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Trends of Potential Evapotranspiration of Warri, Delta State, Nigeria

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Abstract

Evapotranspiration is the second largest quantity in the water cycle and an important indicator for climate changes. Accurate estimations and better understanding of evapotranspiration processes and knowledge about the rates of potential evapotranspiration is required in hydrologic studies and water resources modeling and paramount for designing appropriate responses to climate change. The monthly mean temperature data were used.The study estimates the potential evapotranspiration of Warri between 2004 and 2013 using the Thornthwaite method. The seasonal trends of potential evapotranspiration and temperature were shown through graphical representation and analyses were made accordingly. Results show that the Thornthwaite estimates displays a consistent yearly pattern and similar trends. There is always sharp increase in February, March and November and decrease in July and August of every year. This shows the seasonality to be consistent with the result been compared with the temperature trend for the same year. These changes in trend influence many hydrological, weather and climate related processes.

Keywords: Temperature, Evapotranspiration, hydrology, Thorntwaite, Variational trends

1.0 Introduction

Evaporation is the loss of water from open bodies of water, such as lakes and reservoirs, wetlands, bare soil, and snow cover while transpiration is the loss from living-plant surfaces. In a broad definition evapotranspiration is a combined process of both evaporation from soil and plant surfaces and transpiration through plant canopies. Several factors other than the physical characteristics of the water, soil, snow, and plant surface also affect the evapotranspiration process. Computation with a numerical model of the atmosphere showed that the global fields of rainfall, temperature and motion strongly depend on the land-surface potential evapotranspiration (PET), which validates the long-held idea that surface vegetation, which produces the evapotranspiration, is an important factor in the earth's climate [1]. PET is a difficult parameter to measure, but various methods have been developed to try to get at that upward flux of moisture [2,3]. Human alteration of the Earth's land cover is escalating,this change can significantly impact potential evapotranspiration in regional ecosystems, which in turn influences the global hydrological cycle [4,5].

The magnitude of this influence is unknown as accurate estimates of the human impact on terrestrial PET are lacking [6]. However, five spheres of human activity in Warri are known to affect the potential evapotranspiration vis-à-vis the hydrological process. These include (i) conversion of forests into agriculture, (ii) conversion of forested land to urban areas, (iii) deforestation and tree farms, (iv) creation of water reservoir, and (v) burning of biomass [1,7]. In addition, the reflective characteristics of the land surface also have an effect on the magnitude of potential evapotranspiration. This is where rapid urbanization due to population increase in warri and especially in Africa comes into focus. Tropical forests are disappearing or deteriorating, due especially to population pressures and nonsustainable resource utilization.

The chief concerns surrounding tropical deforestation are the consequent impacts on species diversity, atmospheric chemistry, and land surface-atmosphere interaction [8,9] which is an important component of climate system, posing greater

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challenge in developing or improving the landsurface scheme of Regional Climate Models (RCMs). Tropical forests also play an important role in the hydrological cycle [10,11]. Water is lost from trees to the atmosphere through interception loss (evaporation of the part of the rainfall that remains on leaves) and through normal plant transpiration. Climate change as a global phenomenon affects PET and poses economic, social, and ecological obstacles to the global community. In particular, smallholder farming communities in low-income countries such as Nigeria will be adversely affected by climate change. The more important factors include net solar radiation, surface area of open bodies of water, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and season of year. This study analyzed the potential evapotranspiration levels for Warri.

2.0 Theory

2.1 Thornwaite Method

Thornthwaite (1948) presented an empirical formulae based on temperature for the estimation of potential evapotranspiration. His formula is as follows:

$$E = 1.6\ x\ (\frac{10t}{I})^{a} \qquad (1)$$

Where

E= Evapotranspiration in mm/month

I =heat index for the 12 months in year, given by

$$I = \sum i = \sum \left(\frac{T}{5}\right)^{1.514} \qquad (2)$$

$$a = 6.75\ x\ 10^{-7} I^{3} - 7.71\ x\ 10^{-5} I^{2} + 1.792\ x\ 10^{-2} + 0.49239 \qquad (3)$$

t = mean monthly temperature in °C

Evapotranspiration comprises evaporation from the soil surface and transpiration through the plants via leaves. If the plant completely covers the ground surface, evaporation from the soil surface would be negligible and evaporation takes place completely through the plants, and if the roots can absorb water at a sufficiently high rate, the vapour transfers is controlled by the climate alone. This rate of moisture is referred to as the potential evapotranspiration. Thornthwaite method was discussed in[12,13].

3.0 Study Area, Data Collection and Methods

3.1 Study area, Climate and geographic background of Warri

Warri is an oil rich town with agro petrochemical industries and the major commercial city of Delta state in South-South Nigeria. As with the rest of the Niger delta, the climate of Warri is humid subequatorial with a long wet season lasting from March to October that alternates with a shorter dry season that lasts from November to February. The climate is influenced by two prevailing air masses namely (1) the S. W. monsoon wind and (2) the N. E trade wind. The former prevails during the wet season and the latter during the dry season. The S.W monsoon winds originate from the Atlantic Ocean and they are associated with the wet season, being warm and moisture-laden. In contrast, the N.E. trade winds originate from the Sahara desert and their prevalence is associated with the dry season. The effects of the dry N.E. trade winds are most noticeable in warri from December to February when they usher in the dry and dusty harmattan. Annual rainfall is high throughout the state, being usually up to 2500 mm. In southerly locations such as Warri mean annual rainfall is up to 2800 mm.

The beginning and end of the wet season are usually marked by intense thunderstorms of short duration, often accompanied by strong winds which may blow off roofs of buildings and cause destruction of property. Prolonged and gentle showers, usually lasting several hours or a few days, are more characteristic of the middle of the wet season. The rainfall regime is double-peak, the two periods of peak rainfall being June/July and September which are separated by a relatively dry period in August. Annual temperature average in warri is about 27°C with no marked seasonal departure from the average temperature as the annual range of temperature is quite small; rarely exceeding 3°C. Positionally located at Latitude 05° 31’N, Longitude 05° 44’E and at altitude of 2.4m.

The major material used for this work is mean temperature dates showing durations of rains and consequently, intensities of the rainfall in Warri. The data were obtained from Nigeria Meteorological (NIMET) office in Warri Delta state. The office has the data base for most climatic elements in Warri.

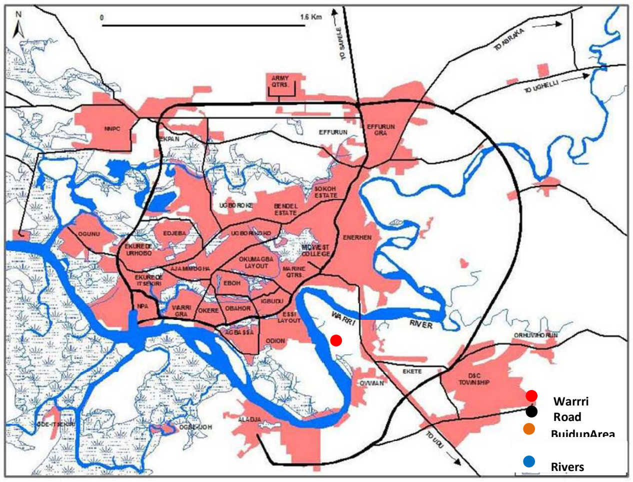


Figure 1: Map of Warri metropolitan.

3.2 Data Collection

The climate data from 2004 to 2013 in Warri i.e. daily mean temperature data were used to retrieve monthly mean temperature data. The data were collected from the Nigeria Meteorological agency in Warri. Determined Monthly mean temperatures data that were used to estimate potential evapotranspiration by Thornthwaite method are given in the table 1.

Table 1: Monthly mean air temperature of Warri for the last decade

M/y	**2004/◦c**	**2005/◦c**	**2006/◦c**	**2007/◦c**	**2008/◦c**	**2009/◦c**	**2010/◦c**	**2011/◦c**	**2012/◦c**	**2013/◦c**
Jan	27.6	25.6	28.3	26.6	26.4	27.8	27.5	26.5	26.9	27.5
Feb	28.6	29.1	28.8	28.8	28.1	28.8	29.6	28.2	28.1	28.8
Mar	29.7	29.3	29.3	29.9	29.2	30.1	30.0	29.5	29.7	29.8
Apr	28.8	29.6	29.9	29.3	28.2	29.1	29.9	29.4	29.3	29.7
May	27.6	28.2	28.1	28.3	27.9	29.0	29.2	28.4	28.3	29.0
Jun	27.2	27.6	28.2	28.0	27.5	28.0	28.1	27.5	27.1	27.7
Jul	26.1	26.3	26.6	26.6	26.4	26.7	27.4	26.2	26.5	26.6
Aug	26.0	26.6	26.1	26.9	26.3	26.0	26.6	26.2	26.8	26.5
Sep	26.6	27.2	26.2	26.3	26.6	26.7	27.0	27.1	27.1	27.1
Oct	27.5	27.5	27.4	26.6	28.4	27.1	27.0	27.3	27.0	28.2
Nov	29.0	29.0	28.9	27.9	29.0	28.6	28.9	29.1	29.1	28.8
Dec	28.2	27.9	27.6	27.6	28.3	28.8	28.3	27.7	28.3	28.1

3.3 Methods

3.3.1 Estimation of Potential Evapotranspiration

This research work has chosen one method to calculate monthly potential evapotranspiration and the method is Thornthwaite method which represents temperature based method.

3.3.2 Thornthwaite Method

The Thornthwaite method derived in[14] that uses only air temperature and latitude of site to estimate potential evapotranspiration will be used to calculate the potential evapotranspiration. Although the method is not recommended for use in areas where sufficient moisture water is not available to maintain active transpiration, it has also been widely used in many studies in the view of simple data requirement.

The Thornthwaite formula for monthly potential evapotranspiration is:

$$PET = 1.6\, x\, (\frac{10T}{I})^{a} \quad (4)$$

Where *T* is monthly mean air temperature (°C);

I is annual thermal index, which is the sum of monthly indices i,

Here $I = (\frac{T}{5})^{1.514}$ (5)

$$a = 0.49 + 0.0179\, I - 0.0000771\, I^2 + 0.000000675\, I^3 \quad (6)$$

The Thornthwaite methodwas developed from rainfall and runoff data for several drainage basins. The result is basically an empirical relationship between potential evapotranspiration and mean air temperature. In spite of the inherent simplicity and obvious limitations of the method, it does surprisingly well.

Potential evapotranspiration represents the synthetic effect of climate factors and is important for estimation of actual evapotranspiration. The characteristics of potential evapotranspiration are analyzed in Warri, based on the Thornthwaite method. The values of potential evapotranspiration and heat index estimated from the mean temperature values by the Thornthwaite methods for the last decade are given in these tables.

Table 2: Monthly mean Temperature and Calculated Potential Evapotranration.

	Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
JANUARY	**Monthly Mean Temperature(^{0}C t_m)**	27.6	25.6	28.3	26.6	26.4	27.8	27.5	26.5	26.9	27.5
	Potential evapotranspiration (cm)	15.29	11.22	16.10	13.13	12.74	15.73	14.68	12.92	13.72	14.83
FEBUARY	**Monthly Mean Temperature(^{0}C t_m)**	28.6	29.1	28.8	28.8	28.1	28.8	29.6	28.2	28.1	28.8
	Potential evapotranspiration (cm)	17.77	19.09	18.31	18.30	16.52	18.31	20.24	16.76	16.49	18.10
MARCH	**Monthly Mean Temperature(^{0}C t_m)**	29.7	29.3	29.3	29.9	29.2	30.1	30.0	29.5	29.7	29.8
	Potential evapotranspiration (cm)	20.83	19.65	19.71	21.40	19.38	22.15	21.45	20.23	20.84	20.92
APRIL	**Monthly Mean Temperature(^{0}C t_m)**	28.8	29.3	29.9	29.3	28.2	29.1	29.9	29.4	29.3	29.7
	Potential evapotranspiration (cm)	18.30	20.83	21.49	19.66	16.77	19.15	21.15	19.95	17.31	18.63
MAY	**Monthly Mean Temperature(^{0}C t_m)**	27.6	28.2	28.1	28.3	27.9	29.0	29.2	28.4	28.3	29.0
	Potential evapotranspiration (cm)	15.29	16.76	16.49	17.01	16.04	18.87	19.07	17.26	17.00	18.65
JUNE	**Monthly Mean Temperature(^{0}Ct_m)**	27.2	27.6	28.2	28.0	27.5	28.0	28.1	27.5	27.1	27.7
	Potential evapotranspiration(cm)	14.39	15.33	16.44	16.26	15.10	16.22	16.13	15.08	14.16	15.10
JULY	**Monthly Mean Temperature(^{0}C t_m)**	26.1	26.3	26.6	26.6	26.4	26.7	27.4	26.2	26.5	26.6
	Potential evapotranspiration (cm)	12.09	12.55	13.05	13.13	12.74	13.22	14.45	12.37	12.88	12.85
AUGUST	**Monthly Mean Temperature(^{0}C t_m)**	26.0	26.6	26.1	26.9	26.3	26.0	26.6	26.2	26.8	26.5
	Potential evapotranspiration(cm	11.89	13.15	12.04	13.76	12.54	11.79	12.69	12.37	13.51	12.64
SEPTEMBER	**Monthly Mean Temperature(^{0}C t_m)**	26.6	27.2	26.2	26.3	26.6	26.7	27.0	27.1	27.1	27.1
	Potential evapotranspiration (cm)	13.09	14.43	12.24	12.52	13.15	13.22	13.55	14.19	14.16	13.92
OCTOBER	**Monthly Mean Temperature(^{0}C t_m)**	27.50	27.40	27.4	26.6	28.4	27.1	27.0	27.3	27.0	28.2
	Potential evapotranspiration (cm)	15.07	15.10	14.81	13.13	17.27	14.09	13.55	14.63	13.94	16.53
NOVEMBER	**Monthly Mean Temperature(^{0}C t_m)**	28.9	28.9	28.9	27.9	29.0	28.6	28.9	29.1	29.1	28.8
	Potential evapotranspiration (cm)	18.84	18.83	18.59	16.03	18.83	17.77	18.23	19.11	19.12	18.09
DECEMBER	**Monthly Mean Temperature(^{0}C t_m)**	28.2	27.6	27.6	27.6	28.3	28.8	28.3	27.7	28.3	28.1
	Potential evapotranspiration (cm)	12.75	16.04	15.28	15.32	17.01	18.31	16.63	15.55	17.00	14.78

4.0 Results

4.1 Trends of Potential Evapotranspiration

The change of potential evapotranspiration during the last decade (Table 2) showing an increasing trend in potential evapotranspiration is the general feature in warri, Delta state, based on the analysis to yearly variation trends of annual and seasonal potential evapotranspiration on climatic comparison between the various periods. Though potential evapotranspiration exhibits similar trends in the last decade with high rates between February and March and lowest rates between July and September, there is small variation between seasons in response to prevailing weather conditions of the year. The graphical monthly potential evapotranspiration for Warri, Delta state of Nigeria, an oil-rich state in Nigeria is shown in Figures 2-12.

The PET seasonality is well accounted for by the dataset obtained from Nigeria meteorological agency Warri, Delta state. Which is in the vicinity of river Niger which is gradually drying out due to climate change and has a high level of potential evapotranspiration for the past ten year? The estimates of monthly potential evapotranspiration ranged from 20.12 cm in July to 10.52 cm in February? In this reverie area, land and water are treasured highly, but because of oil exploration and exploitation activities (onshore) the land-surface and ecology is being degraded.

The extensive degradation contributes to general restiveness in the region with a spiral effect on world crude oil prices. Mismanagement of the hydrological process has negative effects on world economy as highlighted by the several Food and Agricultural Organization (FAO) studies on links between hydrology, agriculture, food security and poverty [15,16]. Although the level of potential evapotranspiration is high, the farmlands are degraded as a result of pollution from oil exploitation activities. This further aggravates socio-politicaltension among the population in the region because crop yield is decreasing and fishing, another important economic sub-sector that supplies fish for nourishment and improved household income is, severely impacted by pollution. Literature on rainfall, runoff and stream flow in addition to biogeochemical hydrology of River Niger is almost absent for this watershed. The PET levels show the seasonality expected since the peak dry season months of February and March had the greatest amounts of potential evapotranspiration (Fig. 2-12) while the peak rainfall months of June, July and August (JJA) had low PET values.

4.2.1 PET graphical representation

The graphical representations of monthly potential evapotranspiration trends for the last decadeusing table 2 are shown below.

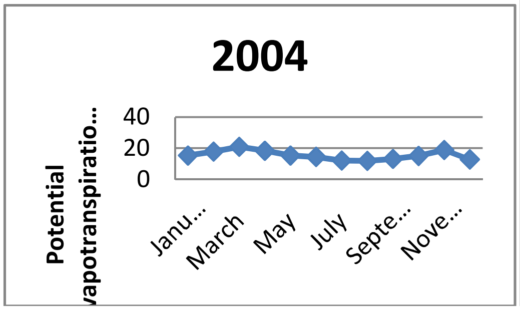


Fig 2: PET trend for 2004

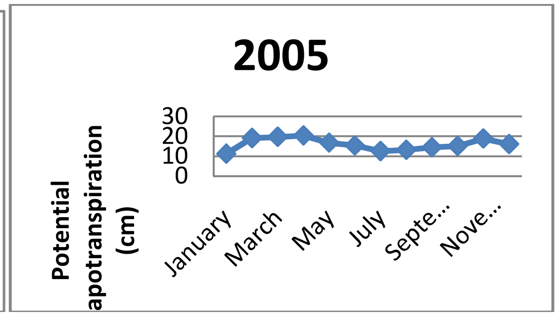


Fig 3: PET trend for 2005.

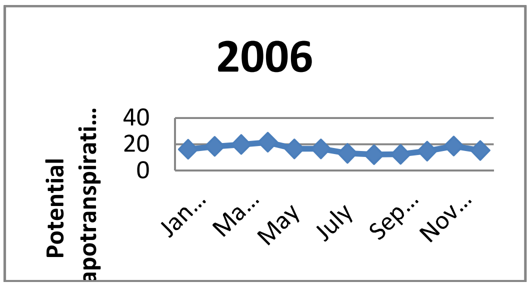


Fig 4: PET trend for 2006.

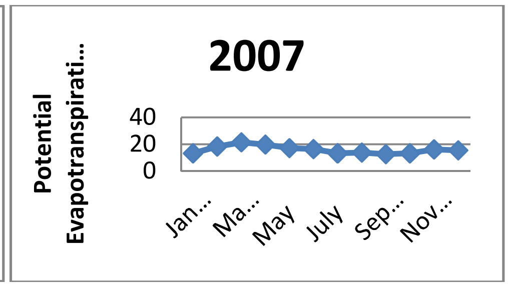


Fig 5: PET trend for 2007.

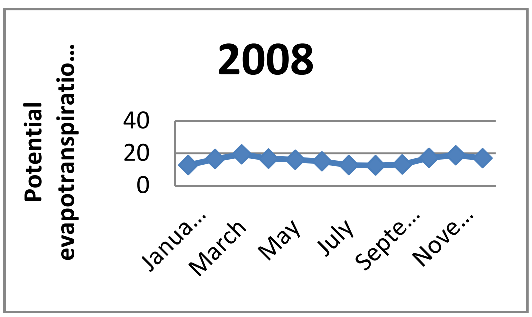


Fig 6: PET trend for 2008.

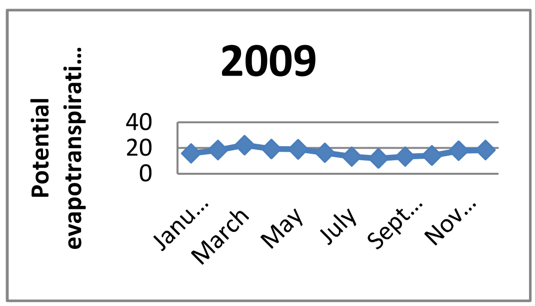


Fig 7: PET trend for 2009.

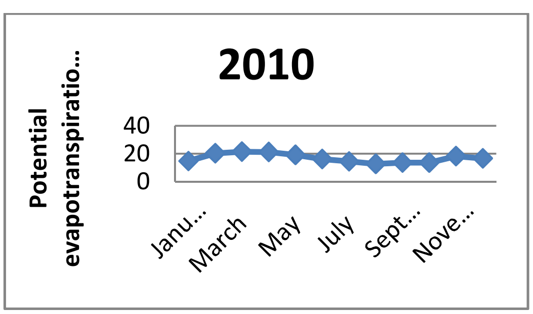


Fig 8: PET trend for 2010.

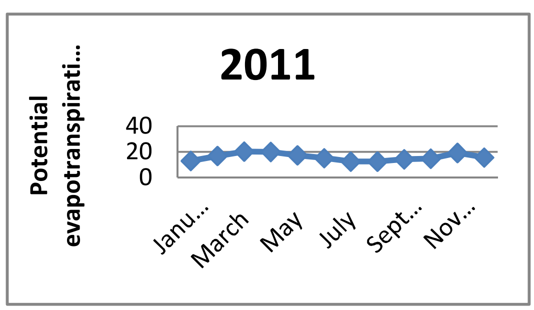
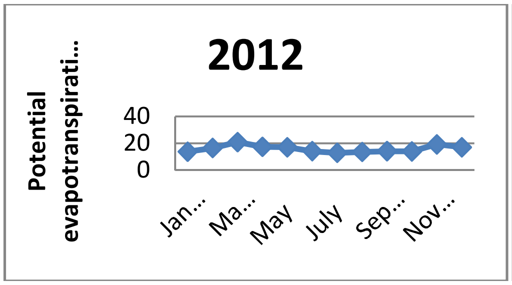


Fig 9: PET trend for 2011.



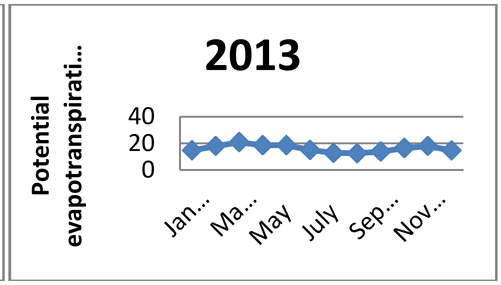


Fig 10: PET trend for 2012. **Fig 11:** PET trend for 2013.

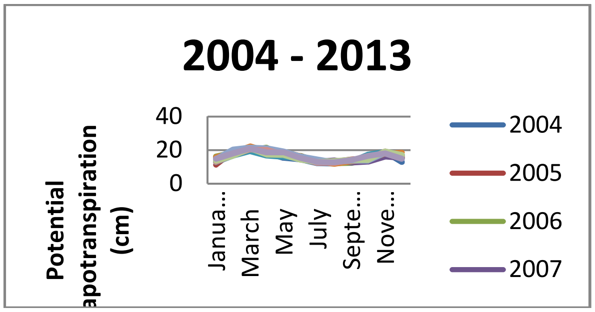


Fig 12: PET trend from (2004-2013)

4.2.2 Graphical Representation of Monthly Mean Temperature

The graphical representation of monthly mean temperature trends for the last decade is represented in figure 13.

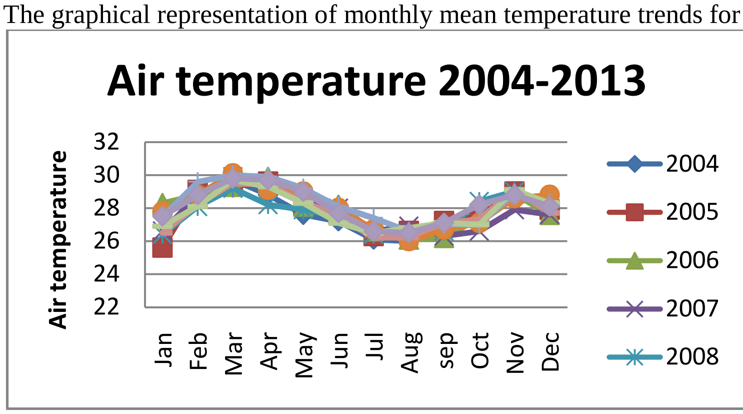


Fig. 13: Mean Monthly Temperature

5.0 Discussion

Land is a critical productive asset, and many livelihoods depend on this asset, in Nigeria, land degradation is a major factor that affects our ability to achieve food security and improve our standard of living Because lands typically have low vegetation cover, they are particularly vulnerable to mismanagement that results in the removal of grasses, bushes and trees exist, exposing the thin layer of fertile topsoil to wind and water erosion [1]. Poorly-managed, intensified land use and deforestation of productive dry lands may result in land which cannot support agriculture. Like in Warri, Delta state, the land-surface is being degraded due to mismanagement and non-adherence to development plans and non-sustainable farming systems. If transparent land tenure reforms are adopted in the sub-region, the hydrological process with benefit in the short and long run.

Increasing temperature and potential evapotranspiration (table 2.) in Warri, Delta state, are impacts of climate change. These bring about either negative or positive ecological impacts in the area. The results are due to differences in climatic conditions and land cover in the area. Rainfall is generally heavier in Warri, Harmattan dry winds blow for 3 to 4 weeks; this brings a considerable drop in relative humidity. Potential evapotranspiration depends on the amount of moisture available in the soil and precipitation. During the dry season, the relative humidity is lower and occur even during the rainy season months of

April to September when the relative humidity should be higher [1] the clouds that normally reduce the amount of solar isolation has more impact in the area. In understanding climate change relationship with water resources, there may be the need for measured and tree-ring-reconstructed stream flow data and ice cores that will inform planners about climate-induced changes in the timing of runoff and the range of climate variability over a period. With the potential evapotranspiration dataset, an ecosystem investigation that tends to understand how plants respond to changes in atmospheric carbon dioxide and how such changes might affect land-use cover and, in turn, the hydrologic system is made possible.

Application of improved potential evapotranspiration estimations in a calibrated hydrological model will demonstrate theadded value of earth observation products for the study of the hydrological cycle. Hydrological processes that determine the exchange of water and energy at the earth's surface, the movement of water in soils, and the processes and pathways linking precipitation to stream flow determine catchment water balances and rainfall-runoff relationships, and hence water resource availability, flood generation and the feedbacks between the earth's surface and the global climate. The result helps agro-meteorologists, agronomists, irrigation engineers and development planners to carry out standard calculations for potential evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes.

Based on the results presented in this study, a number of inferences, conclusions and recommendations for policies can be made. First, Delta state may have to adopt simple policies like returning croplands to forests which will boost potential evapotranspiration levels all over the state and the implementation of sustainable land use concepts for the state environment will require a methodology that is able to quantify the effects on the hydrological processes. Due to population explosion, urban areas are increasing with the natural (permeable) surfaces being replaced by impermeable (man-made) surfaces thereby reducing infiltration and increasing the phenomenon of flooding which is now prevalent across part of Warri urban areas. The farms for food production are located away from the urban areas and since precipitation replaces the moisture removed by potential evapotranspiration from the soil, a regular monitoring of these hydrological processes will yield a means of estimating the amount of water retained in the soil. We had mentioned that the landscape across Warri is changing due to increasing population, development, harvesting of biomass without concrete reforestation policies and efforts. We therefore finally present the PET levels during the "critical hydrological seasons" of March, April, May and June for Warri in (Table 2).

The study of PET will be most beneficial in these southern parts of the country where flooding is becoming rampant and where irrigated agriculture is needed to boost food

production to feed the increasing population as one of the ways of obviating climate change and meeting the United Nations Millennium Development Goals in addition to maintaining the rights of the most vulnerable sector of Deltan's society; the physically challenged, women and children especially those that reside in the rural areas.

6.0 Conclusion

Potential evapotranspiration were estimated for Warri using monthly mean temperature data and because such data has a wide application such as; hydrological model simulations, Water requirement estimation and drought monitor Index can be improved based on the knowledge of potential evapotranspiration. Nigeria and, in particular, Warri in Delta state, the poor have been hit by both food and energy crises. As a consequence, prices for many foods have risen by up to 100% in some cases. As water scarcity is one of the most pressing issues facing humanity today and provision of sufficient water is necessary for human health and poverty reduction, climate change may also add to existing conflicts. The restiveness in Delta state, Warri, of Nigeria, with the spiraling effect on crude oil exploration and exploitation, is also related to management of the environment vis-à-vis the landscape and water resources.

This study analyzed datasets to determine the level of PET for the last decade with a view to enhancing knowledge in the understanding, quantifying and incorporating of hydrological processes. This is done with the aim to providing policy makers and resource managers with information that assist them to make informed decisions on planning and policies related to water resources development. Such information is important given the global phenomenon of climate change which imposes economic, social, and ecological challenges on the community and, to smallholder farmers in particular.

7.0 References

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