BIO Web of Conferences **211,** 01021 (2026) https://doi.org/10.1051/bioconf/202621101021
ICWES 2025

Evolution of water resources in a context of variability and climate change: case of the Bouregreg and Chaouia watershed

Hind Fattah[1*] & *Aïssam* Bouaiche[2]

[1] Mohamed V University, Department of Geography, (STHP), Faculty of Arts and Humanities, Rabat, Morocco.
[2] Hassan II University, (LCEAT), Faculty of Arts and Humanities Ben M'Sick, Casablanca, Morocco.

Abstract: The Bouregreg and Chaouia river basin is one of basins most affected by variability and climate change. The insufficient rainfall recorded over the last decade had a considerable impact on the availability of water resources. The Sidi Mohamed Ben Abdellah dam reservoir has been characterized by a downward trend. And, if we add to this, the excessive use of this reservoir by a population exceeding 8,356,829 inhabitants, The dam alone no longer has the capacity to supply drinking and industrial water to the coastal cities from Kenitra to Casablanca. The main objective of this study is to quantify the rainfall deficit, statistically monitor spatio-temporal trends in precipitation in the Bouregreg and Chaouia watersheds, detect their impact on the evolution of surface water resources (1991-2024), and to highlight the strategy adopted to face water scarcity in the basin's large cities. The adoption of a cross-methodological approach based on descriptive statistics and spatial remote sensing made it possible to determine the main drought sequences, monitor the spatio-temporal trends in rainfall indices, and map the surface area occupied by water at the SMBA dam. The results obtained reveal a remarkably visible water shortage throughout the basin due to multiple climatic and anthropogenic factors.

1 Introduction

Rainfall is an essential element of the water cycle, and its variability is associated with droughts and floods [1]. The analysis of rainfall trends has played a significant role in studies on climate variability and change for nearly four decades. Trends are often detected using parametric (simple linear regression) and non-parametric methods, both conventional (MK Test) [2] and innovative (ITA).

* Corresponding author: h.fattah@um5r.ac.ma

Comparative studies between the Mann-Kendall test and Innovative Trend Analysis have all pointed to the reliability and relevance of ITA [3]. A recent study on long-term spatio-temporal trends in annual and seasonal rainfall patterns in Botswana showed that the MK test detected no negative trends in the annual data, compared with 62.5% for the ITA, and also found no positive significance, compared with 18.8% for the ITA [4].

A similar study conducted across the Sebou river basin showed that ITA could detect trends in 93% of cases, compared to only 36% using the MK method [5].

Identifying monotonous trends generally makes it possible to predict the potential consequences for the urban environment, water resources, agriculture and many other socio-economic aspects of life [6]. In areas in the arid and semi-arid regions of North Africa, particularly in Morocco, the concept of water resource scarcity is not new. Since the onset of significant drought in the northern part of the country in the 1970s, a major imbalance has been observed in water resources, both quantitatively and qualitatively [7].

In this regard, most of the country's rivers have experienced a remarkable drop in their flow rates. The Bouregreg and Chaouia river basins do not seem to be immune to this alarming situation. On the contrary, a considerable decrease in monthly flow rates was detected during the period 1980-2013 compared to the period 1977-1997 [8]. The Bouregreg and Chaouia watershed is one of the basins most affected by climate variability and change. The insufficient rainfall recorded over the last decade had a considerable impact on the availability of surface water resources. The Sidi Mohamed Ben Abdellah dam reservoir has been characterized by a downward trend. Added to this is the excessive use of this reservoir by a population of over 8,356,829 inhabitants, meaning that the dam alone no longer has the capacity to supply drinking water and industrial water to the coastal towns of the central Atlantic coast from Kenitra to Casablanca. The potential danger in the years to come has necessitated the adoption of a project to interconnect the watersheds to avoid water cuts along this coastal strip. In this regard, *what are the spatio-temporal trends in precipitation in the Bouregreg and Chaouia watersheds? What impacts could they have on the evolution of surface water resources? And what strategy should be adopted to address water shortages in the basin's major cities*

The main objective of this study is to quantify the rainfall deficit, statistically monitor spatio-temporal trends in precipitation in the Bouregreg and Chaouia river basins, detect their impact on the evolution of surface water resources (1991-2024), and to highlight the strategy adopted to address water scarcity in the basin's major cities.

2 Data and method used

2.1 Presentation of the study area

The Bouregreg and Chaouia river basin is located between parallels 32°48'00" and 34°06'00" north latitude and between meridians 05°26'00" and 8°02'00" west longitude. According to the Bouregreg and Chaouia Water Basin Agency (Benslimane), it covers an area of 20,470 km^2 divided into three sub-basins that open onto the Atlantic Ocean: the Bouregreg Basin, the coastal rivers basin and the Chaouia plain basin. Analysis of surface data using digital elevation models has revealed significant altitude variability from the north-west to the south-east, where maximum values exceed 1,620 m. The basin is located partly between the central plateau to the east and the Chaouia plain to the west (Fig. 1). In terms of climate, it is characterized by a semi-arid Mediterranean climate. Over the reference period 1991-2020, average annual rainfall varies between 311 mm in Nouaceur and 522 mm in Rabat-Salé, and average annual temperatures are around 18.6°C in Casablanca.

The Bouregreg River is the main river in the basin. It continuously feeds the Sidi Mohammed Ben Abdellah dam reservoir. It originates in the Middle Atlas Mountains at an altitude of 1,627 meters [9] and flows towards the central plateau, emptying into the Atlantic Ocean between the cities of Rabat and Salé. The hydrographic network also includes the Oued Grou and its tributaries (Korifla and Akrach), as well as other coastal waterways, notably El Mellah, N'fifikh, Cherrat and Ykem. Administratively, the Bouregreg and Chaouia river basin covers five prefectures (Rabat, Salé, Skhirat-Temara, Mohammedia and Casablanca) and nine provinces (Khemisset, Benslimane, Médiouna, Nouaceur, El Jadida, Berrechid, Settat, Khouribga and Khénifra) belonging to the regions of Rabat-Salé-Kénitra, Casablanca-Settat and Beni Mellal-Khénifra (Fig. 1).

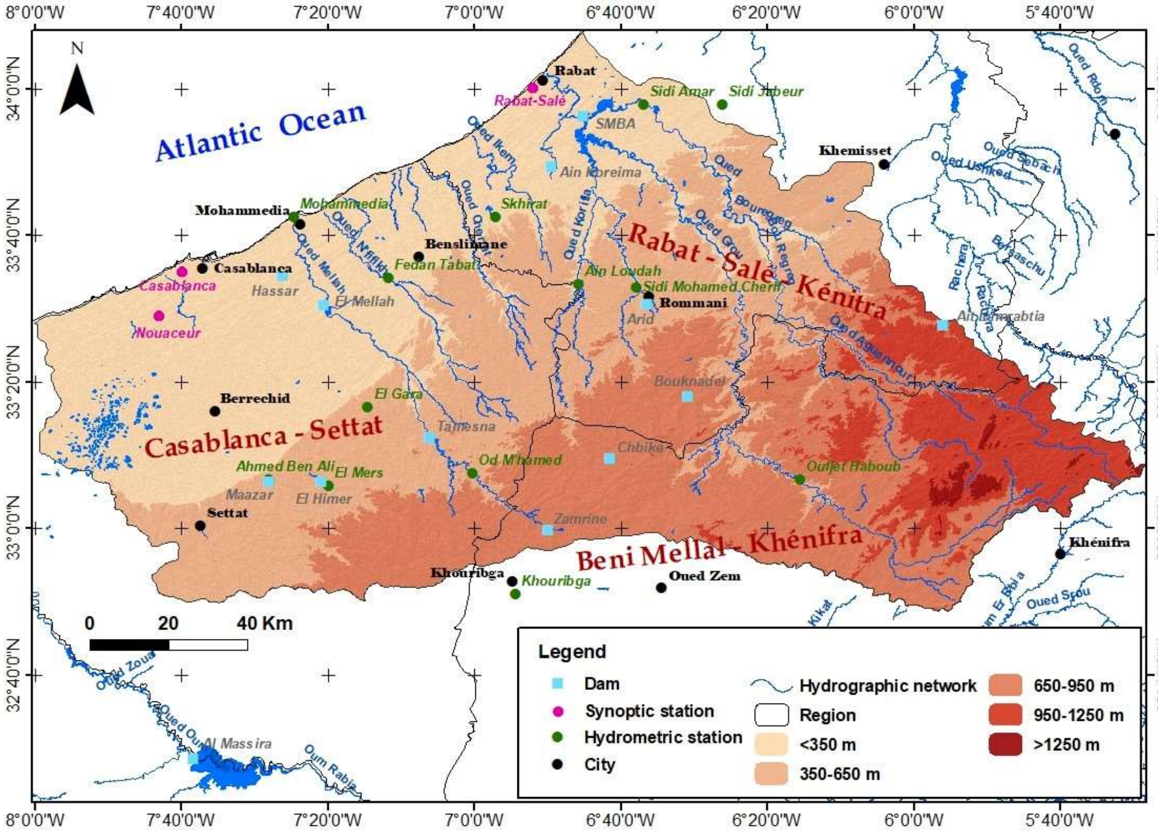

Fig. 1: Location of the Bouregreg and Chaouia watershed

2.2 Data source and method

This study was developed using daily precipitation measurements collected over the last three decades (1991-2024) for five synoptic and hydrometric stations (Rabat-Salé, Sidi Mohamed Cherif, Oujlet Haboub, Casablanca and Nouaceur) from the DGM in Casablanca and the ABH in Bouregreg and Chaouia (Table 1), as well as daily measurements of water inflows to the SMBA dam, provided by the DGE in Rabat for the same period.

To supplement this daily database, satellite images from the Landsat program (Satellites 8 and 9 OLI/TIRS) were used. The period covered is the last decade, spread over four different dates (December 23, 2016 – November 27, 2018 – November 7, 2021 and November 11, 2024).

Table 1: Stations selected for the climate study of the Bouregreg and Chaouia river basins and statistics for the series studied (1991–2024)

Station	Lat. (°N)	Long. (°O)	Elevation (m)	Observation period	Statistics for the series studied (mm)			
					Avr. P	*Max. P*	*Min. P*	*Standard deviation*
Rabat-Salé	34,05	-6,77	45	1991-2024	438,1	861,1	207,5	172,6
SM Cherif	33,54	-6,62	378		383,5	888,7	171,6	160,1
Oujlet Haboub	33,21	-6,23	803		516,5	972,6	251,7	190,2
Casablanca	33,56	-7,67	62		397,9	991,6	195	170,4
Nouaceur	33,37	-7,58	200		316	1045,5	146,1	178,1

The adoption of a cross-methodological approach based on descriptive statistics and spatial remote sensing made it possible, as a first step, to quantify the annual rainfall deficit by calculating the standardised precipitation index:

$$(\boldsymbol{SPI} = \frac{P(i)-P(m)}{P(\sigma)}) \quad (1)$$

where
P(i) = Total precipitation for year (i)
P(m) = Average precipitation for the series studied
P(σ) = Standard deviation for the series studied [10].

Secondly, spatio-temporal trends were determined based on the Mann-Kendall test and the Innovative Trend Analysis (ITA) method developed by Sen in 2012 [11]. This new method, based on representative graphs of subsections, enabled the identification of hidden sub-trends [12]. It consists of dividing the main time series into two equal parts, then ranking them in ascending order [5, 11], which makes it possible to generate objective and quantitative trends based on a well-defined statistical significance threshold (5%).

Of the 27 climate indices previously proposed and validated by the Expert Team on Climate Change Detection and Indices (ETCCDI), 10 indices were selected that reflect the intensity, duration and frequency of rainfall events over the last few decades (Table 2).

Table 2: Rainfall indices selected for the study of current trends in the Bouregreg and Chaouia river basins

Acronym	Index name	Unit
Rx1day	Maximum rainfall on a rainy day/year.	mm
Rx5day	Maximum precipitation over five consecutive rainy days/year.	
R10mm	Annual count of days when RR≥10mm.	Days
R20mm	Annual count of days when RR≥20mm.	
CDD	Maximum number of consecutive dry days with RR<1mm.	
CWD	Maximum number of consecutive wet days with RR≥1mm.	
R95p	Annual total precipitation when RR>95th percentile.	mm
R99p	Annual total precipitation when RR>99th percentile.	
PRCPTOT	Annual total precipitation on rainy days (RR≥1mm).	
SDII	Simple precipitation intensity index ($\frac{PRCPTOT}{Nbr.Wet\ days}$)	

The evolution of the SMBA dam's water retention was determined by calculating the normalized difference water index:

NDWI=(Green-NIR)/(Green+NIR) (2) [13].

Based on the combination of two spectral bands: visible green and near-infrared, it was possible to map and track spatio-temporal changes in the area occupied by water. According

 https://doi.org/10.1051/bioconf/202621101021

to the founder of this index, values generally range between (**-1**) and (**1**). The more positive and higher they are, the more water the area contains.

3 Results and discussion

3.1 Spatial and temporal variability and trends in precipitation between 1991 and 2024 in the Bouregreg and Chaouia river basins

The calculation of the SPI index on a 12-month scale for the period 1991-2024 reveals significant interannual variability in rainfall for all of the stations studied. The 3-year moving averages made it possible to determine the major rainfall cycles and further demonstrated a successive alternation of dry and wet periods: a long dry spell occurred in the basin during the 1990s and 2000s, with the obvious exception of a few generously wet years (1996 and 1997). Subsequently, a relatively wet period from 2008 to 2018 is worth noting, which was interrupted by a few dry years, notably 2015 and 2017. From 2019 onwards, a period of intense and prolonged drought affected the study area and persisted until 2024. Of the 34 years of observation, 23 were affected by a relatively significant rainfall deficit in Nouaceur (67.6%), 21 in Rabat-Salé (61.8%) and 19 in Sidi Med Cherif, Oujlet Haboub and Casablanca (55.9%) (Fig. 2).

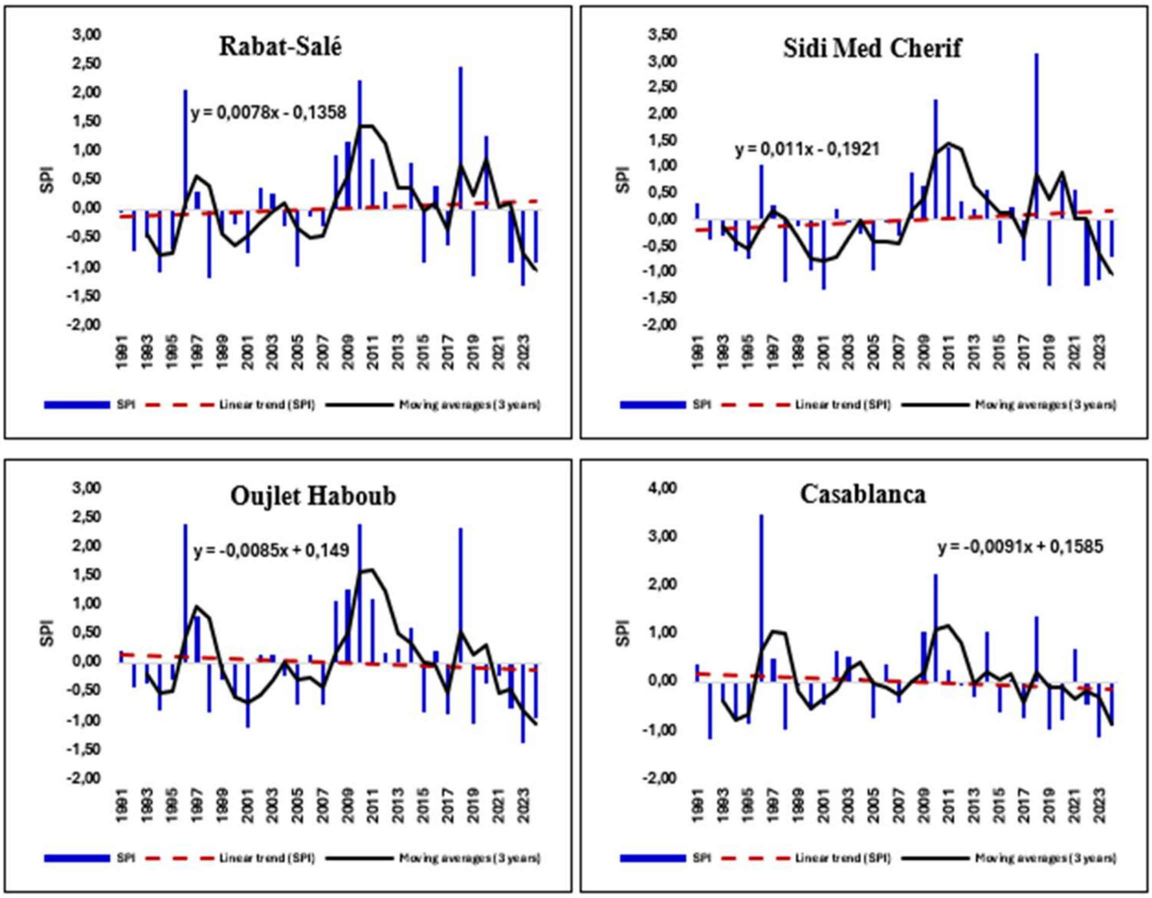

Fig. 2: Results of the SPI index calculation applied to annual data for stations in the Bouregreg and Chaouia river basins.

Spatio-temporal trends in precipitation indices were determined using the nonparametric Mann-Kendall test. The results show a degree of stability in intensity indices (Rx1day, Rx5day, PRCPTOT). The recorded values do not reach the significance threshold of 0.05 and fluctuate slightly between an increase at the Rabat-Salé and Sidi Med Cherif stations and a decrease at the Casablanca, Nouaceur, and Oujlet Haboub stations. The Rx1day index recorded its highest value in 2010 in Casablanca. The rainfall recorded on November 29 (in a single night) reached an all-time high of 178 mm, which represents the cumulative rainfall for six months of normal precipitation.

The SDII, meanwhile, shows a non-significant upward trend for all synoptic and hydrometric stations studied. The indices based on thresholds (R10mm and R20mm) and duration (CDD and CWD) are generally stable and insignificant. A historical study of the maximum durations of dry and rainy periods indicates that the highest CDD value was recorded in Nouaceur in 1999 with 283 consecutive dry days where PR<1mm, while the longest rainy period (CWD) was detected in Oujlet Haboub in 1993, where the maximum value reached 17 consecutive rainy days. In addition, the frequency indices (R95p and R99p) show no significant long-term trend (Table 3).

Table 3: Results of the Mann-Kendall test applied to rainfall indices between 1991 and 2024 at stations in the Bouregreg and Chaouia river basins (95% confidence level)

	Rabat-Salé		**SM Cherif**		**Oujlet Haboub**		**Casablanca**		**Nouaceur**	
	Sen's slope	***P-value***	***Sen's slope***	***P-value***	***Sen's slope***	***P-value***	***Sen's slope***	***P-value***	***Sen's slope***	***P-value***
Rx1day	+0,222	0,3503	+0,208	0,2356	+0,087	0,6458	-0,047	0,8238	-0,36	0,1229
Rx5day	+0,402	0,3817	+0,372	0,4408	-0,06	0,8588	-0,248	0,7331	-0,44	0,1919
R10mm	-0,096	0,1072	0,00	0,9169	0,00	0,7427	0,00	0,6311	0,00	0,6535
R20mm	0,00	0,423	0,00	0,7293	0,00	0,5989	0,00	0,6203	0,00	0,2195
CDD	+0,09	0,8354	+0,833	0,2183	+0,666	0,1303	+0,428	0,4859	+0,47	0,5934
CWD	-0,043	0,33	0,00	0,6169	0,00	0,9161	-0,04	0,1364	0,00	0,208
R95p	+0,538	0,8356	+0,794	0,6565	-0,43	0,9056	-0,85	0,5631	-1,06	0,3062
R99p	+0,31	0,5732	+0,434	0,4234	-0,072	0,8821	+0,105	0,8938	-0,54	0,398
PRCPTOT	+0,22	1	+0,411	0,9527	-1,81	0,5335	-1,664	0,7896	-2,28	0,2858
SDII	+0,035	0,1821	+0,053(.)	0,0997	+0,016	0,5047	+0,012	0,7782	+0,01	0,7782

Dots (.): Trends close to being significant.

To further the analysis, the Innovative Trend Analysis (ITA) method was used to address the shortcomings associated with the MK test, which often seeks monotonic trends without taking into account the different categories of values (low, medium, and high) within the same calculation process [6, 11].

The use of the ITA method reveals relevant details compared to the traditional MK method. The results of Pearson's correlation coefficient show a strong positive correlation between the two halves of the series studied. At a 95% confidence level, the R10mm, R20mm and SDII indices tend to increase slightly, except in a few cases where insignificant decreases were observed, notably in Rabat for R10mm and in Nouaceur and Casablanca for R20mm. The results of the CWD index are statistically significant for the stations Sidi Med Cherif (+0.083 mm/year), Oujlet Haboub (+0.044 mm/year), and Nouaceur (-0.031 mm/year). For the other indices, no trend was detected (Fig. 3).

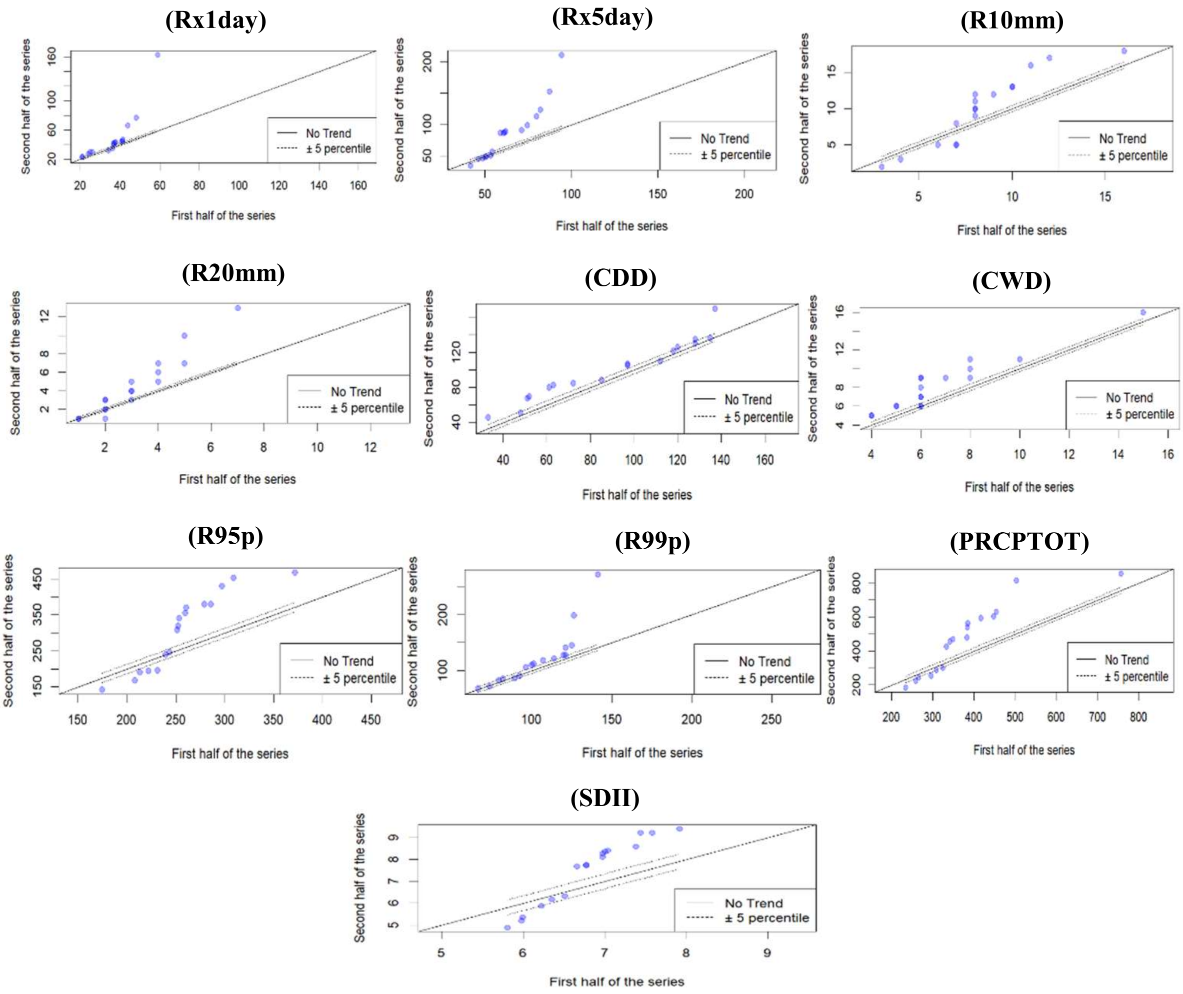

Fig. 3: Demonstration of ITA results for rainfall indices in Sidi Med Cherif.

As for seasonal trends, it appears that summer rainfall totals are tending to decrease significantly in the study area (between -0.028 mm/year in Rabat-Salé and -0.5 mm/year in Oujlet Haboub). This decrease seems to be linked to the negative trends detected on a monthly basis, particularly in June, July, and August. On the other hand, autumn, winter, and spring rainfall totals do not show any significant trends (Table 4).

3.2 Impact study on changes in surface water resources in the Bouregreg and Chaouia river basins (case study of the SMBA dam reservoir)

The Sidi Mohammed Ben Abdellah dam was built on the Bouregreg River at a height of 99 m. Its normal capacity is 974.8 Mm^3. The volume of water stored in its reservoir varies from one period to another and depends on natural and human conditions. In this era of climate change and the resulting variability in precipitation, considerable impacts have been observed on the reservoir. Monitoring of the dam's water inflows between 1991 and 2024 shows a significant drop in the annual, seasonal, and monthly fill rates (Table 5). Drought, a recurring phenomenon in Morocco since the 1980s, appears to have an influence on the availability of water resources. Dry years often coincide with the lowest water inflows: 2022

Table 4: Results of the Innovative Trend Analysis (ITA) applied to annual, seasonal, and monthly precipitation (mm) between 1991 and 2024 in Oujlet Haboub and Nouaceur.

Series	Station	Trend slope (S)	Trend Indicator	Slope standard deviation	Correlation
Annual	*Oujlet Haboub*	+3,556	1,31	0,82	0,907
	Nouaceur	+2,147	1,279	0,455	0,969
Autumn	*Oujlet Haboub*	+2,782	3,877	0,286	0,949
	Nouaceur	+0,061	0,116	0,137	0,977
Winter	*Oujlet Haboub*	+0,539	0,467	0,487	0,908
	Nouaceur	+1,355	1,687	0,384	0,969
Spring	*Oujlet Haboub*	+0,815	0,965	0,276	0,942
	Nouaceur	+0,619$^{(.)}$	1,515	0,093	0,973
Summer	*Oujlet Haboub*	**-0,500$^{(*)}$**	**-3,581**	**0,031**	**0,974**
	Nouaceur	**-0,233$^{(*)}$**	**-7,959**	**0,015**	**0,957**
Janury	*Oujlet Haboub*	+0,867	2,479	0,129	0,976
	Nouaceur	+0,108	0,463	0,185	0,92
February	*Oujlet Haboub*	0,324$^{(.)}$	0,926	0,054	0,991
	Nouaceur	+1,261	5,763	0,422	0,817
March	*Oujlet Haboub*	+1,199	3,291	0,165	0,955
	Nouaceur	0,684$^{(.)}$	3,648	0,088	0,943
April	*Oujlet Haboub*	-0,495$^{(.)}$	-1,612	0,093	0,965
	Nouaceur	-0,383$^{(.)}$	-2,323	0,071	0,953
May	*Oujlet Haboub*	+0,132	0,649	0,132	0,893
	Nouaceur	**+0,318$^{(*)}$**	**5,699**	**0,029**	**0,987**
June	*Oujlet Haboub*	**-0,331$^{(*)}$**	**-4,823**	**0,022**	**0,980**
	Nouaceur	**-0,128$^{(*)}$**	**-7,556**	**0,01**	**0,942**
July	*Oujlet Haboub*	**-0,076$^{(**)}$**	**-3,104**	**0,008**	**0,982**
	Nouaceur	**-0,037$^{(**)}$**	**-7,769**	**0,006**	**0,919**
August	*Oujlet Haboub*	**-0,093$^{(*)}$**	**-2,001**	**0,016**	**0,960**
	Nouaceur	**-0,067$^{(**)}$**	**-8,99**	**0,007**	**0,914**
September	*Oujlet Haboub*	+0,843$^{(.)}$	9,123	0,07	0,959
	Nouaceur	**+0,265$^{(*)}$**	**10,039**	**0,046**	**0,915**
October	*Oujlet Haboub*	+0,507	2,015	0,129	0,945
	Nouaceur	-0,545	-2,381	0,31	0,714
November	*Oujlet Haboub*	+1,431	3,833	0,195	0,952
	Nouaceur	+0,341$^{(.)}$	1,256	0,092	0,979
December	*Oujlet Haboub*	-0,653	-1,442	0,10	0,985
	Nouaceur	-0,014	-0,041	0,289	0,938

Dots $^{(.)}$: Trends close to being significant. Asterisks $^{(*)}$: Significant trends. Double asterisks $^{(**)}$: Highly significant trends.

(34.7%), 2023 (21%), and 2024 (31.2%). In contrast, the dam was filled to 100% capacity during exceptionally wet years (1996 and 1997).

Table 5: Results of the Mann-Kendall test applied to the annual and seasonal fill rates (%) of the SMBA dam between 1991 and 2024 (95% confidence level)

Series	Sen's slope	P-value
Annual	-0,944$^{(**)}$	0,0083
Autumn	-0,668$^{(*)}$	0,0379
Winter	-1,022$^{(*)}$	0,0368
Spring	-0,959$^{(**)}$	0,0024
Summer	-0,909$^{(**)}$	0,0076

Asterisks (*): Significant trends. Double asterisks (**): Highly significant trends.

The calculation of the normalized difference water index (NDWI) reveals the same findings. It also made it possible to map the surface area occupied by water at the SMBA dam reservoir and downstream of the Bouregreg River. The dates selected correspond to the months of November and December, in order to provide a clearer picture of the annual water situation. A reclassification of the values remotely sensed from satellite images made it possible to distinguish four different classes: non-aquatic surface (from -1.00 to 0.00), low water surface (0.01 to 0.30), medium water surface (0.31 to 0.60), and high-water surface (0.61 to 1). The results obtained between 2016 and 2024 reveal marked spatio-temporal changes. High NDWI values correspond to wet periods (2016 and 2018), while low values coincide with dry periods (2021 and 2024). Generally, the bluer the pixel, the more water the area under study contains, and the more orange the pixel, the less water the area contains. On December 23, 2016, the maximum value of the spectral water index reached 0.42. The dam was moderately full, particularly in the southeast. It had a capacity of 724.9 Mm3, thanks to rainfall totals that were relatively higher than the average for the period 1991-2024 (Fig. 4).

In 2018, the water situation improved significantly compared to the previous date. Exceptional rainfall across the entire study area (between 631 and 956 mm) helped to replenish the SMBA Dam's reserves. The SPI values were positively high (between 1.37 and 3.61), reflecting absolute humidity during this period. This remarkable situation also enabled the normalized difference water index to record its highest value on November 27, 2018 (0.63). The surface area occupied by water was highly aqueous, particularly to the north and southeast of the dam. Non-aqueous surfaces were insignificant. With a reserve of 916.6 Mm^3 (compared to a normal capacity of 974.8 Mm^3), the dam had a fill rate of 94% (Fig. 4).

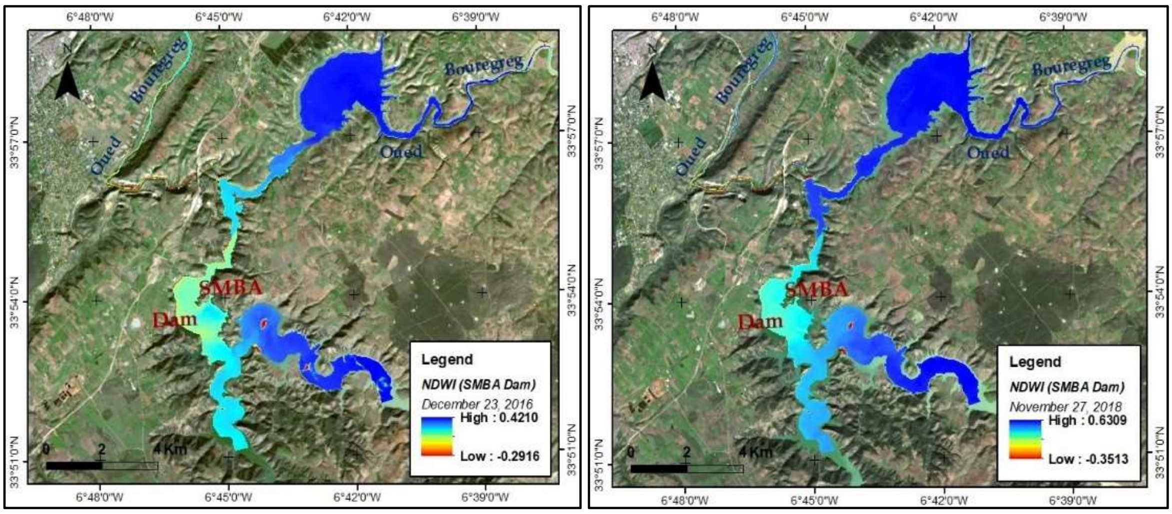

Fig. 4: Water index by normalized difference calculated for the SMBA dam and downstream of the Bouregreg River (Dec. 23, 2016, and Nov. 27, 2018). Results superimposed on natural color satellite images (red, green, blue).

The following dates were marked by a very low NDWI (0.20 for November 7, 2021, and 0.26 for November 11, 2024). These values are a sign of severe climatic drought. The low rainfall in 2024 (between 240 and 331 mm) had a significant negative impact on the SMBA dam, resulting in a very low fill level of no more than 31.2%. The volume of water stored in its reservoir recorded a striking decrease compared to November 27, 2018 (-561.2 Mm3). The warm colors observed in the satellite image show less dense plant biomass in the areas surrounding the dam (Fig. 5).

A similar study focusing on "the quantification, modeling, and use of water resources in the Upper Oum Er Rbia Basin (upstream of the Ahmed El Hansali dam) " [14], identified significant quantitative changes in the lakes of the BV. Lake Azegza experienced a sharp decline in surface area after 2018. The study also examined the probable causes of this decline and established a link between climatic factors and the surface area occupied by water.

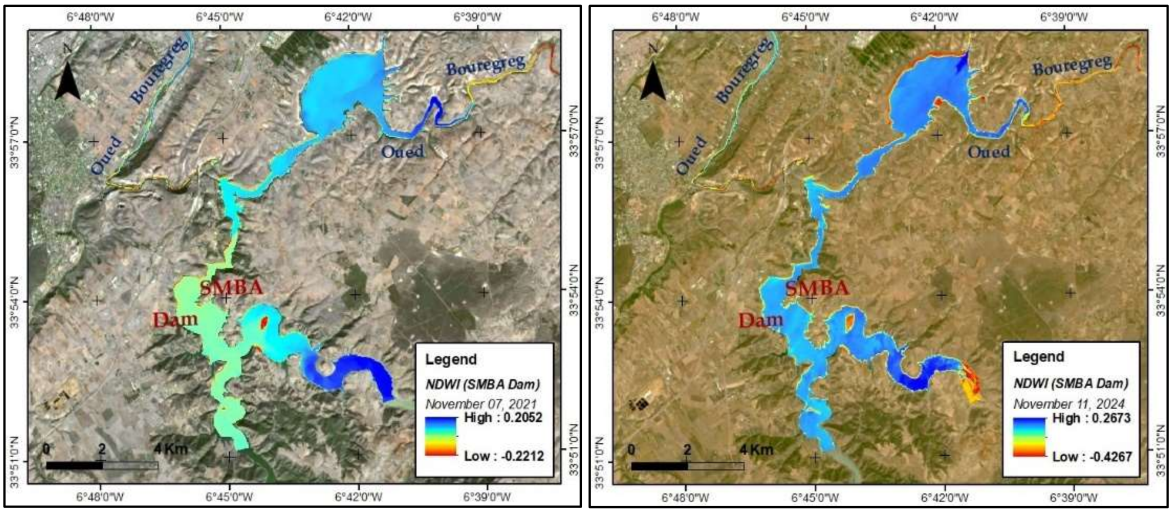

Fig. 5: Water index by normalized difference calculated for the SMBA dam and downstream of the Bouregreg River (Nov. 7, 2021, and Nov. 11, 2024). Results superimposed on natural color satellite images (red, green, blue).

3.3 Integrated management of water scarcity in the major cities of the Bouregreg and Chaouia river basins

The decline in water resources in the Bouregreg and Chaouia river basins, particularly at the SMBA dam reservoir, does not appear to be linked solely to the high variability in precipitation volumes and the increase in drought sequences over the last three decades. Other anthropogenic factors could play a major role, in particular population growth and the overexploitation of water resources for essential socio-economic purposes (industry, irrigation, etc.).

The coastal strip between Kenitra and Casablanca remains densely populated (nearly 22.7% of the country's total population). General population and housing censuses conducted in 1982, 1994, 2004, 2014, and 2024 revealed a gradual and rapid increase in the total population of the prefectures of Salé, Rabat, Skhirat-Temara, Mohammedia, and Casablanca, as well as the provinces of Kenitra, Benslimane, and Nouaceur. The total population rose from 3,781,845 in 1982 to 8,356,829 in 2024, spread across 2,255,842 households (Table 6). Since the SMBA dam came into service in 1974, the coastal cities of the Bouregreg and Chaouia river basins, notably Salé, Rabat, Skhirat-Temara, Bouznika, Mohammedia, and Casablanca, have been supplied with water stored in its reservoir. Due to the daily excessive use of the dam's reservoir by this population, it no longer has the capacity to meet the needs of individuals for drinking water and industrial water. Added to this is the filling of the reservoir with sediments due to soil erosion [8], resulting in an extremely acute water shortage that requires urgent and decisive action. Pollution of various kinds (agricultural, domestic, and industrial) also contributes to the degradation of the quality of available water resources, which increases the costs of the necessary treatment.

Table 6: Change in the legal population of the Atlantic coastal strip between Kenitra and Casablanca (between 1982 and 2024)

	1982	1994	2004	2014	2024
Prov. Kénitra	---	594.987	878.101	1.061.435	1.284.247
Préf. Salé	377.471	631.818	823.485	982.163	1.089.554
Préf. Rabat	526.154	623.457	625.336	577.827	515.619
Préf. Skhirat-Temara	129.796	244.801	395.858	574.543	783.475
Prov. Benslimane	172.870	180.300	198.504	233.123	279.517
Préf. Mohammedia	105.120	170.063	322.286	404.648	514.057
Préf. Casablanca	2.470.434	3.126.78	3.631.061	3.359.818	3.218.036
Prov. Nouaceur	---	---	182.145	333.604	672.324
Total	3.781.845	5.572.21	7.056.776	7.527.161	8.356.829

Data : RGPH, 1982, 1994, 2004, 2014 and 2024

To address water shortages in large cities in the basin, a coherent strategy has been adopted. As a first step, in 2023 the Ministry of Equipment and Water adopted a project to interconnect the river basins, with the aim of increasing the storage capacity of the SMBA dam to over 250 million cubic meters by transferring a large volume of water (15 cubic meters per second) from the surplus Sebou basin to the deficit Bouregreg basin over a distance of 70 km [15]. This promising and historic project has made it possible to supply the cities of Rabat, Skhirat-Témara, Bouznika, Mohammedia, and South Casablanca (Maârif, Anfa, Oasis, Hay Hassani, etc.) with drinking water (Fig. 6 (a) and (b)). According to the General Direction of Hydraulics (Rabat), this project is part of a comprehensive interconnection project linking the four central basins (Sebou, Bouregreg and Chaouia, Oum Er Rbia and Tensift). The next step will be to continue the interconnection from the SMBA dam to the Al Massira dam located in the Oum Er Rbia basin over a length of 340 km [15].

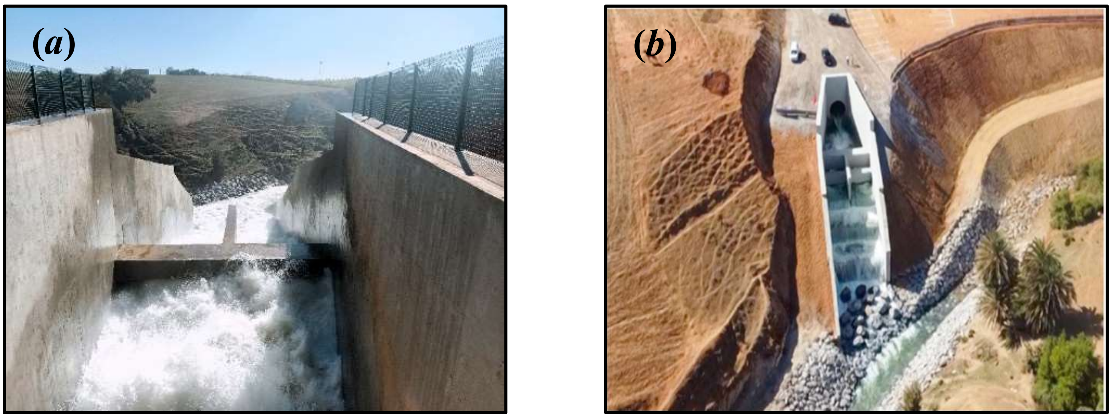

Fig. 6: Water interconnection project between the Sebou basin and the Bouregreg basin. (a) Close-up view. (b) Aerial view (*Date photo taken: November 19, 2023*)

In the same context, numerous urgent and strict measures were considered with the aim of saving water in the major cities of the Bouregreg and Chaouia river basins. Among these measures was the partial closure of public baths in Casablanca three days a week (Monday, Tuesday, and Wednesday). This decision came into effect in January 2024, was suspended during Ramadan, and was reapplied from August to October of the same year. Car washes have suffered the same fate. Other nighttime measures have been planned, including water cuts or reduced flow from 11:00 p.m. to 6:00 a.m. in the southern part of the Casablanca, Dar Bouaâzza, and Nouaceur.

In order to supply industrial water and avoid water cuts in certain towns close to the area under study (Berrechid, Azemmour, El Jadida, etc.), a project to build seawater desalination plants (SD) was adopted. Several plants close to the coast have been set up, notably in Jorf Lasfar and Safi. Other SDs are currently under construction or in the planning and will be used for industry, irrigation, and drinking water supply. These plants will also be able to safeguard depleted (or nearly depleted) aquifers, such as the Berrechid aquifer. According to data from the Ministry of Equipment and Water released in 2023 and 2024, a new SD attached to the city of Casablanca is under construction. It will be located in the municipality of Lamharza Essahel (El Jadida province) and will have a capacity of 300 Mm^3/year. This project, scheduled for the period 2026-2030, will be the largest in Africa and will cover the drinking water (270 Mm^3/year) and irrigation (30 Mm^3/year) needs of the Casablanca-Settat and Fez-Meknes regions.

Conclusion

To combat the structural and recurring water stress threatening Morocco and achieve a strategic objective, namely to "guarantee drinking water for all citizens and cover at least 80% of irrigation needs throughout the country" [15] new infrastructure projects and innovative facilities have been carried out over the past decade, including water highways, the construction of new dams, reservoirs, and seawater desalination plants. These projects are all part of the 2020-2027 national program for drinking water supply and irrigation. Generally speaking, good water resource management requires optimizing daily use (domestic, agricultural, industrial, and energy) and minimizing waste, especially in times of natural climate variability and climate change. Despite the absence of significant long-term precipitation trends at several stations in the Bouregreg and Chaouia river basins, climatic conditions remain problematic due to the increase in drought sequences associated with a gradual change in air temperatures and, moreover, evaporated volumes. Considerable impacts have been observed on the water and agricultural sectors. Most of the country's dams have reached their lowest levels in the last decade. The SMBA dam is just one example among many. The results obtained are fully consistent with those obtained in various scientific contributions developed and published over the last ten years [5, 8, 14]. One thing is certain: Moroccan and Mediterranean watersheds experience the same spatial and temporal variability in terms of precipitation, runoff, and water supply. These studies confirm the essential role of climate factors associated with human activity and emphasize the importance of strategies adopted for the coherent management of water resources.

References

1. H. Wu, and H. Qian, Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s. *International Journal of Climatology*. Vol. **37** (**5**). 2582-2592 (2017). https://doi.org/10.1002/joc.4866
2. H. Khosravi, F. Sajedi-Hosseini, M. Nasrollahi, and H.R. Gharechaei, Trend analysis and detection of precipitation fluctuations in arid and semi-arid regions. *Desert*. Vol. **22-1**. 77-84 (2017).
3. J. Yaméogo, Annual rainfall trends in the Burkina Faso Sahel: A comparative analysis between Mann-Kendall and innovative trend method (ITM). *Discover Applied Sciences*. Vol. **7** (**221**) (2025). https://doi.org/10.1007/s42452-025-06675-1
4. P.K. Kenabatho, Innovative trend analysis of long-term spatial-temporal rainfall patterns over Botswana: Implications for water resources management. *Journal of*

Hydrology: Regional Studies. Vol. **58**. 102217 (2025). https://doi.org/10.1016/j.ejrh.2025.102217

5. R. Kessabi, M. Hanchane, Y. Ait Brahim, B. El Kazzan, R. Addou, and M. Belmahi, Characterization of annual and seasonal rainfall trend using innovative trend analysis (ITA) and classical methods: the case of Wadi Sebou basin (WSB) Morocco. *Euro-Mediterranean Journal Environmental Integration*. Vol. **10**. 555-573 (2025). https://doi.org/10.1007/s41207-024-00507-1
6. Z. Sen, Trend Identification Simulation and Application. *Journal of Hydrologic Engineering*. Vol. **19** (**3**). 635-642 (2014).
7. A. Sebbar, W. Badri, H. Fougrach, M. Hsaine, A. Saloui, Etude de la variabilité du régime pluviométrique au Maroc septentrional (1935-2004). *Sécheresse*. Vol. **22** (**3**). 139-148 (2011).
8. R. El Aoula, G. Mahé, N. Mhammdi, A. Ezzahouani, I. Kacimi, et K. Khomsi, Evolution du régime hydrologique dans le bassin versant de Bouregreg, Maroc. Proceedings of International Association of Hydrological Sciences. Vol. 383. 163-168 (2021). https://doi.org/10.5194/piahs-384-163-2021
9. G. Beaudet, Le plateau central marocain et ses bordures : Etude géomorphologique. Thèse de Doctorat. Lettres. Paris. Imprimeries Françaises et Marocaines. Rabat. 478 p (1969).
10. T. McKee, N.J Doesken, and J. Kleist, The relationship of drought frequency and duration to time scale. Proceedings of the 8th Conference on Applied Climatology. 17-22 January. Anaheim, California. 179-184 (1993).
11. Z. Dong, W. Jia, R. Sarukkalige, G. Fu, Q. Meng, and Q. Wang, Innovative Trend Analysis of Air Temperature and Precipitation in the Jinsha River Basin, China. *Water*, Vol. **12** (**11**), 3293 (2020). https://doi.org/10.3390/w12113293
12. Z. Sen, Innovative Trend Analysis Methodology. *Journal of Hydrologic Engineering*. Vol. **17** (**9**). 1042-1046 (2012).
13. S.K. McFeeters, The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*. Vol. **17** (**7**). 1425-1432 (1996). https://doi.org/10.1080/01431169608948714
14. T. El Orfi, Quantification, modélisation et usages des ressources en eau dans le Haut Bassin de l'Oum Er Rbia (Amont du barrage Ahmed El Hansali, Maroc). Thèse de doctorat. Hydrologie. Univ. Sultan Moulay Slimane (Maroc) et Univ. Lorraine (France). 356 p (2023).
15. H-L. Vedie, Désalinisation, barrages et autoroutes de l'eau (les incontournables de la lutte contre le stress hydrique au Maroc). Policy Center for the New South. Policy paper n° 19/25. 18 p (2025).

Acknowledgments

The authors would like to express their sincere gratitude to the General Direction of Meteorology (Casablanca), the Bouregreg and Chaouia Water Basin Agency (Benslimane), and the General Direction of Water (Rabat) for their support and for the documentation made available to them for purely scientific purposes.

Funding

This study did not receive any funding from governmental or intergovernmental organizations (nationals or internationals).

Data availability statement

The authors declare that they have used official data made available to them by the relevant authorities.

Author contribution statement

Hind FATTAH: conceptualization, methodology, writing of the original draft, revision, research, analysis, and supervision. ***Aïssam BOUAICHE***: writing, revision, and supervision.