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Original Research

Calculating the Water Deficit and Surplus in the Levels of the Euphrates River using the Equations of Ivanov and Najib Kharrufa

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ABSTRACT

The science of hydrology focuses on the earth's waters, including their occurrence, circulation, and distribution, as well as their physical and chemical characteristics and interactions with the surrounding biological and physical environments, including how they react to human activity. Climate is one of the natural factors that directly or indirectly affect the formation of the hydrological characteristics of the Tigris and Euphrates rivers. The data used for the study area included rainfall, evaporation rate, relative humidity, wind speed, length of sunshine hours, Temperature, and water discharge. Data were obtained from NASA, the US National Administration, the Ministry of Water Resources, and the General Authority of Meteorology and Seismic Monitoring from 2013 to 2023. The study area included three stations through which the Euphrates River passes, which is considered one of Iraq's main rivers. The results obtained using the Ivanov and Najib Kharoufa equations indicate a clear water deficit in the Euphrates River, primarily driven by climatic changes. Notably, reductions in rainfall and increases in evaporation rates have been observed, particularly as the river progresses southward. These climatic changes such as rising temperatures, increased wind speed and directional variability, higher water surface area exposure, and extended daylight hours have collectively contributed to significant water losses and a decrease in river discharge. Furthermore, the river's flow has notably diminished in its southern reaches, where observational stations are located. This is largely due to the region’s low surface gradient, which slows the river’s velocity and exacerbates evaporative losses. In addition to climatic factors, several modern anthropogenic influences have significantly impacted the Euphrates’ flow. Chief among these is the construction of large upstream dams, most notably the Atatürk Dam in Turkey, which has greatly reduced the volume of water reaching downstream countries. The modification and diversion of tributaries and feeder waterways for agricultural irrigation and domestic use have further restricted inflows. Climate change continues to play a critical role by decreasing precipitation and intensifying evaporation, ultimately resulting in substantial losses from both the river and its associated reservoirs. , as it was found that a water deficit occurred in the Hilla, Samawah, and Nasiriyah stations during January as an average for the period 10 years and according to the equation Ivanov and respectively -150.5 mm, -166.8 mm and -120.4 mm. The percentage of water deficit, according to the sheep equation for the above stations and for January and the same period, was estimated at -48.5 mm, -46.3 mm, and -41.1 mm, respectively. The primary cause of these water deficits is the high rates of water evaporation observed at the southern stations of the study area, particularly in Samawa and Nasiriya. This is largely attributed to the difference in the angle of incidence of the sun's rays, which is more oblique in these southern locations compared to the northern stations. Additionally, the increased movement and speed of the wind, particularly in the central and southern regions of the study area, contribute to elevated evaporation rates, leading to higher water losses.

INTRODUCTION

Environments sustainability by Achieving sustainable development is the most significant challenge facing water resource management. This is due to the altered climate and the socioeconomic and hydrological effects of global warming, which reduced the amount of precipitation and, in turn, reduced the need for imported water into Iraq, due to the increased demand for water brought on by population growth, environmental factors, and other limitations that impacted water systems. These factors led researchers to look for more efficient ways to distribute water among the recipients. factors led to the hunt for better ways to divide up the water among the recipients (Mohammad et al. 2020, Al-Saadi et al. 2021). The lack of water is a global problem that affects 80 third-world countries, which account for 40% of the world's population (Al-Ansari et al. 2019, Abbood & Al-Taai 2018). There are now more worries regarding the amount of water needed for agricultural production in the Middle East due to notable population growth. Due to the region's dry and semiarid environment, which severely restricts water supplies, many Middle Eastern nations are extremely vulnerable to future water resource shortages (Ohara et al. 2011, Abbood & Al-Taai 2022). These countries are located in the Middle East, which is currently known for its severe water shortage issues. Less than 500 m3 of water is available per person in the majority of these countries of replenishable water resources (Al-Ansari et al. 2018, Abbood et al. 2023). Among other things, the worrisome rates of groundwater depletion in several places suggest that freshwater scarcity is a pressing issue (Bijl et al. 2018, Abd Al Rukabie et al. 2020). In environmental hydrology, one of the key issues is knowing what regulates surface water balance, especially the processes that partition precipitation into evaporation and runoff (Williams et al. 2012, Al-Awadi et al. 2023). Some studies have been conducted to improve Water content in the levels of the Euphrates River and others where climatic characteristics and meteorological water balance were studied through surface runoff and groundwater recharge as a water surplus, through the use of the surplus water using the Thornthwaite formula (Al-Sudani et al. 2017, Al-Jaf & Al-Taai 2019). Others have concentrated on a more precise evaluation of the national water demand rather than using the fixed requirements per person as a stand-in, and they have connected it to the national water demand and the National renewable water supply each year (Rijsberman et al .2006). In prior work, the intricate mechanisms that influence the inputs and outputs of low-flow discharge were simulated using an integrated hydrological model, and the correlations between precipitation anomalies(Paudei&Benjankar.2020), seasonal temperatures, and low-flow indices were examined (Nassif et al. 2021, Redah et al. 2023). The simulation indicates that average river discharge will decrease during the low flow season due to climate change (De Wit et al. 2007, Al-Taai & Abbood 2020). In a prior study, other researchers examined how current modeling was explored in Spain and the impact of climate change on water resources and their variability (Nassif et al. 2024). Concerning the hydrological effects of climate change, the anticipated consequences on water resources, the effects on river basins, and the existing policy frameworks (Estrela et al. 2012, Abd et al. 2025). Numerous earlier research studies have suggested several ways to lessen the water deficit in the Northern Hemisphere, where they have been examined (Nassif et al. 2021, Yehia et al. 2022). To solve these issues and remove riverbed shortages, changes in rainfall, streamflow, and drought indices are required (McCabe et al. 2015, Al-Taai & Abbood 2020). Several hydrological studies have been carried out on four river basins in Africa to compare the effects of climate change on canal flow. Inter-comparisons have additional influence, as this study demonstrated. They are helpful throughout the adaptation conversation and can be utilized to create adaptation plans when considering their entire application (Aich et al. 2014, Al-Taai & Nassif 2020). As demonstrated by earlier research, climate indicators such as rainfall, the aridity index, and water balance can be used to gauge wetness and dryness.

When considering the effects of different climatic factors, water balance is defined as the difference between regional precipitation (P) and potential evapotranspiration (ET0) during specific period components (Liu 2024, Al-Taai et al. 2021). According to several earlier studies, river storage management can be managed, and the unit can result in improvements (Nassif et al. 2022, Yehia et al. 2022). Two substitute roles are decision-making in tank parameters that optimize the combined usage of the surface and subsurface water or optimize the users' overall surface and groundwater supply (Ivanova et al. 2017, Al-Taai et al. 2021). This study aims to determine the water deficit and surplus in the Euphrates River water levels in the southern region over a ten-year period, utilizing both the Ivanov and Najib Kharoufa equations. Adopting a practical and application-oriented approach, the research addresses the critical issue of water scarcity by seeking community-driven solutions that enhance water resource management. The dual application of these empirical equations enables cross-verification of potential evapotranspiration (PET) estimates under arid climatic conditions, offering a more comprehensive methodological perspective than relying on a single equation.

2. MATERIALS AND METHODS

2.1. Data source

Data were obtained from the Ministry of Water Resources, the General Authority for Meteorology, and NASA (Hassan et al., 2018), encompassing monthly records of wind speed, sunshine duration, evaporation, rainfall, temperature (Hashim et al., 2023; Nassif et al., 2021), relative humidity, and river discharge. These climatic and hydrological variables were collected over a ten-year period (2013–2023) from three monitoring stations Hilla, Samawa, and Nasiriya located in the southern part of the Euphrates River basin. The data were aggregated into annual averages to estimate water losses and determine the river’s water deficit or surplus, based on the influence of climate variability on river inflow. All input weather data underwent rigorous quality control procedures, including outlier detection, gap filling through interpolation, and consistency checks across neighboring stations (Mahdi et al., 2021; Nassif et al., 2021).

2.2. Statistical using

The study deals with the climatic water deficit and the climatic water surplus (Sentelhas et al. 2008, Hashim et al. 2022) for the levels of the Euphrates River for the southern stations (Hilla - Samawah - Nasiriyah). (WD, WE) was calculated, as it depends on two values or variables: the effective rainfall, which can be extracted by mathematical methods, and the second variable is the value of potential evaporation and transpiration, which can be extracted using many mathematical equations where they can be defined as (Mihăilă et al. 2017, Mondol et al. 2022):

1. Water surplus (WE), which is the excess amount of water as a result of the difference between precipitation and evaporation, appears from In equation (1) (Jong & Bootsma 1997, Mandale & Bansod 2019):

$$WE = +P - PE \tag{1}$$

2. Water deficit (WD): It is the amount of water that the soil needs for moisture that cannot be captured by rain In equation (2) (Gocic & Trajkovic 2015, Wang & Xu 2022):

$$WD = -P - PE \tag{2}$$

Where: P = Precipitation in mm and PE = Potential Evaporation/transpiration in mm.

Several mathematical methods were chosen to calculate the amounts of evaporation/transpiration, including the Ivanov equation to determine the amounts of evaporation and water losses and the Najib Kharrufa equation to find a correlation between temperatures and the length of the day on the one hand and the amount of evaporation (Radinović & Ćurić 2009, Llamas 2013).

The two methods of the scientist Ivanov were chosen for their simplicity and lack of complexity, in addition to the use of Najib Kharrufa In equation(3 and 4) for its suitability to the conditions of the study area, as well as its producing correct and accurate results for the water deficit and surplus of the levels of the Euphrates River (Ivanov 2013, Nassif et al. 2024).

1. Equation of the scientist Ivanov: After he developed his famous climate classification for the world, which is as follows (Seyedi et al. 2023, Romashchenko et al. 2020):

$$E = 0.0018(T+25)2\ (100 - A) \tag{3}$$

Where:

E = evaporation/transpiration mm.

T = average monthly temperature in ºC.

A = Average humidity year/month.

2. The Najib S. Kharrufa equation is an empirical method developed to establish a correlation between temperature, day length, and the rate of evaporation. It serves as a practical tool for estimating potential evapotranspiration

(PET), particularly in regions characterized by limited water availability. In this study, the Kharrufa equation is one of the primary methods employed for PET estimation, as it is specifically tailored for application in semi-arid and arid climatic zones. Its suitability for such environments makes it an appropriate choice for assessing hydrological conditions in the Euphrates River Basin.. My agencies (Abedalrahman & Mactof 2017, Shamkhi & Neamah 2021):

$$ETO = G.P.TC\ 1.30 \qquad (4)$$

Where: ETO = evaporation mm/month, p = percentage of monthly brightness hours to annual brightness hours, TC = average temperature in ºC, and G = local correction factor.

3. RESULTS AND DISCUSSION

3.1. Wind Speed and Brightness Hours

Fig. 1 shows that at the Hilla station, the average wind speed for January was 1.3 m/s, which is lower than the station that preceded it. This is because the station is protected by a dense cover of plants, including palm groves, which impede the wind speed, in addition to its low location relative to the sea surface. As for the Samawa station, the average wind speed for January for the period (2013 - 2023) was 2.5 m/s, which is faster than the average wind speed at the Hilla station by 1.2 m/s. This is because the Samawa station is located on the edge of the eastern part of the Western Plateau, in addition to its lack of vegetation cover, as well as its low location above sea level. As for the Nasiriya station, the wind speed reached the average for July for the above period 4.6 m/s, meaning that it increased by 2 degrees. This is also because the area is exposed and faces the southeastern edge of the Western Plateau, in addition to the lack of vegetation cover and the station being exposed to alternating times of fast winds (storms), which increased the average wind speed at the last station. The average hours of sunshine for January at Hilla Station is 10.2 hours, while the average for July is 14.1 hours. From the above, Concluded that the angle of incidence of the sun's rays varies temporally and spatially in the study area, as it reaches its maximum value at the end of June of each year, the length of solar radiation arriving at the south of the study area, as in the Samawah and Nasiriya stations, is different from what reaches the center and north of the region due to considerations related to the tendency of solar radiation to vary in the apparent position of the sun from time to time during the year, in addition to the presence of diversity in the surface of the study area. From the above, it was concluded that the length of hours of solar radiation has a clear effect, as the evaporation process increases because of the temperature rise. The influence of wind on water loss is comparatively lower than that of temperature. Wind speed values show minimal variation across the three studied governorates, whereas temperature exhibits significant seasonal fluctuations, particularly between summer and winter. This temperature increase, beginning with the spring equinox on March 21 and continuing until approximately September 23, leads to heightened water losses from river channels, tributaries, and branches due to elevated evaporation rates during the warmer months.

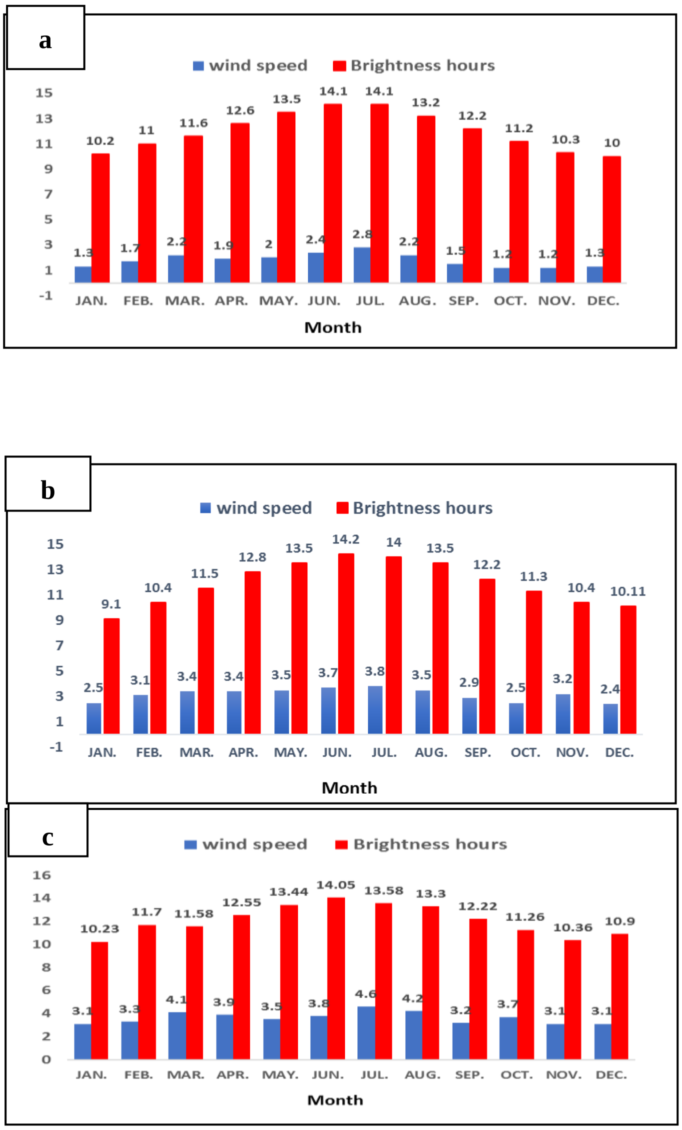


Fig. 1: Average wind speed and length of sunshine hours for the southern stations of the Euphrates River: a) Hilla, b) Samawa, c) Nasiriya for the period (2013-2023).

3.2. Temperature

Temperature it is the most effect in climate chsngr yield hydrological cycle table, starting with the evaporation of water from bodies of water and its return as water in the form of raindrops and other forms. Maximum temperature increases during the summer months of June, July, and August for the Hilla station, for the months above and respectively: 41, 43, and 43.5 for the period from 2013 until the year 2023, as shown in Fig. 2. Nasiriyah station is in the far south of the river basin. The average temperatures for the above months were respectively June 44.5 °C, July 45.3 °C, and August 48.3 °C for the period from 2013 to 2023, The average minimum temperatures for the winter months of December, January, and February for the above stations and the same period were as follows While the minimum temperature averages for the Nasiriyah station in the far south of the study area were as follows: December 5.5 °C, January 4.6 °C, and February 9.6 °C. The main reason is the large extremes in temperatures between night and day, winter and summer at one station, and between one station and another.

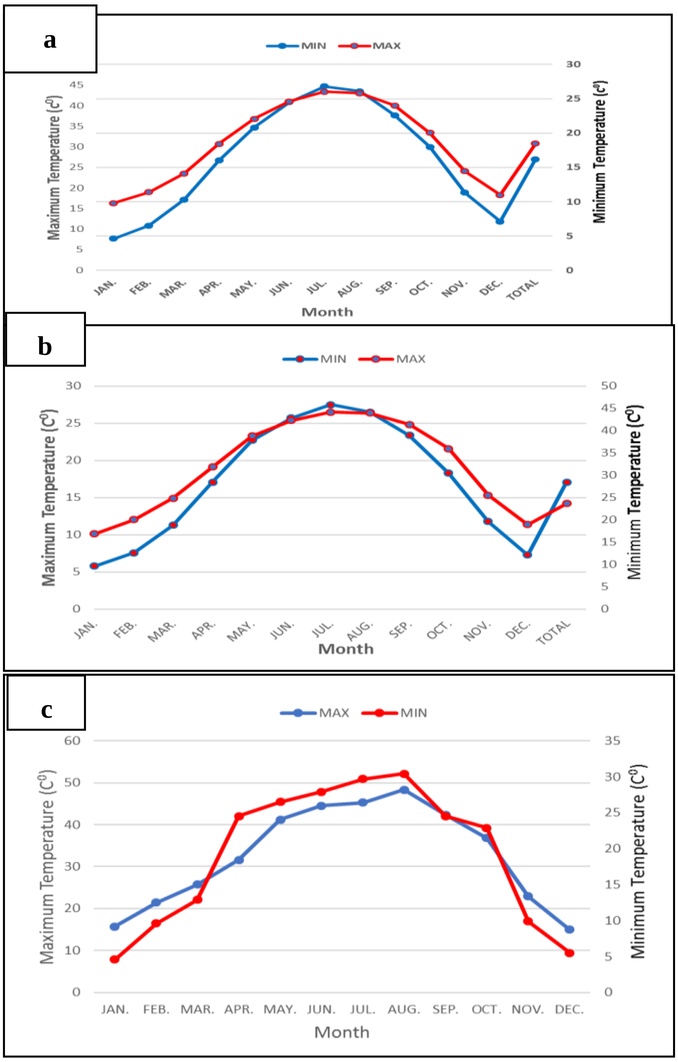


Fig. 2: The monthly averages of maximum and minimum temperatures for the station: a) Hilla, b) Samawa, c) Nasiriya for the period (2013-2023).

3.3. Evaporation and Relative Humidity

The analysis shows in Fig. 3 that the total annual evaporation in Hilla, Samawah, and Nasiriya was 2340 mm, 3500 mm, and 3382 mm, respectively, with an annual average of evaporation values of 195 mm, 292 mm, and 282 mm. This was concluded from the above: The amounts of evaporation at stations in the study area increase significantly, as we move from north to south and from east to west. This is due to the angle of inclination of the sun's rays close to the vertical, which increases temperatures and thus increases the amounts of evaporation. The amount and percentage of water losses in the south of the study area is the highest, which is offset by a decrease for rainfall that does not exceed 400 mm south of 33° latitude. Due to the high temperature from above, it has become clear that studying evaporation is important in determining the actual value of precipitation and determining water losses (water losses). High relative humidity in the air is of great importance because it reduces the rates of dryness in the soil and thus leads to increasing its cohesion, which leads to its resistance to erosion and erosion processes. Aerobic. As the stations of the southern part of the basin region recorded in the stations of Hilla, Samawah, and Nasiriya, the humidity values were as follows: 50%, 41.5%, and 42.9%.

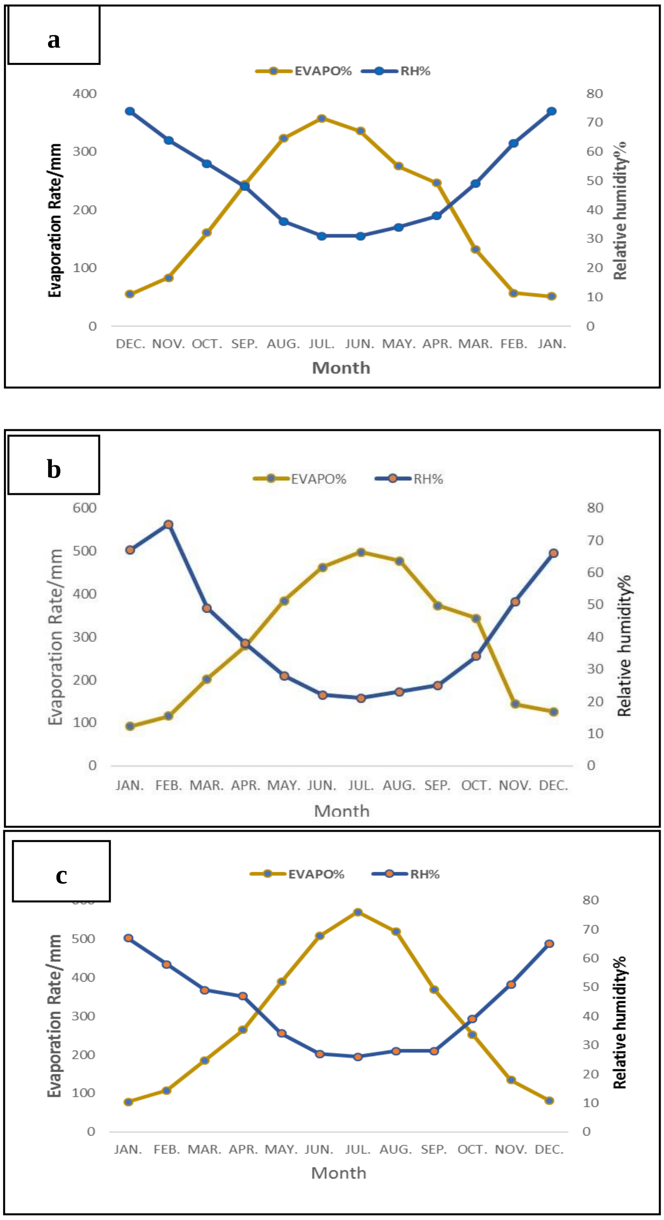


Fig. 3: Humidity and evaporation rates for stations in the southern part of the Euphrates River: a) Hilla, b) Samawa, and c) Nasiriya from 2013 to 2023.

3.4. Water Drainage

Studying the average annual discharge of the Euphrates River is of great importance in hydrological studies as it indicates the succession of wet, medium, and dry years, and thus knowing the volume of water that must be stored from wet years and released for dry years, as well as regulating the river's current in a way that suits the requirements of each stage and each region. A study through which the river passes Fig. 4 shows that the highest water discharge of the Euphrates River levels at Al-Hilla station is 422 m^3/s. As for the Nasiriya station, the average discharge decreases before it reaches the donkey marsh is 365 m^3/s. The observed increase in temperature can be attributed to a latitudinal gradient, with temperatures gradually increasing toward the south and southwest. This pattern is clearly evident at the Nasiriya station, where the high temperatures are significantly affected by the different angle of incidence compared to northern locations. The increased solar radiation contributes to higher evaporation rates. Moreover, the relatively low terrain gradient in the southern part of the Euphrates River slows down water flow, promoting meandering and channel instability. In some years, these conditions contribute to localized flooding within the river basin, resulting in a temporary expansion of the river's surface area. In Nasiriyah, for example, the river can reach an average width of 400 meters during flood periods. This expansion increases the surface area exposed to evaporation, exacerbating water loss. Additional factors contributing to water depletion include increased soil permeability in downstream areas, as well as increased water demand due to urban populations and agricultural irrigation requirements, which rely heavily on river water. The branch, and finally the Samawa station, is a water discharge of 235 m^3/s.

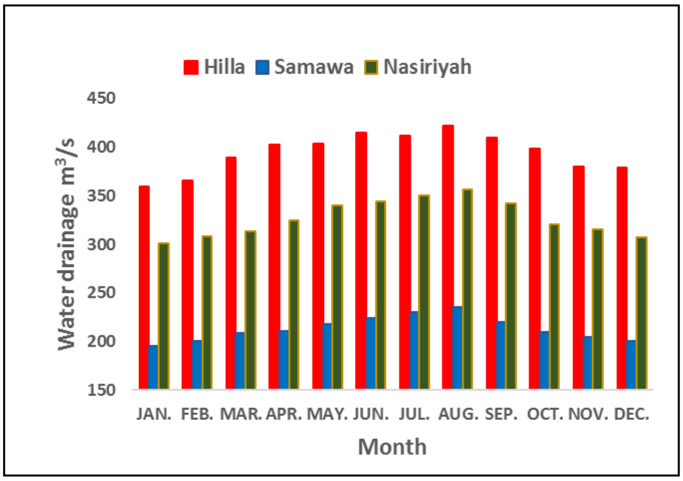


Fig. 4: Average monthly discharge of the Euphrates River at stations in the study area for the year 2022.

3.5. Water Deficit and Surplus

By analyzing the results of Figs. (5, 6) and table 1and 2) after adopting the Ivanov equation to determine the amount of evaporation and water losses, found the following:

It was concluded that a water deficit occurred in the Hilla, Samawah, and Nasiriya stations during January as an average for the period (2013-2023) and, according to the Ivanov equation, respectively -130.5 mm, -156.5

mm, and -122.4 mm. According to the sheep equation, the percentage of water deficit for the above stations and for January and the same period was estimated at -44.7 mm, -56.8 mm, and -31.1 mm, respectively, in Figs. 5, 6 (a), (b), and (c), so that this deficit increases for the above stations to reach its peak during July on average and for the period (2013-2023) to get Al Hillah station -617 mm, Samawah -649 mm, and Nasiriya -677 mm, according to Ivanov's equation. As for the Kharrufa equation, it showed a deficit in the above stations for July on average and for the same period in my agencies: Hilla -496.2 mm, Samawa -489.5 mm, and Nasiriya -509.9 mm. This is due to several reasons, including increased hours of brightness, lack of vegetation, and Slow River flow in the southern river section. In contrast to what happens in the northern region, water evaporation rates are recorded at their highest possible level in stations south of the study area, especially in Samawah and Nasiriya. This is due to the difference in the angle of incidence of sunlight at stations in Nasiriya and Samawah, the movement and speed of wind direction, and the resulting increase in evaporation rates and loss ratios.

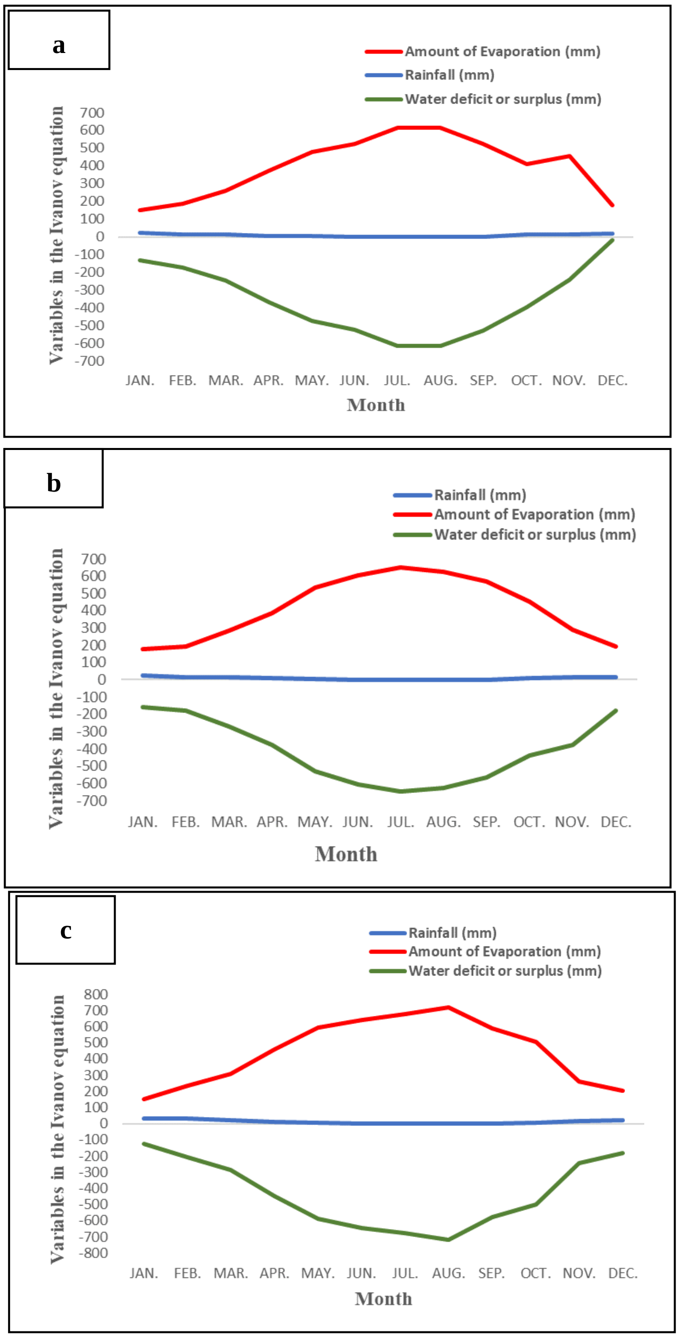


Fig. 5: Water deficit and surplus stations for the stations: a) Hilla, b) Samawa, and c) Nasiriya using the Ivanov equation for the period (2013-2023).

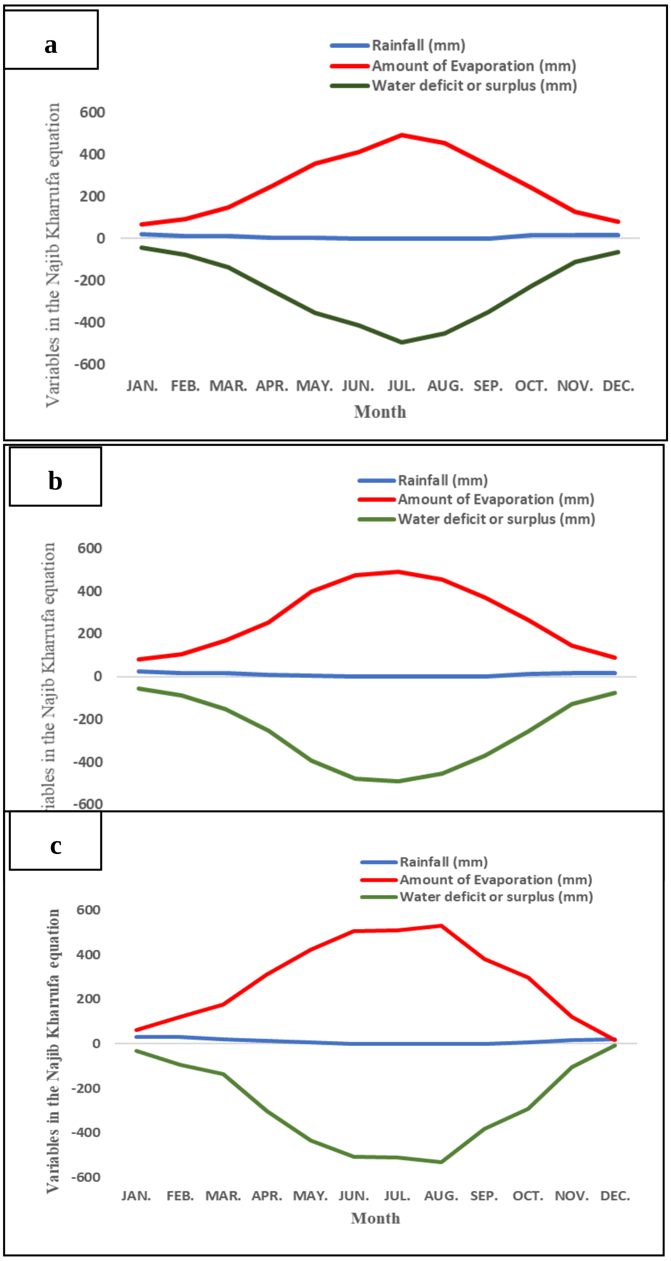


Fig. 6: Water deficit and surplus stations for the station: a) Hilla, b) Samawa, and c) Nasiriya using the N. Kharrufa equation for the period (2013-2023).

Table 1: Water deficit and surplus for stations in the study area using the Ivanov equation for the period 2013-2023.

Station	Climate variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hilla	Rainfall (mm)	22.3	14	12.6	2.6	2.6	2.6	0	0	0	14.7	14.9	17.7
	Amount of Evaporation (mm)	152.8	189	261	373.7	477.3	523.4	617	614	526.5	410	454.5	179
	Water deficit or surplus (mm)	130.5-	175-	248-	371-	474-	523.4-	614-	614-	526.5-	395-	240-	16.1-
	RH%	74	63	56	48	36	31	31	34	38	49	63	74
	Temperature max ^{0}C	16.3	19	23.5	30.7	36.8	41	43.4	43	40	33.4	24.1	18.3
	Temperature min ^{0}C	4.6	6.5	10.3	16	20.8	24.5	26.8	26.1	22.6	18	11.3	7.1
Samawa	Rainfall (mm)	22.9	16.1	16.1	8	4.3	0	0	0.1	2.2	12.6	15.1	16.4
	Amount of Evaporation (mm)	179.4	192	284	385.4	536.5	604.6	649	625	568	453	290	194
	Water deficit or surplus (mm)	156.5-	176-	268-	377-	532-	6.4.6-	646-	625-	566-	440-	375-	178-
	RH%	67	75	49	38	28	22	21	23	25	34	51	66
	Temperature max ^{0}C	16.9	20.1	24.9	31.9	38.8	42.3	44.2	44	41.4	36	25.6	19
	Temperature min^{0}C	5.8	7.6	11.3	17.1	22.7	25.7	27.5	26.5	23.4	18.3	11.8	7.3
Nasiriya	Rainfall (mm)	31.3	30.2	22	12	7.2	0	0	0	0	7.7	16.7	21.7
	Amount of Evaporation (mm)	153.5	237	207	459	593	643	677	721	588	506	259	202
	Water deficit or surplus (mm)	122.4-	207-	285-	447-	586-	643-	677-	721-	588-	498-	242-	181-
	RH%	67	58	49	47	34	27	26	28	28	39	51	65
	Temperature max ^{0}C	15.7	21.4	25.7	31.6	41.2	44.5	45.3	48.3	42.4	36.8	22.9	15
	Temperature min^{0}C	4.6	9.6	12.9	24.5	26.5	27.9	29.7	30.4	24.5	22.9	9.9	5.

Table2: Water deficit and surplus for stations in the study area using the N. Kharrufa equation for the period 2013-2023.

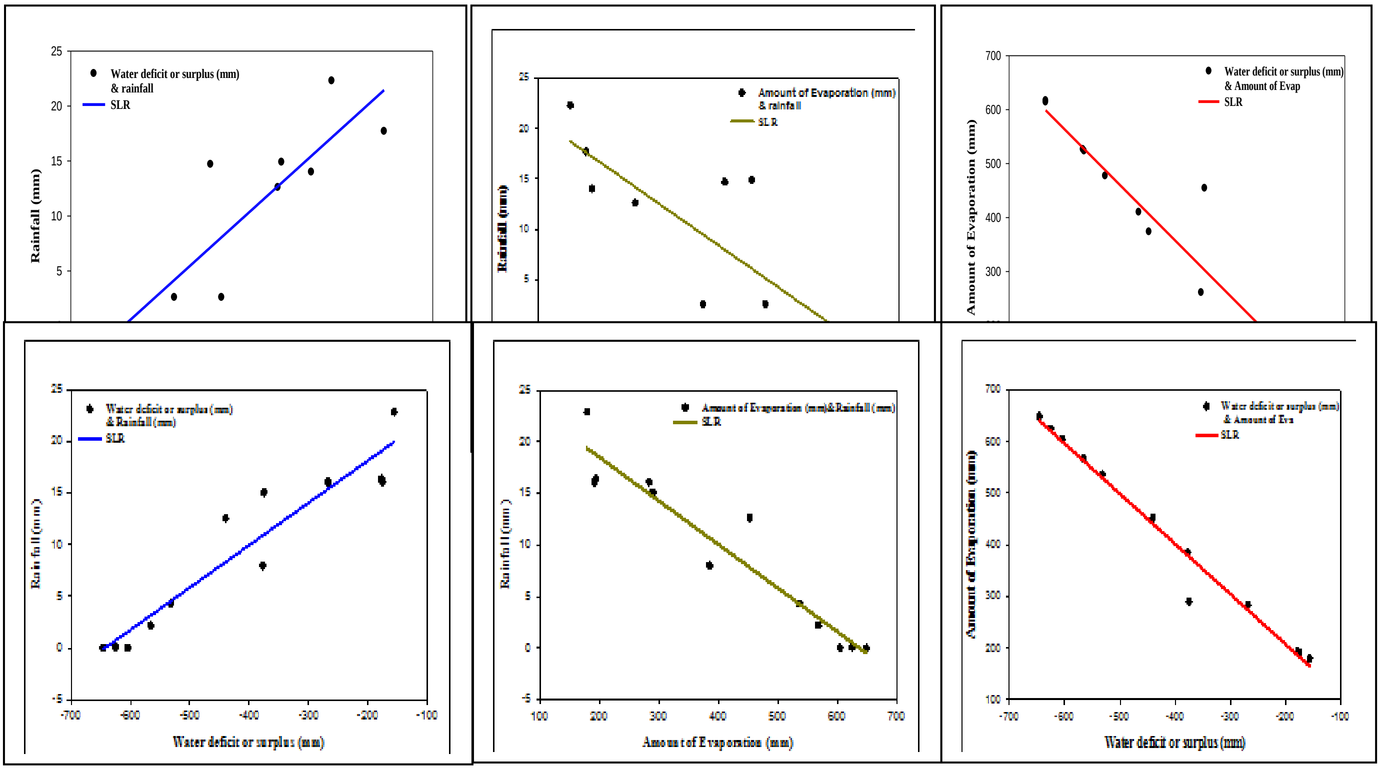
Station	Climate variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hilla	Rainfall (mm)	22.3	14	12.6	2.6	2.6	0	0	0	0	14.7	14.9	17.7
	Amount of Evaporation (mm)	67.03	92.9	149.1	252.7	356.3	414.3	496.2	454.8	350.1	242.1	127.6	82.05
	Water deficit or surplus (mm)	44.7-	78.9-	136.5-	250.1-	353.7-	414.3-	496.2-	454.8-	350.1-	227.4-	112.7-	64.3-
	RH%	74	63	56	48	36	31	31	34	38	49	63	74
	Temperature max ^{0}C	16.3	19	23.5	30.7	36.8	41	43.4	43	40	33.4	24.1	18.3
	Temperature min ^{0}C	4.6	6.5	10.3	16	20.8	24.5	26.8	26.1	22.6	18	11.3	7.1
Samawa	Rainfall (mm)	22.9	16.1	16.1	8	4.3	0	0	0.1	2.2	12.6	15.1	16.4
	Amount of Evaporation (mm)	79.7	103.8	167.5	253.4	398.2-	476.4	489.5	454.1	369.8	263.6	144.2	87.36
	Water deficit or surplus (mm)	56.8-	87.7-	151.4-	251.4-	394.2-	476.4-	489.5-	454.1-	367.6-	257-	129.1-	76.9-
	RH%	67	75	49	38	28	22	21	23	25	34	51	66
	Temperature max ^{0}C	16.9	20.1	24.9	31.9	38.8	42.3	44.2	44	41.4	36	25.6	19
	Temperature min^{0}C	5.8	7.6	11.3	17.1	22.7	25.7	27.5	26.5	23.4	18.3	11.8	7.3
Nasiriya	Rainfall (mm)	31.1	30.2	22	12	7.2	0	0	0	0	7.7	16.7	21.7
	Amount of Evaporation (mm)	62.29	122.7	175.8	313.5	424.8	505.8	509.9	531.3	383.3	298.2	122	15.45
	Water deficit or surplus (mm)	31.1-	92.5-	135.8-	301.2-	435.6-	505.8-	509.9-	531.3-	383.3-	290.5-	105.3-	6.35-
	RH%	67	58	49	47	34	27	26	28	28	39	51	65
	Temperature max ^{0}C	15.7	21.4	25.7	31.6	41.2	44.5	45.3	48.3	42.4	36.8	22.9	15
	Temperature min^{0}C	4.6	9.6	12.9	24.5	26.5	27.9	29.7	30.4	24.5	22.9	9.9	5.

3.6. Pearson Correlation Coefficient Test

The analysis revealed a very high positive correlation (r > 0.85) between precipitation and potential evapotranspiration (PET) across the majority of stations. Although this may initially appear counterintuitive since higher precipitation is typically associated with reduced evaporation due to increased soil moisture and cloud cover this strong correlation is characteristic of arid and semi-arid climates, where both precipitation and temperature (which drives PET) exhibit synchronized seasonal patterns. In such regions, both variables tend to reach their peaks during transitional months, such as spring or early autumn, rather than exhibiting an inverse relationship. Thus, the high correlation suggests that both precipitation and PET respond to shared climatic drivers, including solar radiation and atmospheric circulation patterns. This phenomenon has also been observed in other arid regions, such as the Tigris Basin (Al-Timimi & Salih, 2019) and the Jordan River Basin (Shaban et al., 2010), where seasonal climatic variations induce parallel trends in temperature, humidity, and precipitation . In the Euphrates basin, the relationship between evaporation, precipitation, and water deficit over the past decade appears to be direct. Water deficits are strongly influenced by the increase in evaporation due to rising temperatures, particularly in the southern regions, as well as the lack of precipitation. Additionally, solar radiation plays a significant role in shaping these dynamics. An inverse relationship between evaporation and precipitation is evident at the stations in Hilla, Samawa, and Nasiriya, as shown in Table 3 and Figure 7. The strength of these correlations ranges from moderate to strong, as indicated by the statistical significance (p-values) across all study sites.

Table 3: Pearson correlation coefficient test and simple linear regression results for Evapo, P, and WD, W for the three stations of the Euphrates River (Hilla, Samawa, and Nasiriya).

Stations	Relationship	R	Correlation	Slope	Interpretation
Hilla	WD & EVAPO	0.93	V. High Positive	0.0148	Linear
	WD & P	0.84	V. High Positive	0.0001	Linear
	EVAPO & P	0.89	V. High Positive	0.0001	Linear
Samawa	WD & EVAPO	0.98	V. High Positive	0.5435	Linear
	WD & P	0.94	V. High Positive	0.0001	Linear
	EVAPO & P	0.95	V. High Positive	0.0001	Linear
Nasiriyah	WD & EVAPO	0.99	V. High Positive	0.0001	Linear
	WD & P	0.95	V. High Positive	0.0001	Linear
	VAPO & P	0.95	V. High Positive	0.0638	Linear



(c) Nasiriyah Station

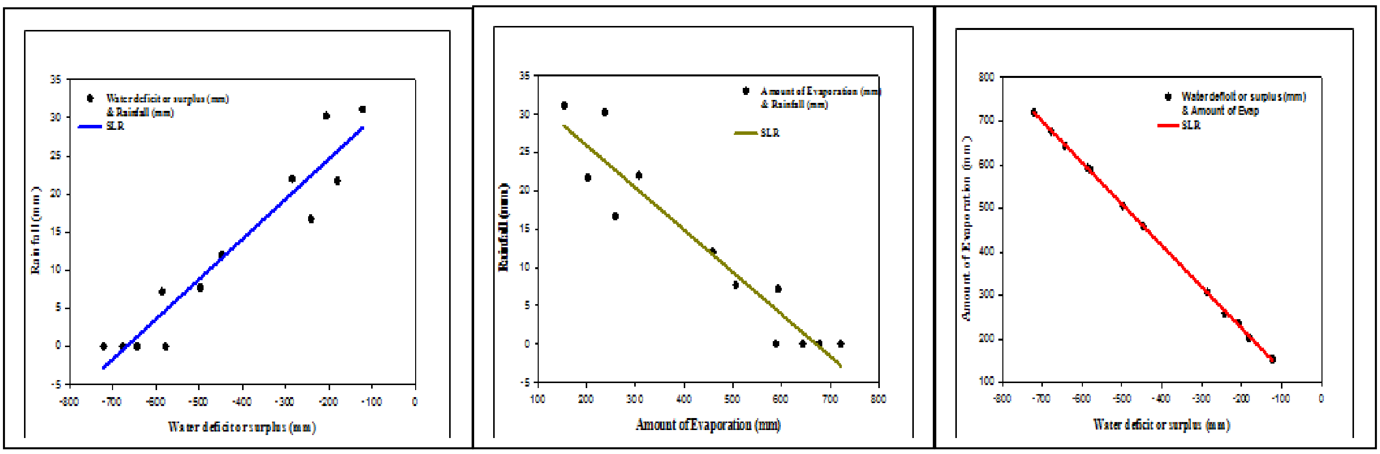


Fig. 7: The relationship between EVAPO, P, and WD, WS for the three stations of the Euphrates River (a) Hilla, (b) Samawa, and (c) Nasiriyah, for a period (2013-2023).

(a) Hilla Station

4. CONCLUSIONS

Prolonged solar radiation and elevated temperatures during the summer months have a direct influence on evaporation rates within the study area. Peak temperatures observed in June, July, and August significantly elevate evaporation, particularly in the southern regions. The spatial distribution of evaporation rates exhibits a clear gradient, increasing progressively from north to south. This pattern is primarily attributed to higher temperatures, extended solar radiation duration, and the greater aridity characteristic of the southern areas. In the southern zones where the study area experiences the highest water losses evaporation exceeds precipitation inputs, resulting in a pronounced water deficit. For instance, the Nasiriya station records the most substantial deficit. Elevated wind speeds, particularly in the central and southern parts of the region, further intensify evaporation. Wind enhances moisture transfer from surface water and soil to the atmosphere, exacerbating water loss and deepening the water deficit. Interestingly, despite its central location within the southern basin, the Hillah station registers the highest relative humidity. This is likely due to increased transpiration, which contributes to maintaining atmospheric moisture levels. However, this transpiration-driven humidity is insufficient to offset the high evaporation losses. As the study area extends southward, both evaporation rates and water deficits intensify, underscoring the acute water scarcity experienced in southern regions such as Nasiriya. These regional disparities highlight the urgent need for adaptive water management strategies tailored to local conditions. While northern regions may benefit from a relatively balanced hydrological regime, southern areas would particularly benefit from interventions such as advanced irrigation techniques and water conservation measures. Overall, these findings underscore the critical role of temperature, solar radiation, wind speed, and regional aridity in shaping evaporation patterns and water availability. They emphasize the necessity for region-specific hydrological planning to mitigate the adverse effects of climate-induced water stress.

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