KIRKUK UNIVERSITY JOURNAL FOR AGRICULTURAL SCIENCES

Effect of changing in Some Sulaymaniyah Climate Elements on Rates of Evapotranspiration from the period 1979 to 2022, Iraq

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• Date of research received 04/01/2024 and accepted 17/02/2024.

Abstract

The present work implementation was achieved in Sulaimaniyah city, north of Iraq In locations N35.55, and E45.44 to study the effect of local climate changes during the study period on the annual rates of evaporations, Daily meteorological Data on Evaporation, Temperature, Relative humidity, Wind speed, and Rainfall for analyzing data using the standardized Penman-Monteith (PM) equation for short canopy reference evapotranspiration value, under current conditions, The month of June is considered the most variable compared to the rest of the months during the study period as evaporation rates decreased by an average of 3.75 mm. Evaporation levels exhibit seasonal variability, as evidenced by the annual evaporation rates. During the colder and rainier months, specifically October through March, a decreasing trend in evaporation rates was observed throughout the study. Conversely, in the warmer months (April through September), The highest annual radiation in 2021, 17.5 (MJ m^{-2} day^{-1}), marked an increase from 1982's 15.5 (MJ m^{-2} day^{-1}). Over 43 years, the average annual rate of radiation change is approximately 0.0263 indicating a gradual increase. Over 43 years (1979-2022), Evapotranspiration ranged from 3.68mm to 4.4mm, increasing due to higher temperatures and solar radiation. higher wind speeds generally result in increased evapotranspiration due to enhanced evaporation and transpiration processes. When comparing the changes in wind speed during the years of the study, the wind speed increased at a general rate for all years of the study amounting to 1.4(m. $sec.^{-1}$) and the change between each year and the following year varied between an increase and a decrease from the general rate of these changes. The rainfall data from 1979-2022 shows notable yearly fluctuations. The 1980s and early 2000s had lower rainfall, while the 1990s and late 2000s experienced higher amounts, with a decrease again in the 2020s .average annual increase of 0.22% and an average value of 46.00%. The standard deviation of 3.17 suggests most values fall within 42.83% to 49.17%. High relative humidity years (e.g., 1982, 1988, 1992, 2003, 2015, 2019) indicate near-saturation air, leading to reduced evapotranspiration rates due to lower vapor pressure gradients and transpiration efficiency. Conversely, low humidity years (e.g., 1984, 1987, 2000, 2008, 2013, 2021) show a higher capacity for air to absorb water vapor.

Key Words: Evapotranspiration, Relative Humidity, Rainfall, Temperature, wind speed

Citation: Abdulrahman, A., Khalid, J., Sharif, H., Tayyib, A., & Umer, L. (2024). Effect of changing in Some Sulaymaniyah Climate Elements on Rates of Evapotranspiration from the period 1979 to 2022, Iraq. *Kirkuk University Journal for Agricultural Sciences*, 15(1), 117-129. doi: 10.58928/ku24.15112.

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Introduction

The process of generating climate change data projections is fraught with uncertainties at every stage. These uncertainties arise both from the input data and uncontrollable local factors in regionalization, presenting significant challenges. A study by [1] observed that water resource management studies often begin with regionalized CC predictions and precipitation forecasts, focusing particularly on potential changes in evapotranspiration and reference evapotranspiration. This focus is vital for assessing possible shifts in water availability in semi-arid areas, which is critical due to [2] highlighted that, in Spain, regionalization and model-related uncertainties are more pronounced in the creation of regionalized precipitation series, while uncertainties in emissions play a lesser role in temperature series, which align more closely with historical reference series. Despite these uncertainties, these projections remain crucial for understanding the impacts of climate change (CC) on water resources and for developing effective adaptation strategies. [3] emphasized that climate changes could alter evaporation rates and intensify the hydrological cycle .its significant consumption of scarce precipitation.

Although there have been limited catchment-scale studies comparing water yield between annual and perennial plants, significant land cover changes from agricultural expansion and reversion have been noted since the mid-20th century. In eastern North America, much of the land originally forested or grass-covered has reverted to forests and successional fields, a trend driven by factors like low profitability and concerns over soil erosion. [4] While the increase in evapotranspiration rates with temperature is well-established [5]. note that is also influenced by various other factors, such as humidity. Increased humidity can reduce transpiration, moderating the effects of higher temperatures on evaporation. Hence, considering concurrent humidity changes is essential when estimating ET under changing climatic conditions. This study accounts for diverse microclimates to understand the varying impacts of climate change .The primary objective of this study is to examine the direct effects of local climate changes in the study area on climate elements and to lay the groundwork for future research on climate change and its implications for the environment and human life. In collaboration with the Department of Meteorology and Seismic Monitoring in Sulaymaniyah Governorate, daily monitoring and data documentation have been undertaken. [6]

Lastly, radiation, particularly solar radiation, is critical for the conversion of liquid water into vapor during evaporation and transpiration. [7] indicate that changes in radiation patterns, resulting from natural variability or anthropogenic climate change, can significantly affect evapotranspiration rates and patterns, with implications for regional water availability and ecosystem functionality quantifying the effects of climate change on agricultural systems is inherently challenging due to several scientific complexities. Three major factors contribute to this challenge: First: Global Warming Models and Incomplete Variables: Foremost is the reliance on numerical models to project the impact of global warming on future climate patterns. These global-scale models, while sophisticated, often do not encompass all the influencing factors, such as the oceans' role in CO_2 absorption. This leads to a significant gap in the accuracy and reliability of predictions. Moreover, the data used in these models can be inconsistent. For instance, predictions about greenhouse gas emissions vary significantly based on human activities, including fossil fuel consumption and emissions, technological advancements, economic development, and population growth in different countries. Each of these elements introduces a degree of uncertainty into the models [8]; [9]. Second: Regional Application of Global Model Results: Another significant hurdle is translating the results of these global climate models into actionable insights for specific regions. Global models typically provide general predictions, such as increases or decreases in temperature and precipitation. However, applying these broad trends to particular localities requires a process of regionalization. If this process is not meticulously executed, it can lead to inaccuracies and misrepresentations in how global climate trends affect specific regions [10]. Third: Limitations of Current

Evapotranspiration Models: Lastly, the current empiric (based on temperature and radiation data) and semi-empiric (such as the Penman-Monteith models) approaches to modeling evapotranspiration (ETo) are not well-equipped to factor in the nuanced changes brought about by climate change. These models, in their present form, are constrained in their ability to accurately reflect the effects of climate change on ETo. They are predominantly suitable for conducting sensitivity analyses, rather than offering comprehensive, future-proofed predictions about ETo under shifting climatic conditions [11]

Method:

Climate Data: Data from the Department of Meteorology and Seismic Monitoring in Sulaymaniyah and the Department of Agricultural Research for the period 1979 until 2022 were used for the analysis, the most important climatic factors that affect evapotranspiration are temperature, relative humidity, wind, rainfall, and solar energy. Bazian is a very important agricultural area southwest of Sulaymaniyah city, the reason that made us care about this region is that it contains huge numbers of agricultural greenhouses amounting to approximately 17,000 greenhouses in addition to its importance as an agricultural area. (fig. 1) which includes in northeastern Iraq, Bazian the study area may be identified by the way its surface looks overall it is surrounded by small plains and valleys positioned on the western slopes between longitude (35o.49'.00" N) and latitude (45o.25'.00" E). Monthly means of daily climate data from 1979 were used to make the daily mean ETo calculations. The daily ETo means were multiplied by the days per month to obtain monthly totals, and the monthly totals were summed to obtain the annual total, Eto. The reference value of evaporation and evapotranspiration

ion was calculated using the FAO Penman-Monteith equation using the ready-made computer program (CropWat V. 8) and according to the following equation FAO Penman-Monteith equation for estimating evapotranspiration. [12]

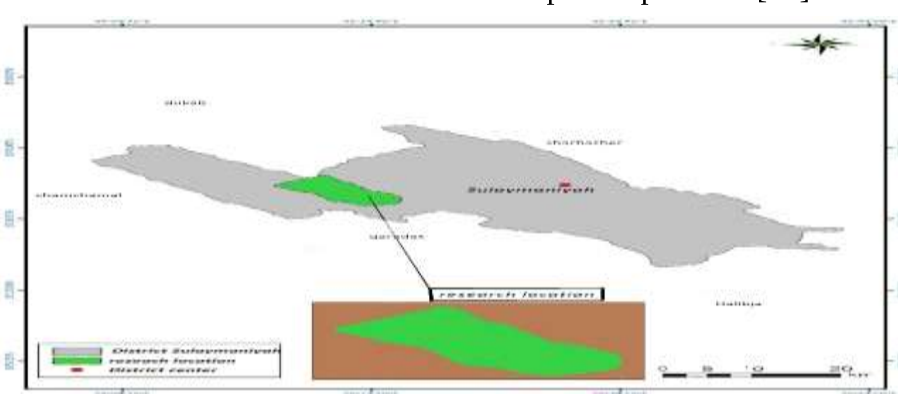


Figure 1. Location study

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

ET_o reference evapotranspiration [mm day^{-1}]
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], megajoule per square meter and per day.
G soil heat flux density [MJ m^{-2} day^{-1}]، megajoule per square meter and per day.
T mean daily air temperature at 2 m height [°C].
u_2 wind speed at 2 m height [m s^{-1}].
e_s saturation vapour pressure [kPa].
e_a actual vapour pressure [kPa].
e_s - e_a saturation vapour pressure deficit [kPa].
Δ slope vapour pressure curve [kPa °C^{-1}].
γ psychrometric constant [kPa °C^{-1}].

Results & Discussion

1- Changes in evaporation over the years of study.

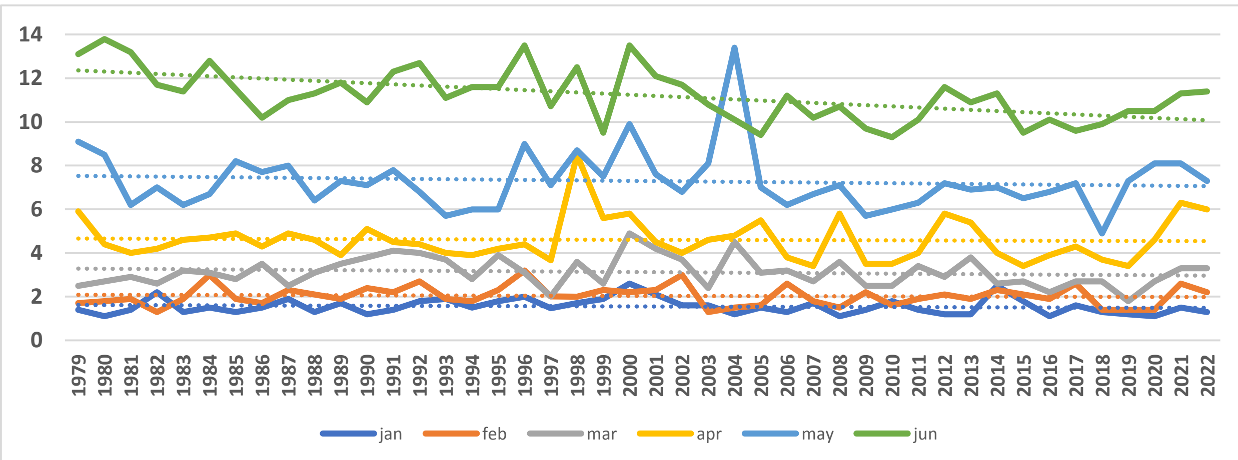
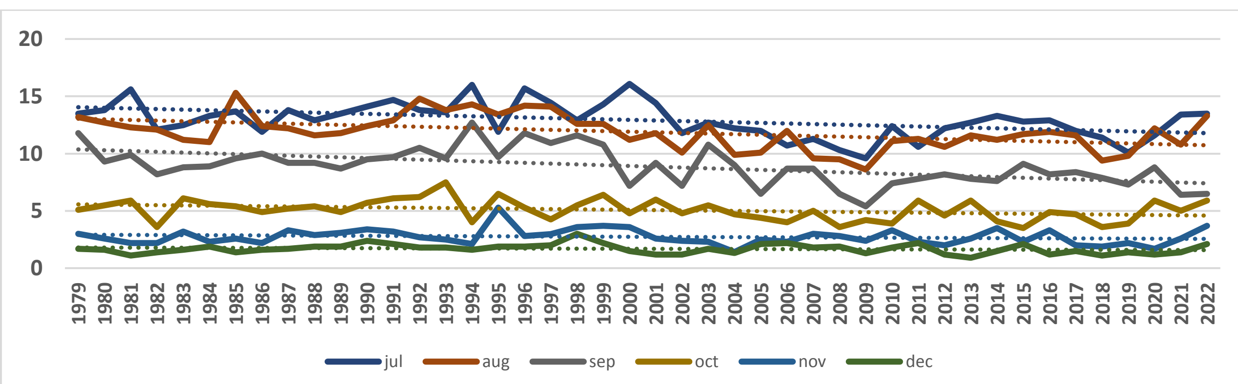


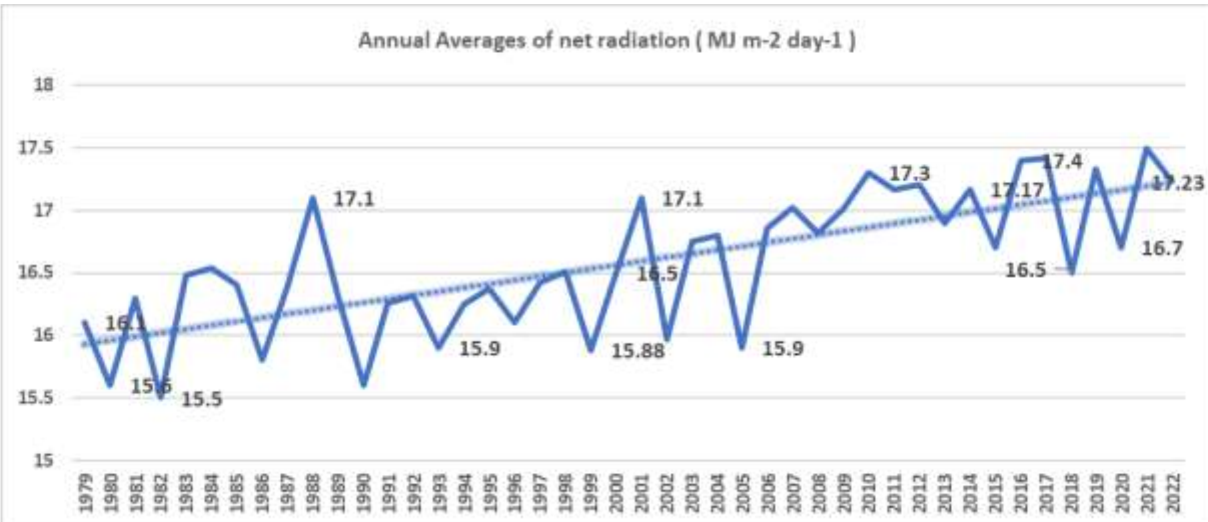
Fig (1). Annual Averages of Evaporation rates (mm) for Jan., Feb., Mar., Apr., May, and Jun months for the study period, Source (Sulaymaniyah Meteorology Department).



Fi. (2) Annual Averages of Evaporation rates (mm) for Jul., Aug., Sep., Aoc., Nov.,t and Dec. months for the study period Source, (Sulaymaniyah Meteorology Department).

The Sulaymaniyah meteorology station measures the rate of evaporation from a standardized open water surface using a "pan" at various outdoor locations .Similar measurements are conducted worldwide. The rate of water evaporation, whether from a surface or through stomata on leaves, is influenced by climatic and weather conditions . Key factors include solar radiation, temperature, relative humidity, and wind. [13]
Figures 1 and 2 demonstrate that evaporation levels vary seasonally. In the cold and rainy

months (October to March), there is a trend of decreasing annual evaporation rates over the study years. In contrast, during the warm months (April to September), evaporation rates do not exhibit significant fluctuations over the years. The decrease in evaporation during the cold and rainy months is attributed to increasing humidity. The air holds a certain amount of water vapor, and when humidity rises, the rate of evaporation tends to decrease. [14] In contrast, during the warm months, the higher temperatures lead to greater kinetic energy of molecules at the substance's surface, resulting in a faster rate of evaporation. the measurement of evaporation at the Sulaymaniyah meteorology station introduces factors influencing evaporation, highlights seasonal variations in evaporation rates, and provides explanations for the observed trends based on climatic conditions [15].

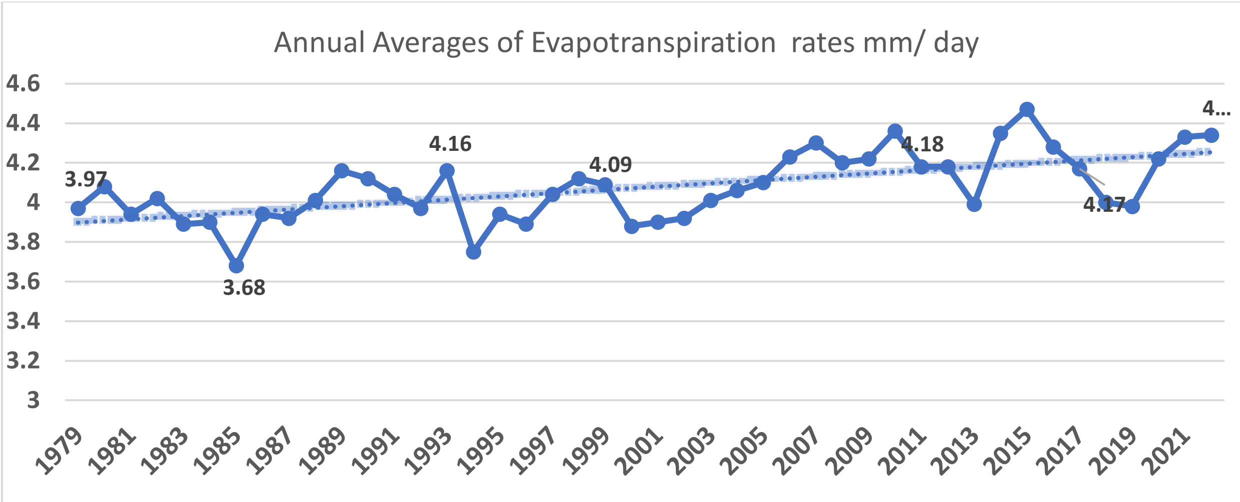


Changes in Radiation over years of study and its impact on Evapotranspiration 1-

Fig. (3) Annual Averages of Radiation rates (MJ m-2 day-1) for the study period (1979- 2022). Source, (Sulaymaniyah Meteorology Department).

The evaporation process requires a considerable amount of energy, which is supplied by solar radiation. Figure (3) illustrates the levels of solar radiation throughout the study years, highlighting the variation and increase in the amount of solar radiation available for evaporation over time. Solar radiation exhibits fluctuations based on the season and weather conditions. [16] In 2021, the annual radiation rate reached its peak at 17.5 MJ m^{-2} day^{-1}, surpassing the levels observed in other years of the study. Comparing this to the 1982 levels of 15.5 MJ m^{-2} day^{-1}, there has been a noticeable increase, as depicted in Figure 3. The average rate of change in radiation over the 43 years is approximately 0.0263 units per year, indicating a gradual rise in radiation levels over time [17].

In his [18] they have explained the effects of climate change, noting an increase in the number of daylight hours over the years in all seasons, particularly in the hot months of June and July. Transpiration, the release of water vapor from plants, primarily occurs through small pores called stomata on their leaves. Solar radiation plays a crucial role in influencing transpiration by driving the process of photosynthesis, the conversion of sunlight into energy by plants. Sunlight provides the necessary energy for photosynthesis, prompting plants to open their stomata to absorb carbon dioxide. This opening allows water vapor to escape from the plant into the atmosphere.



2-vapotranspiration Values change over study years Figure 4, shows the annual averages of Evapotranspiration for the period 1979- 2022. Source,
(Sulaymaniyah Meteorology Department).

The analysis of evapotranspiration (ET) over 43 years from 1979 to 2022 is presented in Figure (4) The data reveal that the lowest ET value recorded during this period was 3.68 mm in 1985, while the highest was 4.4 mm in 2015. A trend analysis of ET values indicates a discernible upward trajectory over the years. This increase is attributed primarily to rising temperatures, which have averaged an increase of 1.3°C, as reported by [19]. Elevated temperatures, coupled with intensified solar radiation, typically lead to augmented rates of evaporation and transpiration, as warmer air can retain more moisture, thus facilitating the transition of water from liquid to vapor. Furthermore, radiative forcing – the discrepancy between incoming solar radiation and outgoing infrared radiation – plays a crucial role in modulating temperature variations. Fluctuations in radiative forcing, particularly those linked to climate change, exert a significant impact on regional and global ET patterns. Additionally, climate change has been associated with an increase in wind speeds, as noted by [20]. This increase contributes to lower humidity levels, as the air becomes less saturated with moisture, thereby enhancing the capacity for drier air to absorb more water vapor Changes that occurred in annual temperature (C^o) averages during the study period and the impact of that on the rate of Evapotranspiration and the effect of that on changes in evapotranspiration.

Kirkuk University Journal for Agricultural Sciences, Vol. 15, No. 1, 2024 (117-129)
Online ISSN: 2958-6585

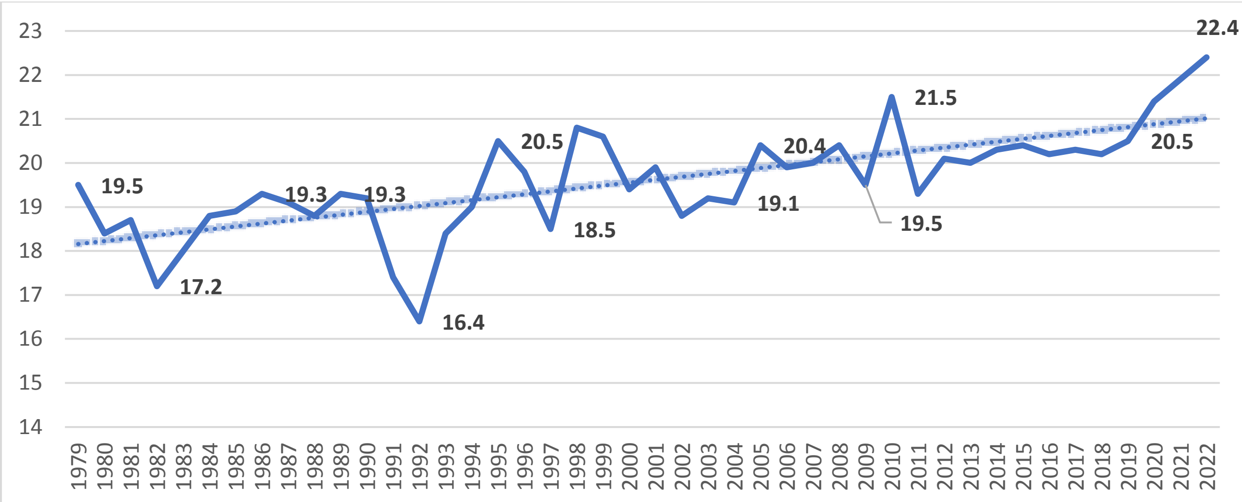


Figure 5, shows the annual averages of temperature for the period 1979- 2022. Source, (Sulaymaniyah Meteorology Department).

As shown in Figure (5) there's a shred of significant evidence that the air temperature degree has increased over these years although there are clear changes between a decrease and a rise in temperatures the change towards an increase is making evaporation a component of the energy balance at the Earth's surface, this temperature changes affect this balance affecting not only water availability but also local climate conditions Changes in evaporation and transpiration rates can affect ecosystems and biodiversity [21]. especially in areas where vegetation is sensitive to water availability like our region. the impact of changing temperature on evapotranspiration rate is a significant factor in hydrology and water resource management, Evapotranspiration is the combined process of water evaporation from surfaces (such as soil and water bodies) and transpiration from plants Here's a brief analysis of the relationship between temperature and evapotranspiration [22].

From Figure (5) Warmer temperatures generally lead to an increase in evapotranspiration rates. This is because higher temperatures enhance the evaporation of water from surfaces, Higher temperatures can stimulate plants to undergo transpiration at a faster rate, as they tend to open their stomata more to cool themselves through the release of water vapor [23]. elevated temperatures, especially in combination with reduced precipitation, can result in increased evapotranspiration without a corresponding increase in available water. This situation can contribute to drought conditions. climate change can alter temperature patterns, potentially leading to shifts in evapotranspiration rates. This can have profound effects on regional and local water cycles [24]. Wind Spead (m. $sec.^{-1}$) changes over the years of the study period and the effect of that on changes in evapotranspiration

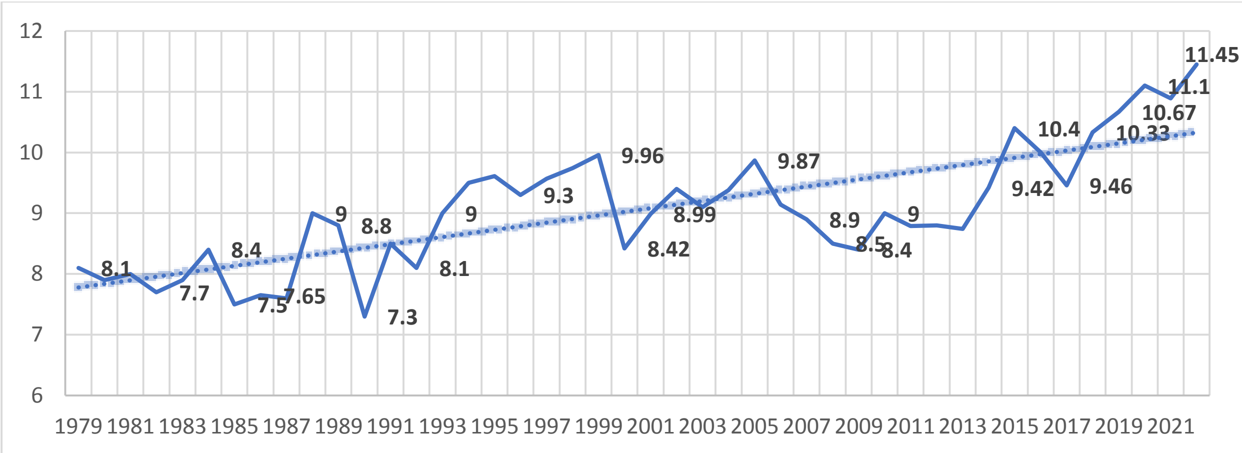


Figure 6, shows the annual averages of Wind Spead (m. sec. $^{-1}$) for the period 1979- 2022.
Source, (Sulaymaniyah Meteorology Department)

Figure (6) clearly shows how Wind speed changes through the study years as the temperature degree changes, from the chart higher wind speeds generally result in increased evapotranspiration due to enhanced evaporation and transpiration processes. However, it's essential to consider other environmental factors, such as temperature, humidity, and solar radiation, as they also play crucial roles in the overall water balance in ecosystems [25]. Reported that Wind disrupts the boundary layer of still air that forms near the surface. This boundary layer can act as a barrier to evaporation, and wind helps thin this layer, allowing for more efficient evaporation, Wind plays a significant role in the process of evapotranspiration, affecting both the rate of water vapor loss from surfaces and the transpiration from plants [26].

When comparing the changes in wind speed during the years of the study, the wind speed increased at a general rate for all years of the study amounting to 1.4(m. sec. $^{-1}$) and the change between each year and the following year varied between an increase and a decrease from the general rate of these changes [27]. Wind speed is one of several factors that contribute to the microclimate around plants. It affects the exchange of heat and moisture between the plant and its surroundings. In windy conditions, the drying effect on leaves can contribute to increased water loss through transpiration. Transpiration is the process by which plants release water vapor through small pores (stomata) in their leaves. Higher wind speeds can accelerate transpiration by removing the water vapor from the vicinity of the leaves. This creates a more favorable gradient for water movement from the plant to the atmosphere [28].

Changes in rainfall (mm) amounts during the years of study and its impact on evapotranspiration processes

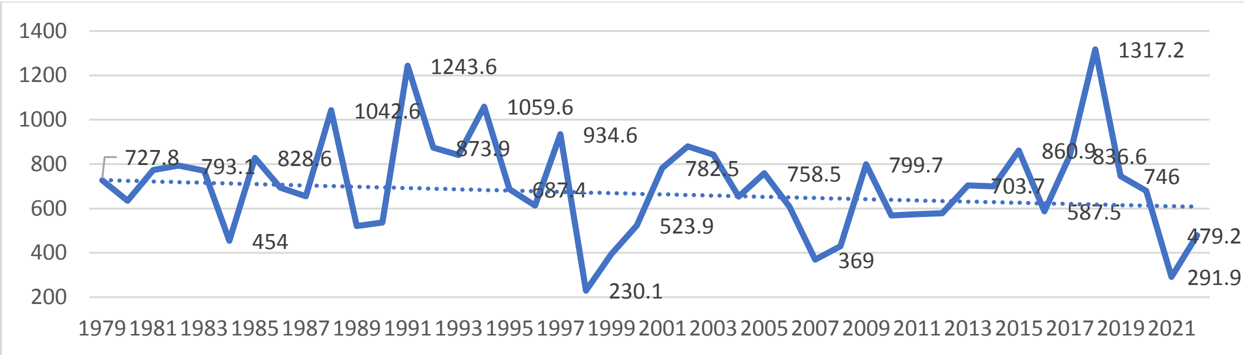


Figure (7) shows the annual averages of Rainfall amounts (mm) for the period 1979- 2022 source, (Sulaymaniyah Meteorology Department)

From Figure (7) The rainfall data from 1979 to 2022 shows significant year-to-year variability. There are periods of both sharp increase and decrease. The 1980s and the early 2000s show relatively lower amounts, the 1990s and late 2000s show higher amounts, and there's a notable decrease again in the 2020s [29].

1979 -1980s: The data starts with 727.8 mm in 1979 and shows variability through the 1980s, with amounts ranging from as low as 454.0 mm (in 1986) to as high as 1042.6 mm (in 1989). This decade shows considerable fluctuation without a clear long-term trend.

1990s: This decade begins with lower amounts (around 520.8 mm in 1990) and sees a significant increase, peaking at 1243.6 mm in 1992. The rest of the 1990s appears to fluctuate but generally stays higher than the early 1980s.

2000 :2010 - The early 2000s start with lower figures (230.1 mm in 2000 being a notable low) and then gradually increase, with some fluctuation, reaching 1317.2 mm by 2010, which is the highest in your dataset. 2010 - 2022: Post-2010, the data again shows variability, with a general decrease from the 2010 peak. The lowest in this period is 291.9 mm in 2021, indicating a significant decrease towards the end of the period. the average rate of change in rainfall over this period is approximately -5.78 mm per year. This indicates a general decrease in rainfall amounts over the period from 1979 to 2022. [30], [31]

Also, rainfall adds moisture to the soil. When the soil is moist, more water is available for evaporation and for uptake by plants. This can lead to an increase in evapotranspiration rates, as plants will transpire more water when it is readily available, and evaporation from the soil surface will be higher compared to dry conditions. As well as Rainfall can also alter local humidity and temperature. Higher humidity levels following rain can reduce the evapotranspiration rate because the air holds more moisture, leading to a smaller gradient between the moisture in the air and the moisture in the soil or plants. Lower temperatures can also reduce evapotranspiration since warmer temperatures typically increase evaporation and transpiration rates [32]. During and immediately after rainfall events, cloud cover is usually more extensive. This reduces solar radiation, which can decrease the energy available for evaporation. In the short term, this might lead to a decrease in evapotranspiration rates. Rainfall can affect plant growth and leaf area, which in turn impacts transpiration. After sustained periods of rainfall and increased soil moisture, plants may grow more vigorously, with greater leaf area, leading to increased transpiration. Conversely, during periods of low rainfall and water stress, plants may reduce their leaf area or close their stomata to conserve water leading to lower [33].

Excessive rainfall can lead to surface runoff, especially in areas with compacted soil, slopes, or poor infiltration capacity. Runoff carries water away from the area, which can reduce the amount of water that infiltrates the soil and becomes available for evapotranspiration. Additionally, if the soil becomes saturated, oxygen levels in the soil can drop, potentially stressing plants and reducing transpiration. The impact of rainfall on evapotranspiration can also be seasonal. For example, in arid and semi-arid regions, rainy seasons can see a significant increase in evapotranspiration due to higher soil moisture and plant growth, while dry seasons may see reduced evapotranspiration [34] Changes in annual Relative humidity (%) averages during the study period and the impact of that on the rate of Evapotranspiration and the effect of that on changes in evapotranspiration

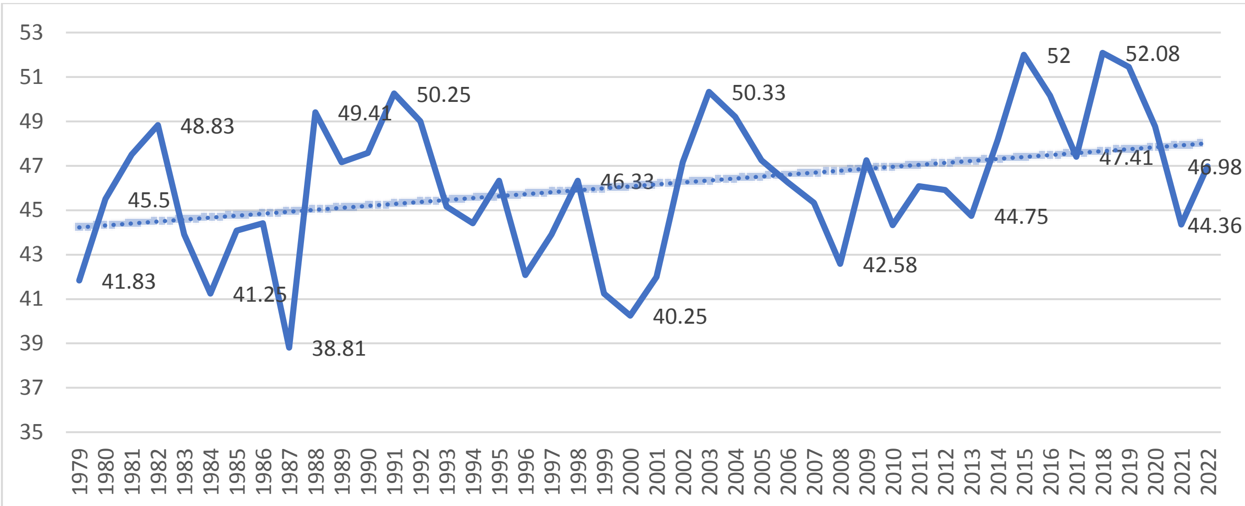


Figure (8) shows the annual averages of Relative Humidity (%) for the period 1979- 2022, Source, (Sulaymaniyah Meteorology Department).

Plotting the relative humidity values over the years on a graph in Figure (8) can provide a visual representation of the trends and fluctuations. and notes that there are discrepancies in relative humidity values between increasing and decreasing in the study years for the average annual increase in relative humidity of about 0.22% over 43 years. Analyzing such data usually involves looking for patterns, trends, or anomalies. Inconsistencies and fluctuations in annual data are affected by a variety of factors, including changes in climate, specific weather events, or changes in local or regional conditions [35]. The average relative humidity over 43 years was about 46.00%. Which is the central point around which relative humidity values cluster, the standard deviation was 3.17 a measure of how much individual values deviate from the mean. A higher standard deviation indicates greater variance in the data. With a standard deviation of 3.17, most individual relative humidity values fall within about 3.17 percentage points above or below the average of 46.00%. In other words, a large portion of the values are likely to be in the range of 42.83% to 49.17% [36].

When the air's relative humidity is high like these values (48.83, 49.41, 50.25, 50.33, 52, 52.08, and 50.48) for the years (1982, 1988, 1992, 2003,2015, and 2019) it means the air is near saturation with water vapor. In such conditions, the air has a reduced capacity to accept more water vapor. This leads to a decrease in the rate of evapotranspiration. When the air is humid, the gradient of vapor pressure between the leaf interior (where humidity is high) and the external air is lower, which slows down the transpiration rate. Similarly, evaporation from soil or water surfaces is less efficient under high humidity conditions [37]. Conversely, low relative humidity like these years (1984, 1987, 2000, 2008, 2013, and 2021) with values (41.25, 38.81, 40.25, 42.58, 44.75, 44.36) indicates that the air is dry and can absorb more water vapor. This creates a higher vapor pressure deficit, which is the difference between the amount of moisture in the air and how much moisture the air can hold when it's saturated.

A higher vapor pressure deficit enhances the rate of evapotranspiration. Dry air can take up water vapor more readily from the soil, water bodies, and plant leaves, thus increasing both evaporation and transpiration rates [38]. Plants often respond to high humidity by closing their stomata, the pores in their leaves, to reduce water loss. This is a protective mechanism to conserve water. In low humidity conditions, stomata are generally more open, assuming sufficient water availability, and allowing more transpiration [39]

Conclusion

This review presents the relationship between relative humidity and evapotranspiration is inversely proportional. Higher humidity typically reduces evapotranspiration rates, while lower humidity can increase them, assuming other factors like temperature and solar radiation are conducive. this relationship is essential in fields like agriculture, hydrology, and climate science, as it helps predict water demand, irrigation requirements, and ecological dynamics. Temperature changes have a direct and complex relationship with evaporation rates. Understanding this relationship is crucial for water resources management, especially in the context of climate change and its potential impact on hydrological cycles.

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Kirkuk University Journal for Agricultural Sciences, Vol. 15, No. 1, 2024 (117-129)
Online ISSN: 2958-6585

مجلة جامعة كركوك للعلوم الزراعية

تأثير تغير بعض عناصر مناخ مدينة السليمانية خلال 43 سنة على معدلات التبخر – النتح من الفترة 1979–2022، العراق

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• تاريخ استلام البحث2024/01/04 وتاريخ قبوله 2024/02/17.

الخلاصة

بيانات الأرصاد الجوية اليومية عن التبخر، ودرجة الحرارة، والرطوبة النسبية، وسرعة الرياح، وهطول الأمطار لتحليل البيانات باستخدام معادلة (PM) Penman–Monteith الموحدة لقيمة التبخر المرجعية للمظلة القصيرة، في ظل الظروف الحالية، ويعتبر شهر يونيو هو الأكثر تغيرًا مقارنة وبقية الأشهر خلال فترة الدراسة حيث انخفضت معدلات التبخر بمعدل 3.75 ملم. وتظهر مستويات التبخر تقلبات موسمية، كما يتضح من معدلات التبخر السنوية. خلال الأشهر الباردة والمطرية، وتحديداً من أكتوبر إلى مارس، لوحظ اتجاه تنازلي في معدلات التبخر طوال فترة الدراسة. على العكس من ذلك، في الأشهر الأكثر دفئًا (أبريل حتى سبتمبر)، أعلى إشعاع سنوي في عام 2021، 17.5 (ميجا جول م–2 يوم–1)، يمثل زيادة عن عام 1982 البالغ 15.5 (ميجا جول م–2 يوم–1). وعلى مدار 43 عامًا، يبلغ متوسط المعدل السنوي للتغير الإشعاعي حوالي 0.0263 وحدة، مما يشير إلى زيادة تدريجية. وعلى مدار 43 عامًا (1979–2022)، تراوح معدل التبخر والنتح من 3.68 ملم إلى 4.4 ملم، ويزداد بسبب ارتفاع درجات الحرارة والإشعاع الشمسي. تؤدي سرعات الرياح المرتفعة عمومًا إلى زيادة التبخر بسبب عمليات التبخر والنتح المعززة. وعند مقارنة التغيرات في سرعة الرياح خلال سنوات الدراسة تبين أن سرعة الرياح زادت بمعدل عام لجميع سنوات الدراسة بلغ 1.4(م.ثانية–1) وتباين التغير بين كل سنة والسنة التالية بين الزيادة والنقصان عن المعدل العام لهذه التغيرات. تظهر بيانات هطول الأمطار من 1979–2022 تقلبات سنوية ملحوظة. شهدت الثمانينيات وأوائل العقد الأول من القرن الحادي والعشرين انخفاضًا في هطول الأمطار، في حين شهدت التسعينيات وأواخر العقد الأول من القرن الحادي والعشرين كميات أعلى، مع انخفاض مرة أخرى في عشرينيات القرن الحادي والعشرين. متوسط الزيادة السنوية 0.22% ومتوسط القيمة 46.00%. يشير الانحراف المعياري البالغ 3.17 إلى أن معظم القيم تقع ضمن 42.83% إلى 49.17%. تشير سنوات الرطوبة النسبية العالية (على سبيل المثال، 1982، 1988، 1992، 2003، 2015، 2019) إلى هواء قريب من التشبع، مما يؤدي إلى انخفاض معدلات التبخر والنتح بسبب انخفاض تدرجات ضغط البخار وكفاءة النتح. وعلى العكس من ذلك، فإن سنوات الرطوبة المنخفضة (على سبيل المثال، 1984، 1987، 2000، 2008، 2013، 2021) تظهر قدرة أعلى للهواء على امتصاص بخار الماء.

الكلمات المفتاحية: التبخر نتح، الرطوبة النسبية، هطول الأمطار، درجة الحرارة، سرعة الرياح.