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Assessment of Impact of Accumulated Potential Water Loss (APWL) on Water Availability in Ijebu-Ode Southwest Nigeria

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Abstract
Understanding accumulated potential water loss (APWL) is crucial because it provides information about the total amount of water that could potentially be lost from a location over a specific time period. The primary goal is to assess the possible effects of climatic and hydrological dryness on Ijebu-Ode's water supply. Climate Data was sourced from Nigerian Meteorological Station (NIMET) Ijebu-Ode station (1989 - 2018) via national portal. The soil moisture storage in Ijebu-Ode was calculated over a period of many months using the Thornthwaite water balance model and the Climatic Water Budgeting Approach. The monthly soil moisture storage is determined using the Climatic Water Budgeting Approach by combining the mean monthly rainfall, the monthly potential evaporation (PE), and a soil water retention capacity of 250 mm. The PE is calculated using the average monthly air temperature data. A meteorological drought that spreads through the hydrological cycle is seen in Ijebu-Ode during the APWL months when the PET>P. This can lead to a decrease in surface and groundwater, causing a hydrological drought in eight months (Nov-May and August) and worsen availability of water. The results of this study shed light on water availability, hydrological studies, and water resource management in Ijebu-Ode. The study recommends the implementation of proactive measures and improved water resource management strategies to effectively address abnormal moisture deficiencies during the APWL months and improve water conservation in Ijebu-Ode. Seasonal variation in soil water storage is recognized as a natural phenomenon in Ijebu-Ode.

Keywords: Thornthwaite method, Accumulated potential water loss, Meteorology/ Hydrological drought, Water availability and Water resource management.

1. Introduction

The knowledge of probability of drought (i.e., meteorological phenomenon) occurrence is an essential step (s) for water resource planning. All contemporary efforts to evaluate the water balance are based on the groundbreaking research of the late C.W. Thornthwaite on potential evaporation (Thornthwaite, 1948). The method of calculating water balance developed by Thornthwaite in 1948 is a significant addition to the study of climatology. The emphasis on moisture availability and moisture patterns provide valuable insight into the availability of water resources in Ijebu-Ode in the different months. According to Utsev, et al. (2023), climate change has become a global phenomenon affecting every region of the world leading to changes in weather patterns, sea levels, and the availability of natural resources, water inclusive. These changes negatively impact human and natural systems, including water resources, food security, and the human, health (Cervigni et al, 2013). Climate change is a global phenomenon caused by the emission of greenhouse gases, primarily carbon dioxide, into the atmosphere (Abado, 2022). These dangerous gaseous emissions cause an increase in the Earth's temperature, resulting in changes in weather patterns, sea levels, and the availability of natural resources such as water, forests, and food (Abado, 2022).

According to Utsev et al., 2023, in Nigeria, climate change is characterized by the changes in precipitation and temperature patterns. Observations in recent years show that there has been an increase in temperature and a decrease in rainfall in some regions of the country (Utsev, et al, 2023). These changes in temperature and precipitation patterns are likely to continue with an increase in frequency and severity of drought and floods (Utsev et al. 2023)). Climate change can have a significant impact on surface and groundwater resources (Utsev, et al, 2023). Lower availability may result from rising temperatures brought on by climate change, particularly when potential evapotranspiration exceeds rainfall (PET>W). This can make it more difficult for communities such as Ijebu-ode and, ecosystems to access the needed water. According to a

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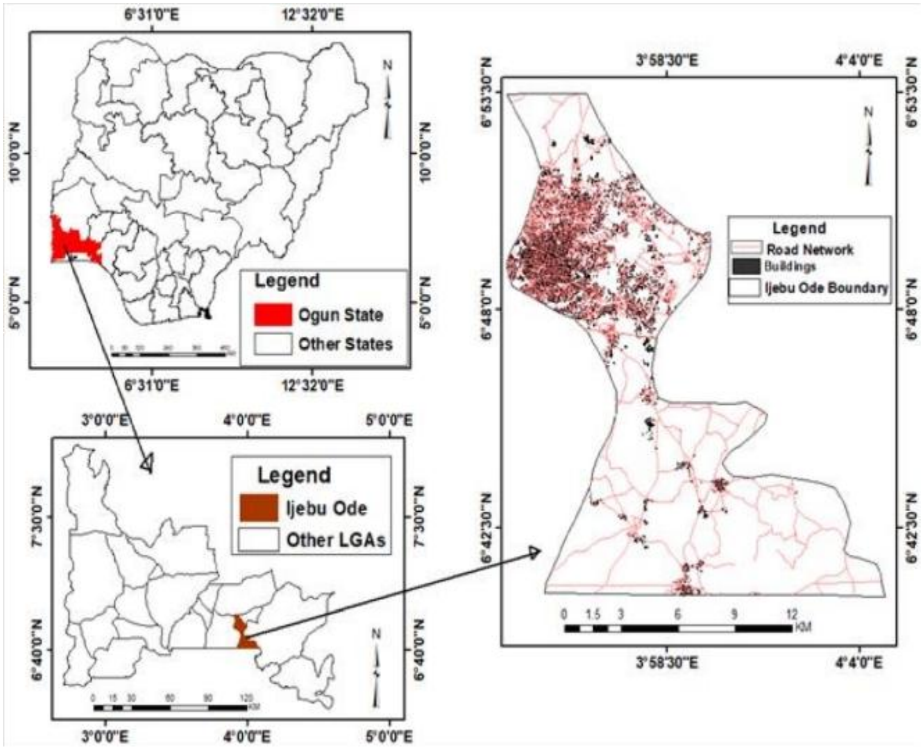

Figure 1: Location of Ijebu-Ode in Ogun State, Southwest Nigeria (Olayowola and Salau, 2022)

study by Ogunbodede, et al. (2019), climate change has led to decreased water availability for crops in Ogun state, impacting crop productivity. Climate change can also lead to changes in the quality of water as warmer temperatures can increase the growth of harmful algae and bacteria and, heavy rains can wash pollutants into rivers and lakes making it more difficult to ensure a reliable supply of clean water for human use and maintenance of the healthy ecosystem (Utsev, et al, 2023). Arakawa, (2017) opined that water is an essential resource for agricultural productivity, directly influencing the crop growth, yield, and the overall sustainability of farming systems. The most prevalent and important element to the human existence is water.

Emphasis on water balance and moisture patterns provide valuable insight into availability of water resources in Ijebu-Ode in different months. A lower water table might result from wells drying up in Ijebu-Ode during the dry season as a result of less rainfall and more evaporation. In wells with lower yields, particularly those drilled during the rainy season, this effect is more noticeable. The wells dried up as the rain stopped. Seasonal variations in groundwater levels are a natural phenomenon. Because they are less able to extract water from the nearby aquifer, wells with lower yields are more likely to dry up. This study emphasizes the necessity of further in-depth research on the substantial effects of accumulated potential water loss (APWL) on water availability in relation to hydrological and meteorological drought in Ijebu-Ode.

2. Methods

2.1 Location

This research was conducted in the ancient city of Ijebu-Ode situated in Ogun State Nigeria (Figure 1). Ijebu-Ode is one of the 20 Local Government Areas (LGA) that makes up Ogun State with a total area cover of 190.543km (Topographic map, Ijebu-Ode Sheet 280 NE, 1963; Landsat 8 OLI/TIR, 2021) (Olayowola and Salau, 2022) and a population of 233,310 at the 2006 census (National Population Commission, NPC). Ijebu-Ode is located at latitude 6^0 28’ N and 60 44’N of the equator and Longitude 30 10’E and 30 55’ E of Greenwich Meridian (Olayiwola and Salau, 2022) in Southwest Nigeria, at an elevation of 74 meters above sea level (Figure 1). The city is third largest urban centre in Ogun State in terms of infrastructural facilities, administration and commerce.

The climate of Ijebu-Ode, SW Nigeria, like other parts of Nigeria is characterised by distinct wet and dry seasons, enabling the occurrence of lowland tropical rain forest. The region on an annual basis is under the influence of hot-wet tropical maritime air mass during rainy season (April-October) and hot-dry tropical continental air mass during dry season (November-March) (Aiyewunmi, 2023). Ijebu-Ode has humid tropical climate annual rainfall is generally intense with peaks occurring in July and September (double maxima) coupled with, high temperature and relative humidity (Adejuwon & Agundiminegha, 2019). The annual rainfall is between 1575mm and 2340mm and the average annual temperature is 27.5°C (Oluwatobi & Oluwakemi, 2016; Fayemi, 2020; Onanuga *et al.*, 2022).

Ijebu Ode, Nigeria, has seen a dramatic increase in built-up areas between 1986 and 2000 by 11.03%, 2000 to 2014 (65.24%), and 2014 to 2021 by 131.25%, according to the overall findings of a study by Olayiwola and Salau (2022) that used satellite imagery data to evaluate the nature and extent of urban land use

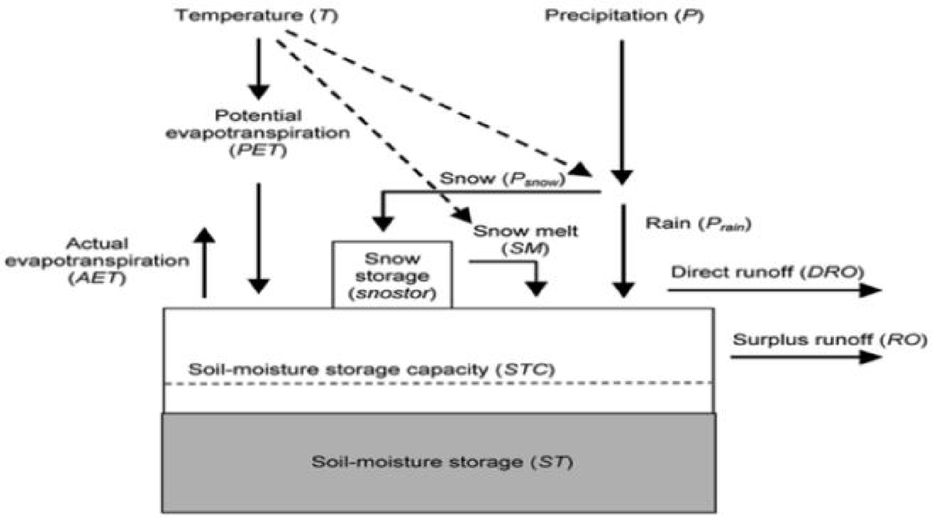

Figure 2: Water Balance Model Schematic (Source: Thornthwaite Monthly Water Model 2020)

change in Ijebu Ode, Nigeria, between 1986 and 2021. According to Olayiwola and Salau (2020), land use and land cover change (LULCC) is an ongoing process with effects on both the spatiotemporal environment. It is essential to have a thorough grasp of the "challenges and potential solution (s) to risk of seasonal soil moisture storage in Ijebu-Ode in Southwest Nigeria.

2.2 Thornthwaite Monthly Water Balance Model

This study followed the Thornthwaite water balance model (Thornthwaite, 1948) which used an accounting procedure to analyse the allocation of water among various components of the hydrologic system. Computation of monthly water balance components of hydrologic cycle were made for ten (10) local communities. According to Thornthwaite (1948), inputs into the model are average monthly temperature and rainfall of 30-years period (1989-2018), whilst outputs include monthly potential evapotranspiration and actual evapotranspiration, soil moisture storage, surplus and runoff. The Thornthwaite monthly water model, 2020) in Figure 2 shows component and connectivity of the Thornthwaite water model. The boxes in Figure 2 represent components; the arrows show data-flow between components.

2.3 Types and sources of data

The study used the mean monthly air temperature; the mean monthly rainfall data and the soil water holding capacity of 250mm contained in the Thornthwaite's (1948) monograph to determine the monthly soil moisture storage in Ijebu-Ode. The Nigerian Meteorological Station (Ijebu-Ode), provided meteorological data for the last 30 years (1989-2018) via national portal, which is used to determine the mean monthly air temperature and the monthly rainfall data. Data is processed using Thornthwaite (1948) Climatic Water Budgeting Approach to calculate soil moisture storage at various months in Ijebu-Ode.

2.4 Method of data analysis

Thornthwaite's (1948) equation is explored in this study because it is more empirical. Water balance is assessed from the results obtained in statistical data computed about rainfall, temperature and evapotranspiration. In conformity with the (Thornthwaite & Mather, 1955; 1957) methods, seven (7) methods are used for estimating the water balance in the present study area. Thornthwaite-Mather water balance equation uses the soil moisture capacity to estimate water budgets (Nugroho et al., 2018). The parameters needed for using this method include:

1. Difference between precipitation and potential evapotranspiration (P and PET)
2. Accumulated potential water loss (APWL)
3. Available water capacity (AWC)
5. Actual evapotranspiration (AET or ETa)
6. Deficit and surplus of the water budget (WD and WS)

2.4.1 Precipitation (P)

Precipitation data on a monthly basis is required. Missing rainfall data can be estimated first by the arithmetic method or the normal ratio method. If a study area has many rain gauge stations, the mean areal precipitation value shall be determined first. Mean areal precipitation in this study determined by averaging the rainfall data from study area (1998-2018) representative rain gauge.

2.4.2 Difference between precipitation and potential evapotranspiration

P-PET The difference value of potential evapotranspiration and precipitation (P-PET) is negative when there is a potential water deficit, while positive P-PET value represents a potential water surplus. If the P-PET value is less than zero, the month called as "dry month" and it is subjected to APWL value. While the P-PET value is more than zero, the month called as "wet month" and it is subjected to surplus value.

$$P - PET \qquad (1)$$

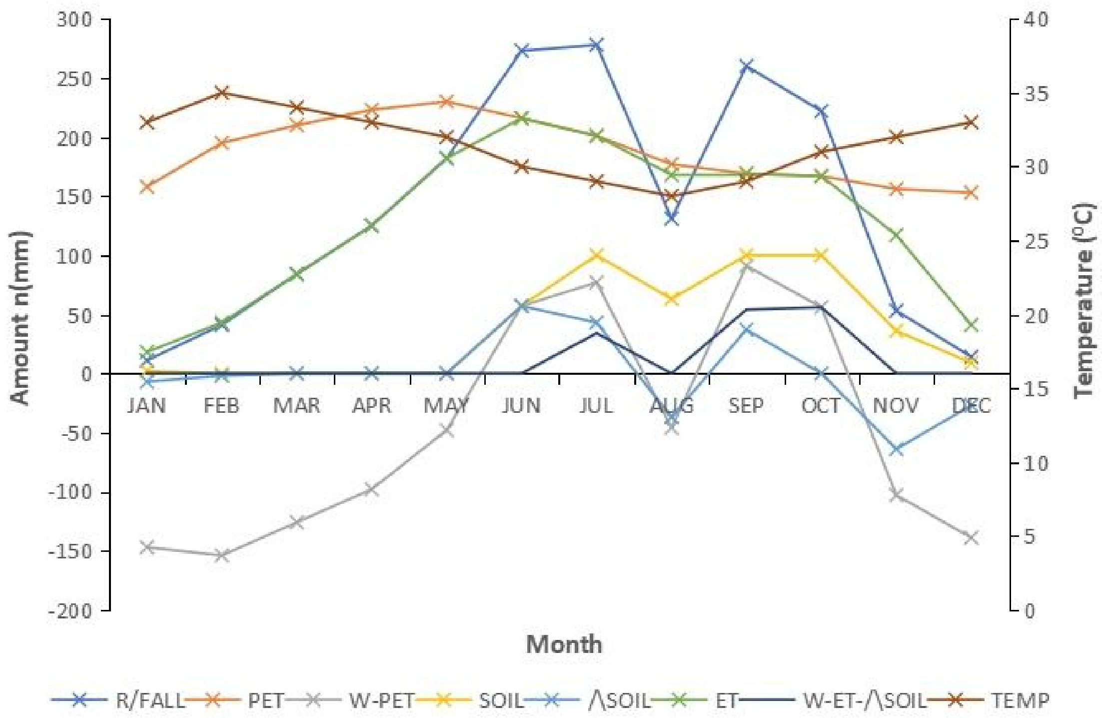

Figure 3: Displaying the actual calculated mean monthly water balance over Ijebu-Ode (1989-2018) in reaction to temperature.

2.4.3 Accumulated Potential Water Loss (APWL)

The accumulated potential water loss is calculated as the cumulative sum of P-PET values during months when P-PET is negative. Accumulated potential water loss increases during dry seasons. It is reduced during wet seasons because of soil moisture recharge. The value would be zero when soil moisture equals the soil's available water holding capacity (Roy, and Ophori, 2012).

$$\mathrm{PET} > \mathrm{P} \text{ or } \mathrm{PET} < \mathrm{P} \qquad (2)$$

*APWL is a cumulative value of $(\mathrm{P} - \mathrm{PET})$

2.4.4 Actual Evapotranspiration (AE or ETa)

The difference between actual evapotranspiration (AE or ETa) and potential evapotranspiration (PEt) is in their relationship with soil moisture storage. The PET accounts water removal from land surfaces only by atmospheric potential (heat), while the AE or ETa accounts change on soil moisture storage in land surfaces. When the precipitation (P) is higher than the PET, it means that soil moisture storage still saturated from the excess precipitation. Hence, the AE or ETa equals the PET because there is adequate water supply and the soil moisture is at field capacity. When the P is lower than the PET, it means there are changes in the soil moisture storage. Thus, the AE or ETa equals the P subtracted by the changes in soil moisture storage.

$$\mathrm{P} > \mathrm{PE} \lozenge \mathrm{AE} = \mathrm{PE} \qquad (3)$$

$$\mathrm{P} < \mathrm{PE} \lozenge \mathrm{AE} = \mathrm{P} - \Delta\mathrm{ST} \qquad (4)$$

2.4.5 Deficit (D) and Surplus (S)

Soil-moisture deficit expressed as the difference between actual evapotranspiration and potential evapotranspiration (Thornthwaite and Mather, 1957). When soil moisture reaches the maximum soil-moisture capacity, which is AWC, any excess precipitation becomes the surplus value, thus makes surplus value equals to

$$\mathrm{P} - \mathrm{PE} \qquad (5)$$

$$\mathrm{D} = \mathrm{P} < \mathrm{PET} \text{ then } \mathrm{AE} < \mathrm{PE} \qquad (6)$$

$$\mathrm{S} = \mathrm{P} > \mathrm{PET} \text{ or } \mathrm{S} = \mathrm{P} - \mathrm{PE} \qquad (7)$$

3. Result and discussion

The main result of this section on water balance is calculated by taking into account potential evapotranspiration (PET), which is widely used in hydrology and is crucial for managing water resources (Figure 3 and Table 1). The results showed that rainfall (W) is higher than potential evaporation (PET) in the months of June through July and September through October (4 months), resulting in a potential water surplus (WS), while rainfall (W) is lower than potential evapotranspiration (PET) in the months of January through May, August, and November through December (8 months), resulting in a potential water deficit (WD). The factors contributing to APWL in Ijebu-Ode include climate change, low precipitation, land use changes and poor water management strategies (Aiyewunmi, 2023). According to Roy & Ophori (2012) the value would be zero when soil moisture equals the soil's available water holding capacity.

Table 1: Displaying the monthly water balance at the actual computed mean over Ijebu-Ode in reaction to temperature.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
P	11	41	84	125	182	273	278	131	260	222	53	14	1674
T	33.0	35.0	34.0	33.0	32.0	30.0	29.0	28.0	29.0	31.0	32.0	33.0	
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
RAIN	11	41	84	125	182	273	278	131	260	222	53	14	1674
SNOW	0	0	0	0	0	0	0	0	0	0	0	0	0
PACK	0	0	0	0	0	0	0	0	0	0	0	0	
MELT	0	0	0	0	0	0	0	0	0	0	0	0	0
W	11	41	84	125	182	273	278	131	260	222	53	14	1674
PET	142	176	189	201	297	194	180	159	152	150	140	138	2028
W-PET	-131	-135	-105	-76	-25	79	98	-28	108	73	-87	-124	
SOIL	3	1	0	0	0	79	100	76	100	100	42	12	
/\SOIL	-9	-2	-1	0	0	79	21	-24	24	0	-58	-30	
ET	20	43	85	125	182	194	180	155	152	150	111	43	1440
W-ET-/\SOIL	0	0	0	0	0	0	77	0	84	73	0	0	233

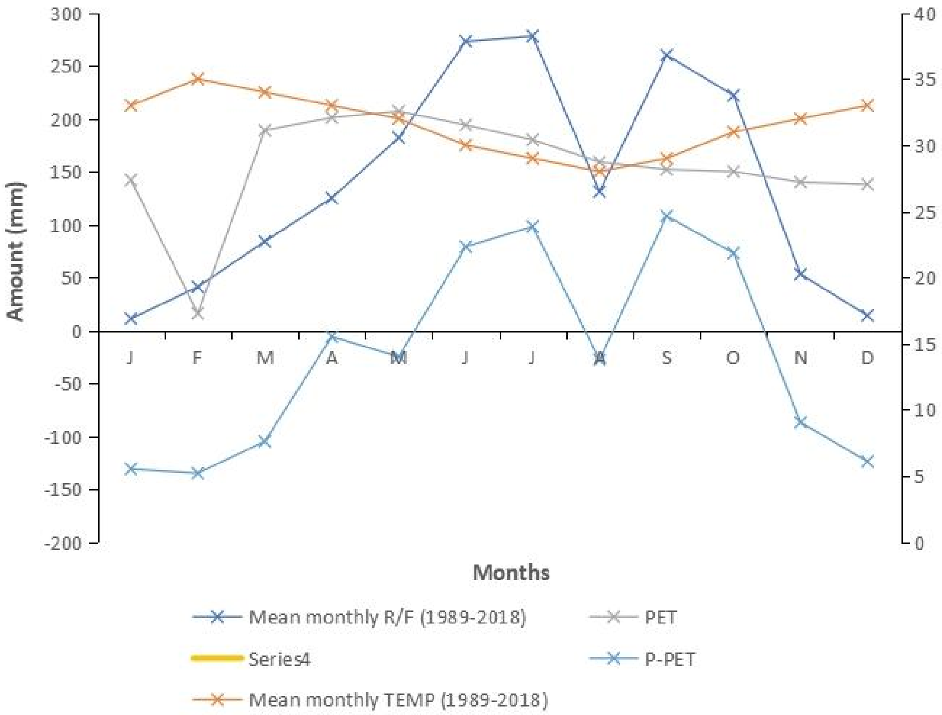

Figure 4: Showing the computed monthly values of PET for the different months over Ijebu-Ode

Following the estimation of the monthly PE for each month in Ijebu-Ode, the values were submitted to the water balance sheet along with the monthly rainfall in order to ascertain the soil water storage (Table 2 and Figure 4). It is important to remember that the monthly values of soil moisture storage (ST) are dependent on monthly rainfall, monthly potential evapotranspiration (PET), and monthly accumulated potential water loss (APWL). While sufficient water is added to the months with positive values, the negative values in PE or PET values (Table 2), which take into account soil moisture between months, suggest that water is taken out of the evapotranspiration storage in the affected months (i.e., a state of extreme dryness, potentially leading to hydrological drought conditions).

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The result in Table 2 showed historic water removal from the storage in the months of Nov-May and August, confirming the months experiencing meteorological and hydrological drought in Ijebu-Ode. According to Roy and Ophori, (2012), positive value of ΔST means there is enough water to add to the soil moisture storage, while negative value implies that water is removed from the storage because of

Table 2: Calculating the soil moisture storage (ST) monthly values

Months	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Mean monthly R/F (1989-2018)	11	41	84	125	182	273	278	131	260	222	53	14
Mean monthly TEMP (1989-2018)	33.0^0	35.0^0	34.0^0	33.0^0	32.0^0	30.0^0	29.0^0	28.0^0	29.0^0	31.0^0	32.0^0	33.0^0
PET	142	176	189	201	207	194	180	159	152	150	140	138
P-PET	-131	-135	-105	-76	-25	79	98	-28	108	73	-87	-124
/\SOIL	-9	-2	-1	0	0	79	21	-24	24	0	-58	-30
PE > P				APWL MONTHS			SOIL MOISTURE WATER STORAGE	APWL MONTH		SOIL MOISTURE WATER STORAGE		APWL MONTHS
APWL months	J	F	M	A	M				A		N	D

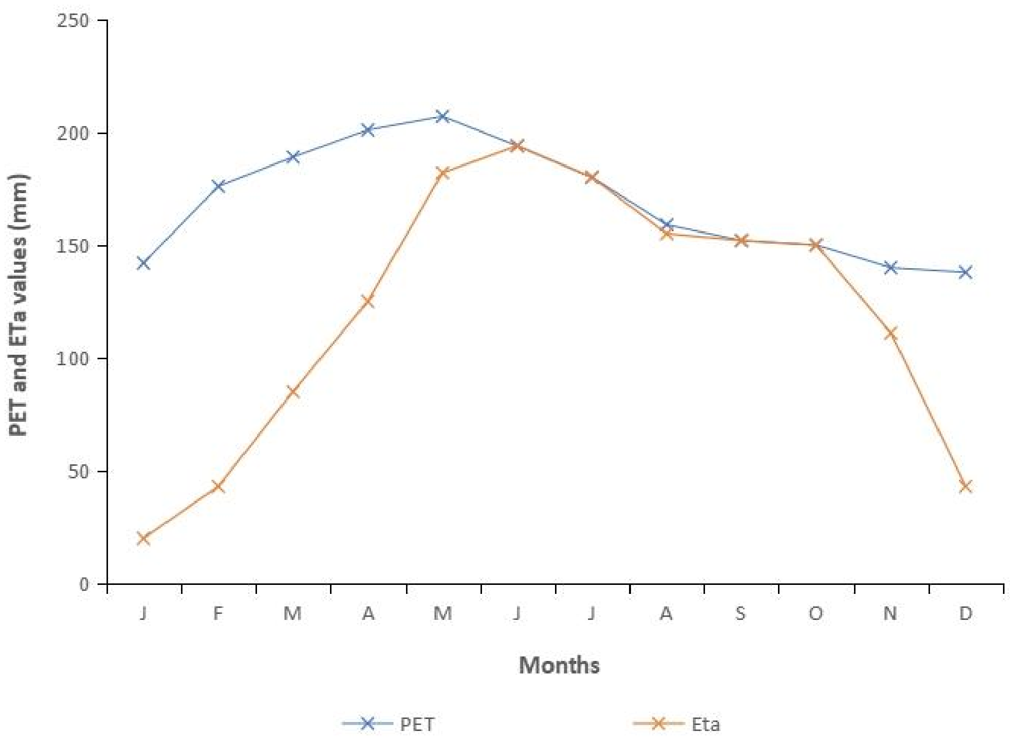

Figure 5: Illustrating the availability of soil water, either from rainfall or stored in the earth

evapotranspiration. Table 2 and Figure 4 showed the computed monthly values of PET for the different months for Ijebu-Ode (1989-2018). Musa and Aliyu (2021) established that the high – accumulated potential of low soil moisture storage. Table 2 and Figure 4 show the monthly spatial trends of soil moisture storage in water loss in many places across Nigeria is an indication Ijebu-Ode.

The Thornthwaite model assumes that the actual evapotranspiration (ETa) rate is equal to the prospective evapotranspiration (PET) as long as there is water available (either from rainfall or storage in ground water); if not, it will occur at a lower rate or deficit (November through December and August). (Table 3 and Figure 5). In Table 3, soil-moisture potential deficit is expressed as difference between actual evapotranspiration (AE or ETa) and potential evapotranspiration (PE or PET). AE or ETa accounts for change in the soil moisture storage in land surface whilst PE or PET accounts for water removal from land surface only by atmospheric potential (heat). Result in Table 3 when PE or PET > AE or ETa in soil moisture indicate that soil is experiencing water stress. This happens when water demand (PE or PET) exceeds available water supply (AE or ETa) in the soil. In

Table 3: Showing the availability of soil water either from rainfall or stored in the earth

Months	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
PET	142	176	189	201	207	194	180	159	152	150	140	138
Eta	20	43	85	125	182	194	180	155	152	150	111	143

months (Jun-Jul and Sep-Oct), there is no change to the soil moisture storage because AE or ETa equals PE or PET, indicating adequate water supply, meaning soil is at or near field capacity. In this situation, the soil holds max amount of water it can drain, and plants can transpire and evaporate water at max potential rate determined by climate conditions. According to Thornthwaite (1948), when the soil moisture reaches its maximum soil-moisture capacity (AWC), any excess precipitation becomes surplus value, and 50% of surplus water in larger watersheds will become runoff in any month. If the P-PE or PET is positive, then the soil moisture storage value is equal to the available water capacity (AWC) in Ijebu-Ode (see Table 2, 3 and Figure 3, 4). In general, months when P < PE or PET equates with months PE or PET < AE or ETa indicate that the soil moisture is still saturated due to the excess precipitation.

Increase in global temperatures impact evapotranspiration (Table 1 and 2), humidity of the air affecting the ability of the atmosphere to store water, with direct effects on the magnitude, frequency, intensity, and spatio-temporal distribution of precipitation (Wang et al. 2016). As a consequence's, the frequency and severity of extreme events such as droughts and floods would increase, being droughts the slowest to develop, but the longest to last (Band et al. 2008 and Yeh et al. 2015). Consequently, APWL months (Table 2) in Ijebu-Ode exposes the communities by triggering hydrological drought i.e., reduce water availability and poor water quality whilst non-drought months (June-July and Sep-Oct) exposes the communities by triggering hydrological flood i.e., increased water availability and poor water quality. Water shortages during the APWL months have implications for the inhabitant's health, agricultural practices i.e., food production, hence affecting food demand and their overall well-being. Research have shown that APWL can significantly impact water quality by affecting the concentration of pollutants and the availability of water (Peňa-Guerrero et al., 2020).

Climate change led to a rise in the frequency of dangerous water-related happenings such as flood and drought (Mohan et al., 2019). This causes a negative impact on the environment, economy and human health. Floods have a wide range of environmental effects and one of implications include water pollution (Foulds et al., 2014; Zhang et al., 2024). Flood primarily introduces pollutants and contaminants and pathogens into both surface and groundwater sources which can negatively impact on water quality, hence, can lead to a range of health and environmental problems (Sholihal et al., 2019). Depending upon the local conditions and sanitation facilities of an area, the flood water can contaminate drinking water sources such as surface water, groundwater, and even the water distribution systems (Mohan et al., 2019). Climate change is also expected to intensify existing pressure on water availability and will affect agricultural systems particularly in semi-arid environments (IPCC, 2014).

In the context of this study, meteorological drought refers to a period of significantly reduced monthly rainfall compared to historical potential evapotranspiration average in Ijebu-Ode, leading to a moisture deficit (Table I, 2, and 3). This lack of rainfall in the APWL months (Table 2 and 3) leads to a shortage of water, potentially impacting the water resources, agriculture, and ecosystem in Ijebu-Ode. In the same vein, the hydrological drought in Ijebu-Ode refers to the APWL months, a period of abnormally low water levels in surface and sub – surface water bodies like groundwater etc. characterised by a deficiency in water resources within hydrological cycle in Ijebu-Ode, a consequence of prolonged meteorological drought. According to Mishra and Singh (2010); Mosley (2015), meteorological drought that spreads through the hydrological cycle can reduce surface and groundwater level (triggering hydrological drought) and can lead not only to reduce water availability but also deterioration of water quality. This condition also intensifies water shortages by lowering the amount of usable water for the high APLW months in Ijebu-Ode. Low flows and water level hydrological droughts can affect water quality of the freshwater systems (Mosley, 2015; Palmer and Motagna, 2015).

4. Conclusion

The main findings of the study, namely the temporal fluctuations of hydrological and climatic droughts, have significant implications and could significantly impact the supply of water for various enterprises, residential applications, and agricultural sectors. Additionally, they may affect ecosystems, particularly aquatic areas. The results indicate that a lower water table in Ijebu-Ode villages increases the risk that wells may dry up during the APWL months of November through May and August. A high accumulated potential water loss (APWL) in the months of January-May, August and November-December indicates a significant deficit in available water within the Ijebu-Ode communities, leading to potential impacts like severe drought conditions due to inadequate soil moisture causing water scarcity for human consumption i.e., the reduce stream flow and potential drying up of water bodies (wells etc.) potentially leading to water conflicts due to limited supplies/access, stress on the natural ecosystem i.e., impacting plant and animal life disruption and increased risk of wildfires including increased risk of soil erosion due to the reduced vegetation cover.

In light of climate unpredictability and change, this study highlights the significance of monitoring APWL's contribution to water availability and quality during drought circumstances. From observation Ijebu-Ode has four distinct seasons for soil moisture: recharge (June and August); utilization (January, February, November, and December); deficit (March, April, and May); and surplus (July, September, and October), when the soil moisture storage reaches 250mm (100%) and more water runs off, raising the risk of flooding over Ijebu-Ode.

5. Recommendation

The pattern of the relationships between meteorological (i.e., reduced monthly rainfall) and hydrological droughts (i.e., depletion of soil moisture) is visible in present study, hence also is the relationship between the hydrological drought and water quality. The result of this study suggests a meteorological anomaly characterised by a prolonged and abnormal moisture deficiency.

The study suggests adopting proactive measures and improved water resource management strategies to effectively address abnormal moisture deficiencies and enhance water conservation in Ijebu-Ode.

1. To increase water retention, ecosystem restoration, water harvesting, soil conservation, indoor water conservation, biodiversity preservation, soil moisture retention, and other related activities must be put into practice.
2. To proactively manage water resources, take into account drought monitoring and drought-resistant landscaping, often known as water-wise landscaping.
3. Strong national and international policies are required to alleviate the water scarcity caused by climate change in order to use water sustainably.
4. When using irrigation interventions (such drip irrigation and smart irrigation systems), water resources should be handled efficiently without being wasted.
5. Policies and programs to support the most vulnerable communities, in order to ensure their resilience to the impacts of climate change.
6. This study recommends further investigation into the physiochemical analysis in order to substantiate the types of water pollutants and germs.

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