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Assessment of Climate Change in West Godavari District of Andhra Pradesh, India Using Water Balance Approach

P. Swarna Latha[1*] and K. Nageswara Rao[2]

[1]Department of Geography, Andhra University, Visakhapatnam-530003(AP), India
[2]Discipline of Geography, School of Sciences, Indira Gandhi National Open University (IGNOU), Maidangarhi, New Delhi-110068 (DL), India
([*]Corresponding author, Email: dr.swarnapisupati@gmail.com)

Abstract

The present research work sought to analyze climatic changes in the West Godavari district of Andhra Pradesh State by utilizing historical climate data spanning 119 years, from 1901 to 2019. During the first five decades of the twentieth century, the average annual temperature in the research region was 27.18°C, whereas the next five decades were 0.46°C warmer than the first. The twenty-first century's first two decades were even warmer, with an average temperature of 28.2°C, 0.56°C higher. During the SW-monsoon season, the maximum average annual rainfall received was 642.6 mm (about 60% of total rainfall). According to the Thornthwaite water balancing approach, the district has a mega thermal type of climate (A′) based on thermal regime classification and a semi-arid (D) kind of climate based on moisture regime classification. Studies on water balance have been shown to be crucial for comprehending the climate change scenario in any place in the context of strategic plans for managing natural resources and fostering economic growth.

Keywords: Climate, Temperature, Rainfall, Water Balance, West Godavari, Andhra Pradesh

Introduction

The United Nations Intergovernmental Panel on Climate Change (IPCC) has warned that continued emissions of greenhouse gases into the atmosphere will result in a 3.5°C rise by the end of the twenty-first century. With present global policies, warming can only be limited to 1.5°C. However, if emissions are decreased by 27% by 2030, warming can be limited to 2 or 2.2°C (IPCC, 2018). This amazing development has the potential to cause significant adjustments in the climate and weather. Climate change has a wide range of consequences, notably for food, water supplies, and human livelihoods. Freshwater extraction rose more than six-fold globally during the previous century and, furthermore, around 65% of the world's river flows and aquatic ecosystems are under moderate to severe threat of deterioration (Vorosmarty *et al.*, 2010; Kahlil *et al.*, 2015). The globe is now confronted with increasingly pressing problems in fighting the impacts of climate change. Changes in rainfall patterns and distribution, intense rains, unexpected floods, severe heat waves and droughts, and other repercussions are already obvious (WMO, 2019). It is very likely to receive heat waves more often and for longer, and extreme precipitation events will become more intense and frequent in many regions. Climate is a very dynamic phenomenon that fluctuates on all time scales: monthly, yearly, decadal *etc*. Over both periods, the warming was slightly greater in the Southern Hemisphere than in the Northern Hemisphere (Jones *et al.*, 1999). Several studies conducted in previous decades have revealed variations in atmospheric temperature and rainfall (Ghosh *et al.*, 2016). The annual and effective growing seasonal rainfall trended upward in the east, downward in the west and virtually unchanged in the central areas of northwestern India (Singh *et al.*, 2018). There is an urgent need to analyze climatic variables, notably temperature and rainfall, in order to estimate the implications of climate change in planning development operations and to overcome water and food scarcity. Litho-stratigraphic research also aids in understanding the tectonic background of the sediments as well as signs of climatic change (Gurav *et al.*, 2021). There are many statistical techniques used for detecting time series trends of various meteorological variables like rainfall and temperature (Mazhar and Rehman, 2019; Alashan, 2020).

India's 1.2 billion people rely heavily on only 4% of the world's water resources for a variety of economic activities, including agriculture, which employs roughly 70% of the country's population. The summer monsoons provide around 4000 cubic kilometers (km^3) of total precipitation and snowfall to India, while the availability of surface and groundwater resources is estimated to be around 1869 km^3. However, the country has abundant water resources, but their distribution is unequal. As a result, the most challenging problem for water resource managers in the near future will be guaranteeing water security in the face of changing ecological, climatic, and demographic factors. Water balance is the

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best way to address the hydrology of a basin or region (Lakhera *et al.*, 2016). Reddy *et al.* (2021) examined the influence of several water balance components on water resources from a local to global scale. For each natural region or water body, the water balance equation gives the relative quantities of input, outflow, and change in water storage (UNESCO, 1970). Thornthwaite (1948) initially systematically created monthly water balance models in the 1940s, and Thornthwaite and Mather (1955) later updated those. Thornthwaite water balance uses average monthly data in a "bookkeeping" style to display a landscape's hydrologic inflows, storages, and outflows; as a result, it provides a simple, unified representation of the overall moisture environment and its seasonal change (Ferguson, 1996). In their study of monthly water balance models, Xu and Singh (1998) concluded that a viable model might be created on multiple time scales and with variable degrees of complexity. The Thornthwaite procedure can be used to calculate actual potential evapotranspiration (PET), soil water deficits, and surpluses (Subrahmanyam, 1956; Silva *et al.*, 2006; Krishnaiah, 2014). Downscaling approaches, climate data availability, PET estimate, baseline period, non-stationary climate information, and anthropogenic forcing can all be additional obstacles to a valid drought assessment under climate change (Mukherjee *et al.*, 2018). Coastal areas all over the world are highly urbanized and are able to accommodate high population densities (UNEP, 2012). These areas are frequently affected by disasters like cyclones, typhoons, hurricanes, and floods, resulting in the loss of agriculture-related economic and livelihood activities. The coastal Andhra plain has a large population, and the region receives enough rainfall during the monsoon and post-monsoon seasons to maintain it (Murthy *et al.*, 2020). Due to unprecedented and erratic rainfall events and non-availability of surface water, groundwater depletion, and salinity problems in coastal regions, they affect developmental activities and the living standards of the population (Jayasankar *et al.*, 2021). Keeping this in mind, the current study was conducted in the West Godavari district of coastal Andhra Pradesh to examine the climate pattern utilizing water balance methodologies and historical data spanning the period 1901-2019.

Study Area

The West Godavari district is situated in the western delta of the River Godavari and lies between latitudes of 16° 15' N to 17° 30' N and longitudes of 80° 50' E to 81° 55' E. The study area covers about 8506 km^2 with a density of 470 people per sq. km and is administratively divided into 48 mandals with four revenue divisions. The population of the study area is about 39,36,966 people (Census, 2011; censusindia.gov.in). The Godavari is the important river flowing in the district and forming the large-scale deltaic plains. The quaternary sediments with recent to sub-recent alluvium formation, mainly unconsolidated to semi-consolidated gravel, sand, silt, and clay, are occupied in the entire area. The delta sediments of the area consist of brown, grey, gravelly sands and silty clay. The thickness of the sediments is gradually increasing towards the sea. Groundwater extraction structures in the study region are mainly open, bore or tube wells. The average depth of the dug well recorded was 7 meters below ground level, whereas the bore well depth ranged from 10 to 65 mbgl. Groundwater development is limited in alluvium and the deeper zones are brackish to saline in nature (CGWB, 2017). The area consists of a large number of aquaculture ponds, lake and coastal backwaters.

Materials and Methods

The meteorological data *i.e.* temperature and rainfall of the study area were obtained primarily from the India Meteorological Department (IMD), while in the case of missing values; the data was gathered from the District Hand Books of Andhra Pradesh. The analysis was carried out using the collected data for the period from 1901 to 2019. For calculating statistical measures, tabulation, and analysis, Microsoft Excel (2016) and SPSS 20.0 software were used. Monthly, seasonal, annual and decadal temperature and rainfall analyses were performed in order to find out the climatic variations of the study area. For the purpose of analysis, the last nine-year period from 2011–2019 was considered a decade. Water balance techniques were used to estimate the temperature, rainfall situation, and climatic types within the study area. The hydrology of a region can be approached through the water balance for the best planning administrative units for water resources assessment (Lakhera *et al.*, 2016; Kansara and Lakshmi, 2021). An average monthly water balance was calculated using the standard procedure of Thornthwaite and Mather (1955). The comparison of monthly precipitation with evapotranspiration facilitates obtaining other related water balance parameters, namely water surplus (WS), water deficit (WD), and soil moisture storage. Further, these parameters are used to derive important climatic indices like the index of aridity (Ia), the index of humidity (Ih), and the index of moisture (Im). The Thornthwaite expression for the Im is presented below:

$$Im = Ih - Ia \text{ (all units are expressed in mm)}$$

Where, Ih is the percentage ratio of the annual water surplus (WS) and the annual water need PE; and Ia is the percentage ratio of the annual water deficit (WD) and the annual water need PE.

Ih and Ia are calculated as:

$$Ih = \frac{\text{WS}}{(\text{PE})} \times 100$$

$$Ia = \frac{\text{WD}}{(\text{PE})} \times 100$$

Ih and Ia indicate the wetness or dryness of a region (Table 1). Positive values of the moisture index (Im) indicate moist climates, whereas negative values indicate dry climates, and a moisture index value of zero separates the dry and moist climates.

Results and Discussion

Temperature Trends

The average annual temperature (AAT) was noted at 27.8°C during the study period of 1901–2019. The AAT noted a maximum of 32.5°C in May and a minimum of 23.6°C in January during the study period. The ten-year average temperature in different decades from 1901 to 2019 is given in Table 2. From the table, it was observed that the maximum decadal temperature was recorded at the same 28.2°C during 2001–10 and 2011–19, followed by 27.9°C (1991–2000) and 27.8°C (1981–91). The minimum average annual decadal temperature noted was 27.1°C during the decades of 1901–10 and 1931–40. The decadal mean annual temperature analysis reveals that an overall increasing trend in temperature was observed throughout the study area. There has been a 1.1°C increase

Table 1: Classification based on thermal and moisture regimes (*After,* Thornthwaite and Mather, 1955)

Thermal Regime Classification	Annual PE (mm)	Climatic type	Symbol
	Above 1140	Megathermal	A'
	997 to 1140 855 to 997 427 to 855 570 to 427	Mesothermal	B'4 B'3 B'2 B'1
	427 to 570 285 to 427	Microthermal	C'2 C'1
	142 to 285	Tundra	D'
	Below 142	Frost	E'
Moisture Regime Classification	Moisture Index (Im%)	Climatic type	Symbol
Humid Climates (Im>0)	100 and above	Per-humid	A
	80 to 100 60 to 80 40 to 60 20 to 40	Humid	B_4 B_3 B_2 B_1
	0 to 20	Moist sub-humid	C_2
Dry Climates (Im<0)	0 to -33.3	Dry sub-humid	C1
	-33.3 to -66.7	Semi-arid	D
	-66.7 to -100	Arid	E

in the average annual temperature during the last twelve decades. Almost similar temperatures were recorded during the hot weather and the south-west monsoon seasons (Fig.1). Overall, four seasons showed a constantly increasing trend in the study area. A considerable increase in temperature has been observed during the second half of the twentieth century and early twenty-first century. The average annual temperature of the study area during the first five decades of the twentieth century was 27.18°C, while the following five decades were 0.46°C warmer than the first half. The two decades of the twenty-first century were even warmer, with an average temperature of 28.2°C, a difference of 0.56°C. It can be concluded that the whole study area has witnessed a noticeable warming in the decadal temperatures during different seasons.

Rainfall Trends

The long-term average annual rainfall (AAR) noted was 976 mm during the study period of 1901–2019. The maximum and minimum rainfall received were 186 mm and 3 mm in the months of June and January, respectively. The ten-year average rainfall in different decades from 1901 to 2019 is given in Table 2. From the table, it was observed that the maximum decadal rainfall recorded was 1131.3 mm during 2001–10, followed by 1109 mm (1991–2000) and 1063.3 mm (1931–40). The minimum decadal rainfall recorded was 933.1 mm in 1901-10, followed by 1009.8 mm in 1921-30 and 1015.2 mm in 1911-21. At the beginning of the twentieth century, the study area received around 75.4 mm more rainfall than the initial decade (1901–10) (933.1 mm) and it increased to 136.2 mm of rainfall (1999–2000) during the later century. The first two decades of the 21st century have witnessed an average rainfall of 1078.8 mm with an increase of 69 mm. The highest AAR recorded was 642.6 mm (61.5% of total rainfall) during the SW-monsoon season, followed by 320.3 mm (30.6%) in the NE-monsoon, 6.5% in the hot weather, and only 1.4% in the winter. During the twelve decades, a fluctuating trend was observed throughout the study area.

Climate Scenario: Water Balance

The water balance is the equilibrium between the water intake from precipitation and the water outflow from evapotranspiration (Thornthwaite and Mather, 1955). Table 3 displays the monthly results of the normal year's water balance elements for the research region. The study region gets a total of 1758 mm of yearly potential evapotranspiration (PE), with the peak being 190 mm in May and the lowest being 101 mm in December. During the same months, rainfall was 42 mm and 12 mm, and temperatures were 32.5 °C and 23.7 °C, respectively. According to the results, the average annual rainfall of 976 mm recorded during a normal year means the supply of water in the form of precipitation (P) is less than the supply of water in the form of PE. Rainfall only reaches PE during the monsoon season, when it receives more than 70% of the rainfall in the study area. The monsoon season's extra rainfall is sufficient to recharge the soil moisture store.

Climate Categories: Thermal Regime Classification

The thermal regime and the moisture regime were computed to categorize the climatic patterns. The thermal regime is based on potential evapotranspiration and the moisture regime is based on moisture status. The thermal regime classification of the present study is presented in Table 4. Based on the classification, the study area comes under the Megathermal (A') type of climate with an annual thermal efficiency of more than 1758 mm.

Table 2: Decadal average temperature (°C) and rainfall (mm) during 1901-2019 in the study area

Year	Winter		Hot-weather		SW-monsoon		NE-monsoon		Annual	
	Temp. (°C)	Rainfall (mm)	Temp. (°C)	Rainfall (mm)	Temp. (°C)	Rainfall (mm)	Temp. (°C)	Rainfall (mm)	Temp. (°C)	Rainfall (mm)
1901-1910	24.2	14.6	29.7	63.8	29.2	607.8	25.2	246.9	27.1	933.1
1911-1920	24.2	13.3	29.7	70.9	29.3	611.0	25.6	320.1	27.2	1015.2
1921-1930	24.3	13.9	30.1	67.9	29.5	592.1	25.3	335.8	27.3	1009.8
1931-1940	24.2	19.8	29.7	73.3	29.2	597.8	25.3	372.5	27.1	1063.3
1941-1950	24.2	12.6	30.0	68.1	29.3	593.7	25.4	346.7	27.2	1021.0
1951-1960	24.6	7.0	30.3	59.1	29.4	705.9	25.5	299.2	27.5	1071.2
1961-1970	24.5	13.6	30.3	67.9	29.3	673.3	25.5	306.7	27.4	1061.5
1971-1980	24.6	12.2	30.6	63.6	29.6	617.5	25.8	353.7	27.6	1047.0
1981-1990	24.9	25.1	30.6	74.7	29.7	677.7	25.9	280.2	27.8	1057.6
1991-2000	24.9	18.4	30.6	60.6	29.8	674.6	26.1	355.3	27.9	1109.0
2001-2010	25.4	13.9	31.0	74.2	30.0	669.4	26.5	373.8	28.2	1131.3
2011-2019	25.3	15.0	31.0	68.4	30.0	690.8	26.7	252.2	28.2	1026.4

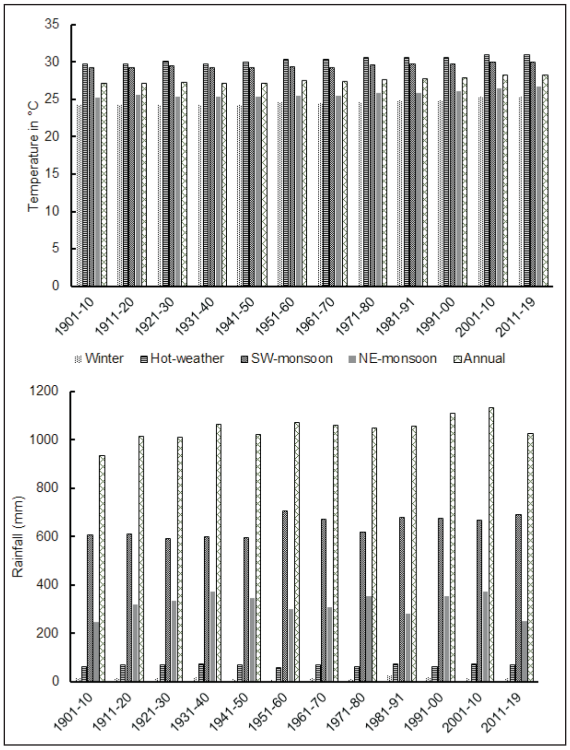

Fig.1. Decadal annual average temperature and rainfall variations in the study area (1901-2019)

Moisture Regime Classification

The state of the moisture conditions in the research region was evaluated based on the categorization. The indices, particularly the Index of Aridity (Ia) and the Index of Humidity (Ih), are derivatives of the water deficit and surplus. According to the data, just 13 years out of 119 fall under a dry, sub-humid environment, with the remaining years falling under a semi-arid climate. The decadal average moisture index results of the study area are presented in Table 4. The Im (%) ranges from-51.26 (1901-10) to-41.35 (1961-70), indicating that the studied region experienced a semi-arid (D) climate and supports steppe vegetation. The sub-moisture regime classification was used to estimate seasonal variations in wet or dry conditions throughout the year. The minimum and maximum indexes of humidity (%) recorded in the study area were 1.37 (1921–30) and 29.54 (2000–10), respectively. The data shows that six decades had little or no water surplus (d), two had a moderate winter/summer surplus, and the final three decades, combined with the decade 1961-1970, had a large winter/summer water surplus (Fig. 2). Overall, the moisture regime subcategory categorization and the humidity index of the historical analysis suggest that the research region belongs within the 'd', group, with little or no water excess.

With nine coastal districts and a long 972 km coastline, Andhra Pradesh is particularly prone to cyclones, which cause major property damage and fatalities. The study area, West Godavari district is a part of sensitive coastal zones, where temperature, rainfall, air pressure, etc. are the main elements increasing vulnerability in the coastal zone. Today's frequent cyclones and other instances of intense rainfall along with extreme heat conditions cause a 50–100% loss in agricultural output. It not only affects crops but also aquaculture output, which is at risk of losing 20-40% of its production. Cyclones in brackish water and high temperatures in freshwater regions are the next biggest risks in the area (Muralidhar *et al.*, 2013). Reduced precipitation and changing rainfall pattern along with extreme heat conditions and

Table 3: Normal year water balance elements of the study area for the period of 1901-2019

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T	23.6	25.3	27.6	30.2	32.5	31.4	29.1	28.7	28.6	27.6	25.4	23.7
PE	102	106	148	168	193	186	175	167	156	145	111	101
P	3	7	6	15	42	117	186	171	175	161	81	12
P-PE	-99	-99	-142	-153	-151	-69	11	4	19	16	-30	-89
Acc P WL	-609	-708	-850	-1003	-1154	-1223				-391	-421	-510
ST	21	14	8	4	2	2	11	4	19	52	46	32
ΔST	-11	-7	-6	-4	-2	0	9	-7	15	33	-6	-14
AE = (P+ΔST)	14	14	12	19	44	117	175	167	156	145	87	26
WD = (PE-AE)	88	92	136	149	149	69	0	0	0	0	24	75
WS	0	0	0	0	0	0	0	0	0	0	0	0

(All values are expressed in mm; T: Mean Air Temperature; PE: Potential Evapotranspiration; P: Precipitation; Acc P WL: Accumulated Potential Water Loss; ST: Storage; ΔST: Change in Soil Moisture; AE: Actual Potential Evapotranspiration; WD: Water Deficit; WS: Water Surplus)

Table 4: Sub-category classification of moisture regime (Thornthwaite and Mather, 1955) showing decadal difference in the study area

Year	Moisture Index (%)	Type of Climate	Humidity Index (%)	Type of Climate	Symbol
1901-1910	-51.26	Semi-arid (D)	5.3	Little or no water surplus	d
1911-1920	-45.94		7.5		
1921-1930	-50.78		1.4		
1931-1940	-42.37		3.2		
1941-1950	-44.59		15.9	Moderate winter/summer surplus	s/w
1951-1960	-45.70		4.1	Little or no water surplus	d
1961-1970	-41.35		25.4	Large winter /summer water surplus	s_2/w_2
1971-1980	-46.49		5.9	Little or no water surplus	d
1981-1990	-46.88		17.3	Moderate winter/summer surplus	s/w
1991-2000	-43.47		24.8	Large winter /summer water surplus	s_2/w_2
2001-2010	-42.37		29.5		
2011-2019	-42.70		23.6		

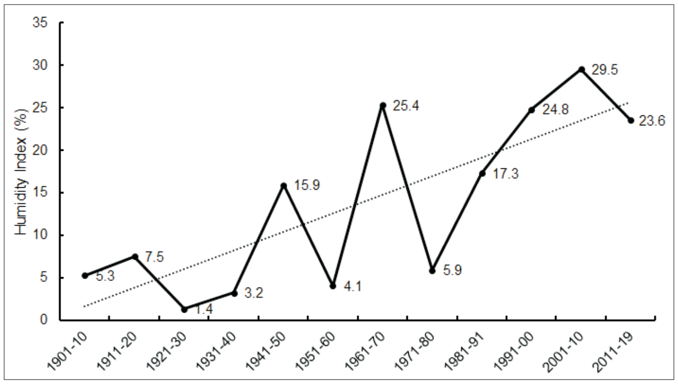

Fig.2. Sub-category classification of moisture regime showing decadal difference in the study area.

drought have an impact on the availability of potable water, contaminating water sources, and diseases, among other things. The susceptibility is caused by anthropogenic and natural factors such as population shifts, overcrowding, poor sanitation and hygiene, floods, and other climate disasters (Basheer *et al.*, 2019). The IPCC report (2014) states that a number of variables such as social and climatic changes, adaptation strategies and mitigation efforts, result in an overall risk or possible repercussions when combined. For in-depth understanding of how different climate change scenarios will effect agriculture and industry, taking into account both transitional and physical dangers and possibilities, scientific analyses and studies must be conducted.

Conclusions

A detailed investigation of historical data records for a period of 119 years during the 20th and 21st centuries was carried out to identify the variability in rainfall and temperature on annual, decadal, and seasonal scales in the West Godavari district region of Andhra Pradesh state, India. Water balance studies were also carried out, and climatic types were evaluated in order to better understand the impact of climate change on the research region. The investigation yielded the following significant findings: According to temperature data, the study region receives the highest temperature in May (32.5 °C) and the lowest temperature in January (23.6 °C). The temperature rise becomes noticeable as we approach the twenty-first century. Warmer temperatures were observed in the second half of the twentieth century compared to the first. The long-term average yearly temperature increased by 1.1 degrees Celsius, with 0.08 degrees Celsius in the first half of the twentieth century, 0.46 degrees Celsius in the latter half of the twentieth century, and 0.56 degrees Celsius in the first half of the twenty-first century. Rainfall statistics show that the largest quantity of about 92% of total rainfall occurred during the SW-monsoon and NE-seasons. The second part of the twentieth century saw significantly increased rainfall, with a number of decades seeing more than the long-term average. The research location has a megathermal (A) climate with an annual thermal efficiency of above 1758 mm. During the hot-weather season, the region experiences increased thermal efficiency. According to the moisture regime research, only 13 years out of 119 fall under a dry sub-humid environment, while the rest fall under a semi-arid climate (D). Water balance investigations have revealed that the research region falls into the "d" category, with little or no water surplus. Understanding climate change scenarios is critical for developing development plans for sustainable natural resource management. This study would be useful in understanding precipitation and temperature patterns, as well as in policy planning and development, particularly in agriculture and related activities. It can also assist disaster management and other regional stakeholders with coastal planning and development operations.

Authors' Contributions

P. Swarna Latha: Conceptualization, Data Curation, Formal Analysis, Original Draft Preparation, Writing-Reviewing and Editing. **K. Nageswara Rao**: Formal Analysis, Reviewing and Editing.

Conflict of Interest

Authors declare no conflict of interest.

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