Monitoring water reservoirs in southern Italy and fighting water scarcity

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***Abstract*—Water scarcity in Sicily, exacerbated by climate change, irregular rainfall and inefficient waterworks networks, poses significant challenges to the region's water system, particularly affecting agriculture. This paper explores the monitoring and management of Sicilian water reservoirs, highlighting the importance of accurate and timely data. By analyzing water levels and rainfall patterns, sustainable management strategies can be developed to mitigate drought effects. The study emphasizes the use of modern technologies for effective monitoring and provides recommendations for a sustainable water future in Sicily.**

Keywords: Water scarcity, Sicily, reservoirs, climate change, rainfall, agriculture, water management, monitoring technologies.

I. Introduction

Water scarcity has become a crucial issue in Sicily, the biggest Italian island, located in the middle of the Mediterranean Sea (see Fig. 1).

Fig. 1. Location of Sicily in the Mediterranean Sea

The island has an extension of 25,832 km^2 and is home to 4.8 million of citizens.

Thanks to its position, this region is characterized by the as well-known Mediterranean climate, thus mild, wet winters, and hot, dry summers and two intermediate seasons.

However, as a consequence of the climate changes, Sicily is now affected by even frequently drought and irregular distribution of rainfall. In recent decades, the growing demand for water resources for agricultural, industrial [1], and domestic use [2], [3] has put the entire regional water system under strain [4]. The annual rainfall ranges between 600 and 800 mm/year.

Thence, water reservoirs are a key element in managing Sicilian water resources, as they accumulate fresh water during rainy periods and serve as crucial reserves during drought times. Their proper management is essential not only to ensure adequate water supplies but also to support agriculture, which is a pillar of the Sicilian economy [5]. With 70% of extracted water used for agricultural purposes, the significance of water reservoirs is amplified in the fight against water scarcity [6].

This paper aims to explore the monitoring of water reservoirs in Sicily, analyzing the importance of accurate and timely data. By acquiring and analyzing information on water levels and rainfall, sustainable management strategies that can mitigate the effects of drought periods can be identified and implemented. The presentation of modern technologies and monitoring methodologies will offer a perspective on Sicily fighting water crisis and ensure a safer and more sustainable water future for future generations.

II. Context and Relevance

Sicily, the largest island in the Mediterranean Sea, is characterized by a typical Mediterranean climate, with mild winters and hot summers. However, the already delicate water situation in the region has been exacerbated in recent decades by a series of factors, including climate change and increased pressure on water resources.

Currently, water scarcity is a significant problem in Sicily, with many areas facing long periods of drought. Estimates indicate that the availability of water resources in Sicily has decreased by about 30% over the past twenty years [7]. During the summer, the situation becomes particularly critical, as precipitation drastically decreases, with some municipalities experiencing extreme water shortages that compromise supply for agricultural and domestic use [8]. Already vulnerable aquifers are under constant stress from excessive withdrawals, leading to salinization and deterioration of water quality [9].

In recent years, rainfall data in Sicily show a worrying trend. Rainfall has become increasingly irregular, with brief and intense rain periods followed by long drought intervals. For instance, in 2023, many areas of Sicily recorded a decrease in precipitation exceeding 40% compared to the historical average, with rainfall events concentrated in a few weeks and insufficient to replenish reservoirs and aquifers [10]. This climatic variation has had devastating effects on agriculture, a crucial sector that represents a significant part of the local economy [11]. Crops of cereals, fruits, and vegetables suffer particularly from water scarcity, with direct consequences on food availability and market prices [12], [13].

In response to this growing crisis, it is essential to adopt an integrated vision of water resource management. Adaptation and mitigation measures must include regular monitoring of reservoirs and analysis of climate data to predict future conditions. Only through a proactive approach can the sustainability of Sicilian water resources be ensured, and the challenges posed by water scarcity be addressed. In particular, the use of modern technologies for monitoring rainfall and water levels in reservoirs is essential to develop more effective management strategies and promote the resilience of local communities.

Given these challenges, the relevance of accurate mapping and analysis of water resources becomes imperative. Understanding the dynamics between rainfall, reservoir water levels, and water demand is a crucial step to ensure that future water resource development and conservation plans are based on solid and up-to-date data [14],[15].

III. Monitoring Methodology and Data Analysis

Monitoring water resources in Sicily requires the use of advanced methodologies and technologies to acquire accurate and up-to-date data. In particular, the analysis of collected data is crucial to understand the hydrological and climatic dynamics of the region, thus addressing the challenges related to water scarcity.

The Sicilian water reserves are represented by artificial lakes, built up during the last century. The most relevant are 29 lakes, with an overall water capacity of one billion of cubic meters of water.

Basin Authority of the Hydrographic District of Sicily (in Italian "Autorità di Bacino del Distretto Idrografico della Sicilia") publish monthly a bulletin (updated at the first day of the month), reporting the stored water for each lake [16].

At the same time, climatic data provided by the official website of the "Sicilian agrometeorological information service" (in Italian SIAS – Servizio Informativo Agrimeteoorologico Siciliano) [10]. This resource offers a wide range of climatic data, including temperature, wind speed, air pressure, humidity, and rainfall data, with different time scales. Indeed, it is possible to obtain until hourly data.

By using all these data, it is possible to process and interpret this information to generate detailed reports and forecasts on water resource availability.

A. *Analysis of Collected Data*

The analysis of data collected through the mentioned technologies involves several steps:

- Statistical Processing: Through statistical analysis techniques, including regression models and time series analysis, historical trends in rainfall and water resources are observed. These models help to forecast future trends and identify significant anomalies [14].
- Data Visualization: The use of visualization tools allows the graphical representation of variations in water levels and rainfall over time, facilitating the interpretation of data and their use in water resource management planning.
- Reporting: Finally, the results of the analyses are organized into meaningful reports for local authorities, policymakers, and communities, providing practical recommendations for sustainable water resource management in Sicily. This integrated methodology enables a deep understanding of water dynamics in Sicily, facilitating the identification of necessary measures to address significant challenges related to water scarcity.

IV. Analysis of Rainfall Data and Correlation with Water Levels

A. *Rainfall Data*

Analyses were run with the goal of obtaining rainfall patterns and trends over the past 22 years in Sicily. The following Fig. 2 shows these results.

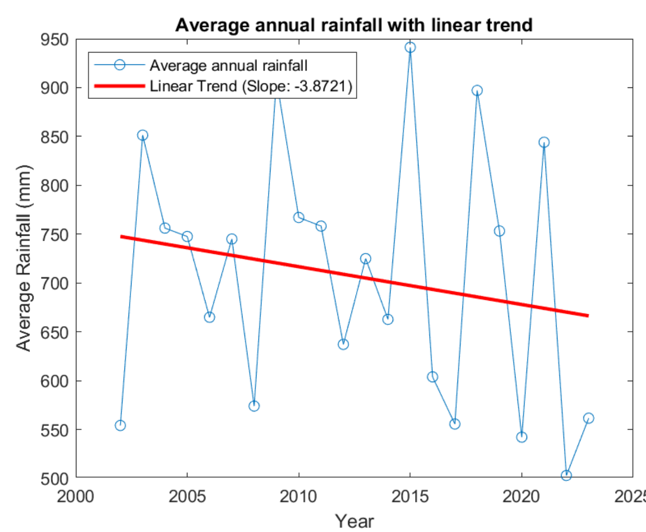

Fig. 2. Variation of average annual rainfall with linear trend

The figure shows that in the single year there have been good rainfall conditions but dangerous is the negative trend. This means that on average less and less rain falls in Sicily. Generally, years with good rainfall and years with low rainfall have alternated. But the last 5 years have been slightly rainy.

B. Reservoir Data

The layout of the reservoirs in Sicily is highlighted within the map; this was created from a data array in which all the reservoirs in Sicily are collected, whether they are natural or artificial basins. It does not distinguish between the use of water, whether for drinking or irrigation purposes. The basins (listed in Table I) were georeferenced in the initial array and fixed with MATLAB's geoscatter, see Fig. 3. The total capacity of all the Sicilian reservoirs is: 1010.70 M m³.

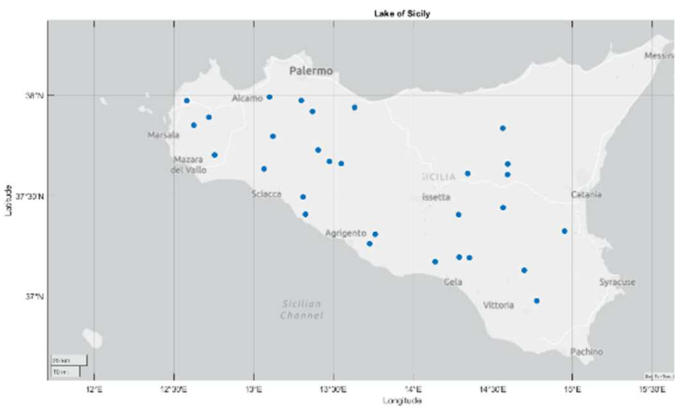

Fig. 3. Geoscatter basin georeferenced

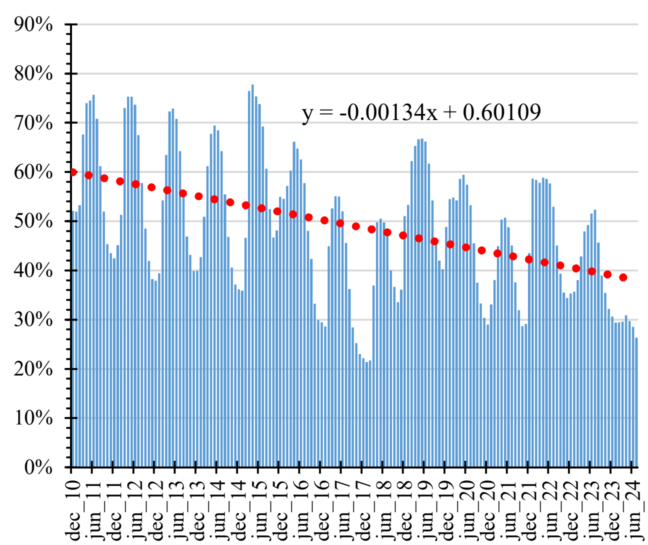

Fig. 4. Total reservoir volume (in % of global capacity)

The degree of filling of the water reservoirs has a decreasing trend (see Fig. 4). In April 2018, the trend seems to have an increase, but this is done by the fact that the lake Lentini was connected to the water networks, thus 134 M m^3 were added to the total capacity of the Sicilian water reservoirs. Considering all data, reported in Fig. 4, the degree of filling is reducing by 0.134% per month (1.416 % per year).

TABLE I. MAIN INFORMATION ON THE SICILIAN WATER RESERVOIRS

Dam	**Constr.**	**Uses**	**Coordinates**	**Maximal elevation** *[m]*	**Nominal capacity** *[M m^3]*
Ancipa	1949-1953	I, P, H	37.83598 N 14.56312 E	944	30.40
Arancio	1949-1951	I	37.63414 N 13.06563 E	178	34.80
Castello	1976-1982	P, I	37.49472 N 13.31033 E	88	21.00
Cimia	1975-1980	I	37.19126 N 14.35346 E	136	10.00
Comunelli	1961-1968	I	37.17110 N 14.13915 E	208	8.00
Disueri	1981-1997	I	37.19406 N 14.28967 E	151	23.60
Fanaco	1951-1956	P	37.66051 N 13.54967 E	677	20.70
Furore	1977-1997	I	37.26128 N 13.72771 E	167	7.00
Garcia	1976-1984	P, I	37.79611 N 13.12113 E	194	80.00
Gorgo Lago	1956-1972	I	37.40793 N 13.32517 E	65	3.41
Lentini	1983-1991	I, F	37.32413 N 14.95082 E	25	134.55
Leone	1927-1933	P, H	37.67117 N 13.47581 E	830	4.19
Nicoletti	1963-1971	I	37.61115 N 14.34277 E	382	20.20
Ogliastro	1961-1973	I	37.44158 N 14.56505 E	204	110.00
Olivo	1976-1982	I	37.40658 N 14.28605 E	437	15.00
Paceco	1980-1984	I	37.97250 N 12.58138 E	41	6.70
Piana degli Albanesi	1921-1923	I, P, H	37.97367 N 13.29950 E	604	32.80
Poma	1963-1970	I, P	37.99063 N 13.09999 E	194	72.50
Pozzillo	1955-1959	I, H	37.65821 N 14.59394 E	356	150.50
Prizzi	1940-1942	I, P, H	37.72785 N 13.40516 E	652	9.20
Ragoleto	1961-1962	F	37.12812 N 14.69788 E	356	20.10
Rosamarina	1972-1992	P, I	37.93927 N 13.63301 E	170	100.00
Rubino	1967-1970	I	37.89071 N 12.71963 E	185	11.50
S. Giovanni	1969-1981	I	37.30838 N 13.76309 E	301	16.30
S. Rosalia	1976-1981	I	36.97536 N 14.77605 E	373	20.00
Scanzano	1957-1965	I, P	37.91885 N 13.36954 E	517	18.00
Sciaguana	1984-1992	I	37.60561 N 14.59303 E	254	11.35
Trinità	1954-1959	I	37.70337 N 12.75571 E	68	18.00
Zaffarana	1974-1978	I	37.85101 N 12.62528 E	83	0.90

Legend: I = Irrigation, P = Potable use, H = hydropower, F = Industrial use

If the analysis is done, by considering the last 6 years, in which the nominal total capacity is stable, the monthly variation of degree of filling is equal to -0.248%, corresponding to an annual variation of -2.976%. In absolute terms, this mean a loss of 30 M m^3 per year of the available water stored inside the Sicilian water reservoirs.

C. Case study

The case study examines the four most important basins in the water supply network to the city of Palermo, managed by AMAP, local water distributor of Palermo. The names of these 4 lakes are Poma (A, see Fig. 5), Piana degli Albanesi (B), Scanzano (C) and Rosamarina (D).

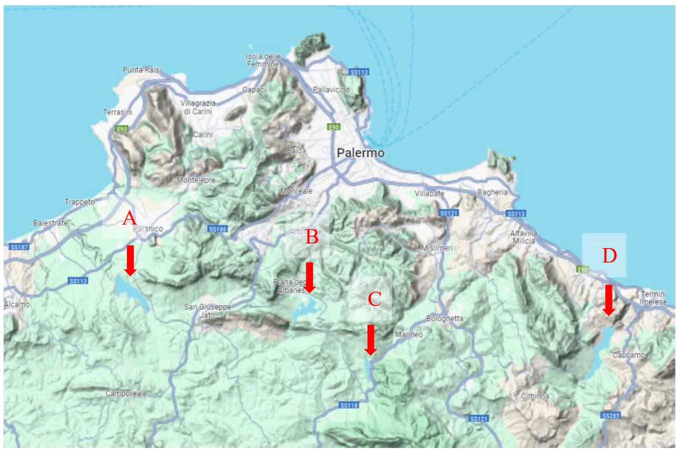

Fig. 5. Lakes maps of Palermo

Extracting the data of the only four lakes under analysis, Fig. 6 was obtained. The trend is quite similar to the one reported in Fig. 4, underling that the province of Palermo is affected by the same water scarcity in the same period.

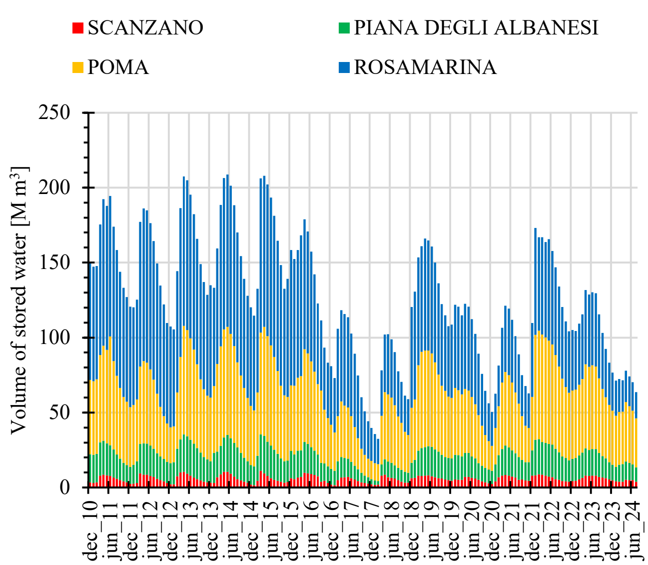

Fig. 6. Trend of the water stored inside the lakes in Palermo

In the same way a linear regression is carried out to examine the fulfill capacity of the 4 lakes during the 2010 to 2024, see Fig. 7.

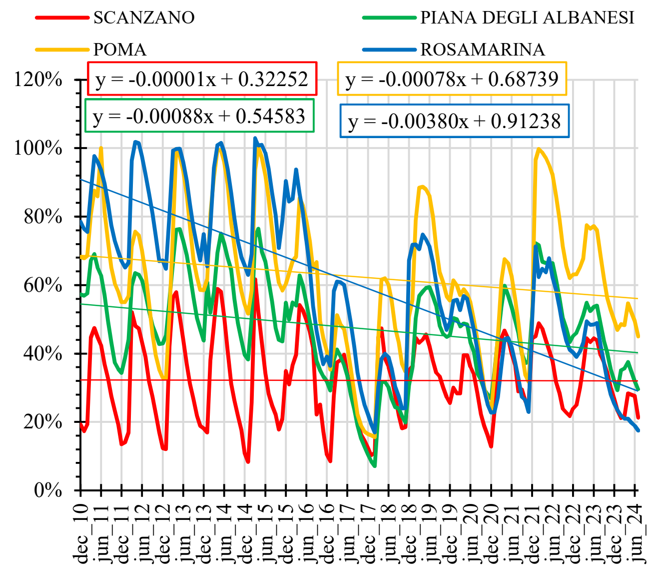

Fig. 7. Degree of filling and linear regression of water in the reservoirs

From Fig. 7, it is possible to observe that Scanzano is almost stable in the entire period (except the annual fluctuation due to the alternance of dry and wet seasons). Differently, the other three lakes (having a bigger water capacity) show decreasing trends: in detail, Rosamarina is losing 0.380% of the stored water per month (4.56% per year, corresponding to 4.56 M m^3), Piana degli Albanesi is losing 0.088% per month (1.056% per year, 0.35 M m^3), Poma is losing 0.078% per month (0.936% per year, corresponding to 0.679 M m^3). The graph reveals also that these lakes started with a degree of filling equal to 32.25% in the case of Scanzano, 68.74% Poma, 54.58% Piana degli Albanesi, and 91.38% Rosamarina.

Now, the degree of filling is drastically reduced: 21.28% in the case of Scanzano, 45.01% Poma, 29.60% Piana degli Albanesi, and 17.51% Rosamarina.

Considering the same month of the year, from December 2010 to December 2023, 86.54 M m^3 have disappeared altogether from these water reservoirs.

V. STRATEGIES

To address the growing water crisis in Sicily, several strategies have been identified based on data analysis and technological integration. Among these, the main ones are:

- Implementation of advanced monitoring systems: using IoT sensors for real-time monitoring of water levels in reservoirs.
- Optimization of water uses: Development of sustainable agricultural practices and efficient irrigation technologies to reduce water consumption.
- Water resource planning: Creation of water resource management plans that considers climate variations and future demand.
- Desalination plant: Construction of desalination plants to make up for the 30 M m³ of water lost annually, of which

almost 3 M m³ are required to compensate the annual losses of the lakes in Palermo. Desalination plants can turn seawater into potable water, providing an alternative and sustainable source of fresh water. These plants can be designed to meet the specific needs of the region and can be integrated with renewable energy sources to minimize environmental impact.

- Community Education and Engagement: Promotion of awareness campaigns to educate the population on the importance of water conservation.

Considering the energy required for the Reverse Osmosis treatment (5 kWh/m^3), the freshwater demand could be satisfied by installing an overall desalination capacity of 100,000 m^3/day, that could be divided in 10 plants along the Sicilian coastline [17]. The corresponding energy demand could achieve the value of 150 GWh/y. For the Palermo province, a capacity of 10,000 m^3/day, could be enough. In this case, the freshwater production could be stored directly inside the same Rosamarina lake, being the closest to the coastline and the one at the lowest quote from the sea level or distributed to the existing water network in order to reduce the intake from the water reservoirs.

VI. CONCLUSIONS

The integration of advanced monitoring systems, water resource planning, optimization of water use, and the construction of desalination plants, along with community awareness, constitute a comprehensive approach to addressing the water crisis in Sicily.

Through the implementation of these strategies, it is possible to ensure a sustainable future for the region's water resources, while also supporting local agriculture and the economy. The case study underlined the requirement for freshwater in order to compensate the progressive reduction of the water stored inside the Sicilian water reservoirs.

A possible solution is represented by desalination, thus, an overall freshwater capacity of 100,000 m^3/day is required, of which 10,000 m^3/day for the Palermo province.

To ensure the environmental sustainability of the freshwater production, the amount of required energy must be produced by renewable energy sources.

In future works, the authors will assess the energy mix for the freshwater production and possible techniques to use desalination units to balance the potential instability to thee grid due to a high share of non-programmable energy sources, connected to the grid. An interesting opportunity could be also the possibility to use sea wave energy to supply the desalination plants [18], [19].

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