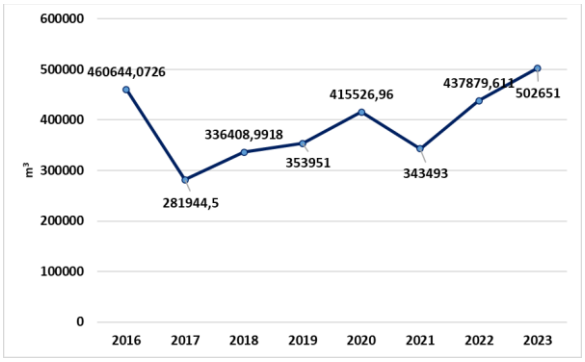

Fig. 13. Abstracted Water Used for Other Purposes from Groundwater Bodies in the Varna Region (2016–2023).

The highest recorded consumption was in August 2023 (84 195 m³), significantly exceeding previous years. Summer months (June, July, and August) consistently show high values, reflecting seasonal demands. The lowest consumption was recorded during winter months, with January 2017 registering only 7354 m³. A notable increase was observed in October 2023 (51 882 m³), marking a significant deviation from previous years.

IV. CONCLUSIONS

The share of groundwater in total water consumption in Bulgaria increased from 9.9% in 2016 to 11.06% in 2020, indicating a growing dependence on groundwater as an alternative source for the country.

Groundwater abstraction in the Varna region for the period 2016–2023, showing a decline of 22.6%, highlights a positive trend in resource management. Groundwater used for drinking purposes through public water supply accounts for between 90% and 87% (2016-2023) of the total water consumption in the area. The data emphasize the current state of water consumption in the Varna region and the significant role of groundwater in compensating for the shortage of surface water.

Groundwater is critically important for the water supply of the Varna region, especially during seasonal peaks in consumption and in the context of climate change. During the summer season, when water consumption increases significantly due to the influx of tourists and seasonal workers, groundwater provides a critical reserve for domestic, agricultural, and industrial needs. A clearly defined peak in groundwater use is observed during the summer months, demonstrating its significance in the context of unpredictable rainfall and droughts in the region.

Changes in the structure of groundwater use in the area and the recovery of water consumption in industry and agriculture after 2021 highlight the need for sustainable groundwater exploitation to ensure water security and supply stability in the region.

Industrial water consumption remains stable, with growth in specific sectors such as the chemical and food processing industries. Water use for cooling in the industry showed a significant decrease until 2020, with a decline of up to 54.8%, followed by a recovery until 2023, reflecting the economic revitalization of the region.

Agricultural water consumption through public water supply decreased by 85%, which may be due to a shift to alternative water sources or a reduction in agricultural land. However, private water supply for irrigation showed a growth of 49.3%, highlighting the increased dependence on independent water sources for agricultural needs.

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