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Assessment of groundwater quality and climatic water balance studies in the Pageru River basin, Andhra Pradesh, India

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Abstract An analysis of the climatic water balance and drought in the Pageru River basin, a chronically drought prone area in south India, has been prepared using rainfall data from eight raingauge stations located in and around the basin. The values of rainfall and temperature have been collected and the water balance parameters have been computed using the Thornthwaite and Mather method. In addition, 99 water samples were collected during both pre- and post-monsoon seasons and analysed for major ions to assess the water quality in relation to agriculture and domestic uses in the basin. The results indicate that the annual water deficit of the basin is 821 mm. The maximum water deficit is observed during the months of March and June and it is minimal in September. The analysis of the data revealed that the annual distribution is mainly controlled by the physiography of the region. A comparison of the water balance and cropping pattern used in the villages indicates that the basin area is only suitable for cultivation of drought resistant crops such as *Sorghum bicolor*, *Eleusine coracana* and *Pennisetum typhoides*. Assessment of water samples from various methods proved that most of the water is good for drinking as well as for agriculture in both seasons.

Key words climate; crops; drought; groundwater quality; Pageru River basin, India; water balance

INTRODUCTION

The Pageru River basin is situated in the drought prone Rayalaseema region, Andhra Pradesh, India. The river is ephemeral and originates from the Seshachalam range of hills (maximum elevation 449 m) in the western part of the study area. Groundwater has become an important source of water and has an important role in the development of industry and agriculture and for domestic purposes. There are no assured sources of surface water for irrigation such as major and medium irrigation projects. The mainstay of the people living in district is agriculture. The total area of the basin is 480 km^2 and is located on the Survey of India 1:50 000 toposheet numbers 57 J/6, J/7, J/10 and J/11. The basin area lies between latitudes 14°39′04″ and 14° 39′51″N, and longitudes 78°19′12″ and 78°41′32″E.

CLIMATE

The general climate of Pageru River basin is semiarid in nature. The temperature gradually rises from January and reaches its maximum in the month of April, then decreases gradually from May and reaches a minimum in the month of December.

The Pageru River basin receives an average annual rainfall of 580.79 mm with significant seasonal variations. Usually the region receives its first rainfall of the year from pre-monsoonal convectional showers in May; however, its occurrence is erratic. The intensity and amount of rainfall is unpredictable during the southwest monsoon period (June to September). In fact, the highest rainfall occurs in the basin during the northeast monsoon period (October and November). The period between January and May is the main dry season; some rain may occur due to convection or winter cyclonic disturbances.

METHODOLOGY

The water balance parameters have been computed on the basis of the book-keeping procedures of Thornthwaite & Mather (1955). Data from the eight raingauge stations: Cuddapah, Gangireddipalli, Vempalle, Pulivendla, Jammalamadugu, Muddanur, Yerraguntla and Kamalapuram (Table 1), in and around the Pageru River basin were collected and analysed to compute the water balance parameters. The field capacity or water-holding capacity of the basin is defined as 200 mm based on the soil texture and type of vegetation. The potential evapotranspiration (*PE*) is calculated from the mean monthly temperature data collected. Using precipitation and potential evapotranspiration data, the actual evapotranspiration (*AE*), water deficit (*WD*), and water surplus (*WS*) were computed. The index of moisture (*Im*), index of aridity (*Ia*), index of humidity (*Ih*), and index of moisture adequacy (*Ima*) were also calculated to determine the climate of the basin. Water balance graphs were prepared for each station.

Water sampling was performed in accordance with the standard procedures given by international standard methods. Ninety-nine samples were collected in the basin in January 1997 and subsequently in June 1997. Both post- and pre-monsoon water samples were analysed.

Table 1 Rainfall statistical parameters of Pageru River basin (mm).

Station / Period	Yearly mean	Std	Coeff. variation	Lowest value	Year	Highest value	Year	Rainfall ratio
Cuddapah 1901–1995	737.5	201.5	27.3	299.1	1904	1226.3	1903	126.1
Gangireddipalle 1981–1995	417.4	181.2	43.4	138.6	1984	710.9	1989	137.1
Vempalle 1931–1995	613.1	155.9	25.4	349.5	1934	888.8	1947	90.0
Pulivendla 1901–1995	591.4	192.9	32.6	300.6	1980	1286.6	1977	166.7
Jammalamadugu 1901–1995	604.2	147.7	24.4	347.1	1942	958.1	1916	99.7
Muddanur 1981–1995	452.9	125.3	27.7	229.4	1994	662.6	1988	95.7
Yerraguntla 1987–1995	600.7	131.0	21.8	406.7	1994	787.0	1990	63.3
Kamalapuram 1891–1995	629.1	217.5	34.6	272.9	1971	1565.5	1958	207.3

WATER BALANCE ELEMENTS

Rainfall data for 105 years (1891–1995) from the Kamalapuram station, which is within the basin area, has been used to compute yearly water balance parameters, while for the remaining seven stations, monthly averages were used to compute the water balance parameters of the region.

Analysis of the rainfall data also revealed that the annual distribution is mainly controlled by the physiography of the region. The distribution of rainfall is high at the central and western parts and decreases towards the eastern, northern, and southern parts of the basin.

The *PE* was computed using the Thornthwaite (1948) formula based on the temperature data. The average annual *PE* of all the stations was computed as 1810 mm. The monthly *PE* is high with 200 mm in May, and a low of 88 mm in December. In general, the water needs of the basin are uniform except in the hilly terrain, which receives very low amounts of water when compared to the plain regions. It was observed that the monthly *PE* gradually increases from January onwards and reaches a maximum in May and decreases gradually from June and reaches a minimum in December.

The computed annual *AE* values indicate that the maximum (989 mm) occurs at Cuddapah, and the minimum (571 mm) at Gangireddipalli. The average annual *AE* value at Kamalapuram station is 789 mm. The annual range of *AE* is large, from 1334 mm in 1985 to only 274 mm in 1971.

The amount of water by which the *AE* and the *PE* differ in any month is the *WD*. The values of annual *WD* of the eight stations in and around the basin reveal that all the stations have *WD* of more than 821 mm year^{-1}. An average annual *WD* of 1021 mm was estimated for Kamalapuram station. It ranged from as high as 1536 mm in 1971 to as low as 476 mm in 1985. The computed monthly values for all the stations, show that the maximum *WD* occurs during the months of March and June and its minimum is in September.

WS is the excess of precipitation after the soil moisture reaches its maximum field capacity of 200 mm for the basin. The analysis reveals that at all the stations there is no *WS* in any of the months. The annual *WS* values for Kamalapuram station reveal that out of 46 years, 1950–1995, in only 11 years did the region enjoy a water surplus. The highest *WS* of 392 mm occurred in 1958 and the lowest surplus, 2 mm, in 1981. It was also found that there was no WS during a 35-year period (Table 2).

Table 2 Water balance parameters of the Pageru River basin.

Station name	*PE*	*AE*	*WD*	*WS*	*Ia*%	*Ih*%	*Im*%	*Ima*%
Cuddapah	1810	989	821	0	45.36	0	–45.36	54.64
Gangireddipalle	1810	571	1239	0	68.45	0	–68.45	31.55
Vempalle	1810	776	1034	0	57.13	0	–57.13	42.87
Pulivendla	1810	763	1047	0	57.85	0	–57.85	42.15
Jammalamadugu	1810	805	1005	0	55.53	0	–55.53	44.47
Muddanur	1810	625	1185	0	65.47	0	–65.47	34.53
Yerraguntla	1810	764	1046	0	57.79	0	–57.79	42.21
Kamalapuram	1810	789	1021	0	56.41	0	–56.41	43.59

INDICES DERIVED FROM WATER BALANCE STUDIES

The aridity index (*Ia*) was computed from the *WD* by comparing it with *PE* (Table 2). It is the percentage ratio of *WD* and the water requirement. The annual average aridity indices calculated for all the eight stations reveal that the values are more than 55% with a maximum of 68.45% at Gangireddipalli. The highest aridity index of 84.86% occurred in 1971 indicating the severity of drought in the basin. The lowest aridity index (36.91%) occurred in 1956 indicating a less intensive drought.

Another important derivative element determined from the *WS* is an index of humidity (*Ih*). It is the percentage ratio of *WS* to the water need. This parameter helps to define the climate of the region as "moist" or "dry". The computed values show that the index of humidity is zero for the entire basin. Clearly the basin has a dry climate. The analysis of 46-years of data from Kamalapuram reveals that the index of humidity is zero for 36 years. The highest value of *Ih* (21.66) occurred in 1958 indicating the maximum *WS* year during the study period.

The moisture index (*Im*) is derived from the difference between the index of humidity and the aridity index (*Ih* – *Ia*). The index of moisture values are all negative indicating the high values of *Ia* for all eight stations. The annual analysis of 46 years of data from Kamalapuram show that the *Im* values are all negative, ranging from –81.86 in 1971 to –17.57 in 1958.

WATER BALANCE AND DROUGHTS

The agriculture potential of any region depends on the availability of water during different crop growth periods. The availability of water for plant growth (amount and timing) can be accurately estimated through water balance studies of the region. The water balance is not only a handy technique for determining the moisture status of the soil in a particular region, but also helps in assessing the drought conditions and their severity. The annual climatic water balance is used to determine the drought years and their severity in the basin.

Among water balance indices, *Ia* is the most suitable parameter for the analytical study of drought conditions with special reference to their frequency. An analysis of droughts and their intensity was made from the percentage departures of *Ia* from the median value. Categorization of droughts was done by following the standard deviation technique employed by Subrahmanyam *et al.* (1965) (Table 3).

Applying this taxonomic system, the drought years at Kamalapuram station during the 46 years (1950–1995) were classified (Fig. 1). The percentage departure of *Ia* from

Table 3 Categorization of droughts.

Departure of the *Ia* from the median value	Drought intensity
$<1½\ \sigma$	Moderate
$½\sigma$ to σ	Large
σ to 2σ	Severe
$>2\sigma$	Disastrous

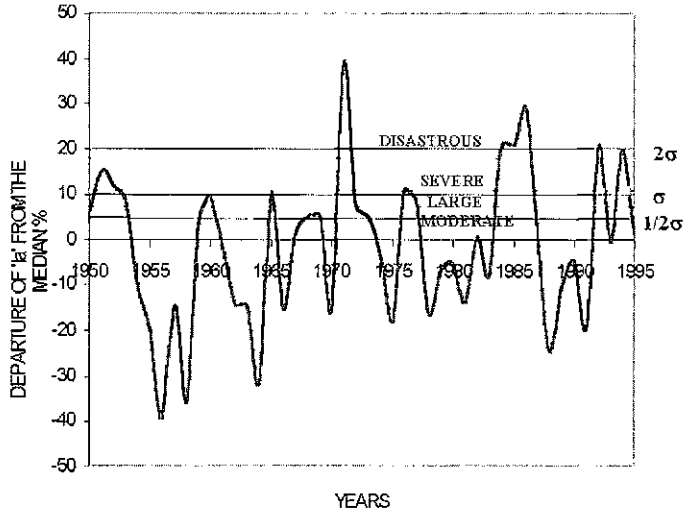

Fig. 1 Droughts of Kamalapuram.

the median value shows considerable variation in drought conditions prevail in the basin. During the study period, the basin experienced 24 drought years, of which seven years were moderate, eight were large, four were severe, and five years were disastrous. This type of analysis of drought intensity is helpful to evolve a better drought management system in the basin. However, the present study is expected to serve as an initial step in opening a new field of research in drought climatology, i.e. from the water balance angle.

WATER BALANCE AND CLIMATIC SHIFTS

The water balance of any region is not stable over of time. Study of climatic shifts due to changes in the moisture regime of the climate and their periodicities is another important aspect of drought climatology. Hence, it is necessary to study the variation in *Im* for certain consecutive years to understand the shifts in the climate to a "wetter" or "drier" condition. This aspect is of great practical value in long-term economic planning.

The 46-year series of *Im* values calculated for Kamalapuram were plotted to understand the climatic shifts of the basin (Fig. 2). The years of wetness and dryness were identified based on the Thornthwaite classification of climates.

The study has revealed that the climate of the river basin is arid to semiarid type as most of the negative values of *Im* fall under the two categories. However, on two occasions during the study period the climate has shown a shift to the dry sub-humid category and has shown a tendency to shift negatively towards a high-dry category. Though climatic shifts are temporary such a study helps understanding of the extremes of climate, which may result in severe flood or drought, depending upon the intensity and duration of water surplus or deficiency.

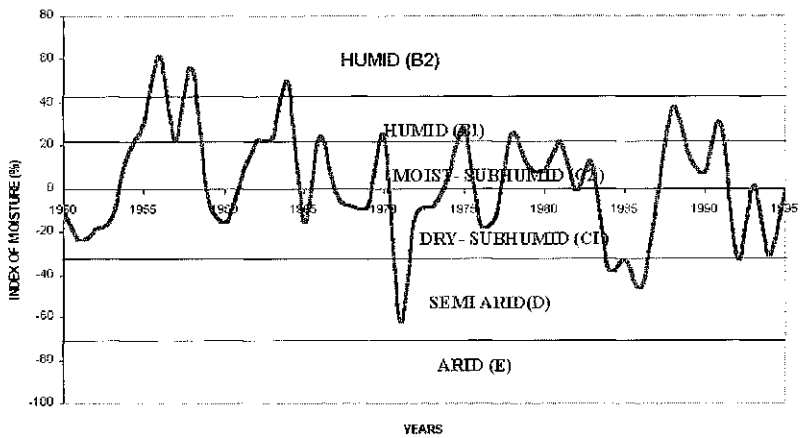

Fig. 2 Climatic shifts at Kamalapuram.

WATER BALANCE AND AGRICULTURE

Agricultural planning of any region, but especially in low rainfall areas, requires a sound knowledge of the local climatology, as the climate determines much of its agricultural potential. The suitability of a region for agricultural development can be clearly assessed with the Index of Moisture Adequacy (*Ima*), another important derivative element in a water balance study.

Ima is the percentage ratio of the *AE* to *PE*. Based on the percentage of moisture adequacy values, the suitability of crops that can be grown successfully in the absence of supplemental irrigation are given by Subrahmanyam *et al.* (1963) (Table 4).

Ima values of the eight stations vary from 32 to 55%. The analysis of the 46-years of data at Kamalapuram station, also reveals that *Ima* values ranged from 15% in 1971 to 63% in 1956. In most years the *Ima* values are less than 40% indicating the poor moisture status for agriculture in the basin.

A comparison of water balance and cropping pattern adopted in the villages indicates that the basin area is only suitable for cultivation of drought resistant crops, such as *Sorghum bicolor*, *Eleusine coracana*, *Pennisetum typhoides*, etc. However, the crops grown in the villages include wet crops, such as *Oryza sativa*, *Arachis hypogea*, etc., with exploitation of groundwater for irrigation countering the dry moisture conditions of the basin. For cultivation of wet crops, such as *Oryza sativa* and *Arachis*

Table 4 Moisture adequacy and suitability of crops.

Index of moisture adequacy percentage (*Ima*)	Crop suitability
80–100	*Oryza sativa* (high yields)
60–80	*Oryza sativa* (low yields)
<60	*Oryza sativa* (uneconomical)
40–60	Millets
20–40	Drought resistant crops
<20	Unsuitable for irrigation

hypogea, supplemental irrigation is absolutely necessary to improve the agricultural potential and obtain maximum yields. Hence, the quantity of groundwater extracted from the wells is more than the annual recharge in the basin area. If this trend continues, there is every possibility of complete depletion of groundwater. It is, therefore, essential to restrict the extraction of groundwater to a specific limit in the basin while promoting methods to increase recharge.

GROUNDWATER QUALITY

The geochemical characteristics of the water samples reveal seasonal variations. The values of TDS estimated by the residue evaporation method range 328–1878 mg l^{-1} with a mean of 842 mg l^{-1} for post-monsoon, while the pre-monsoon water samples range 122–1647 mg l^{-1} with a mean of 599 mg l^{-1}. Likewise specific conductance varies from 624 to 3442 µmhos cm^{-1} at 25°C for post-monsoon, and from 235 to 2840 µmhos cm^{-1}, with a mean of 1001 µmhos cm^{-1} at 25°C for pre-monsoon samples. In post-monsoon water samples the hydrogen ion concentration (pH) varied from 8.3 to 9.0 with a mean of 8.53, and in the pre-monsoon samples it varied from 8.3 to 8.9 with a mean of 8.54, indicating their alkaline nature.

Percent sodium is a parameter computed to evaluate irrigation water quality (Wilcox, 1948). In the post-monsoon water samples, the percent sodium varied from 6 to 96% with a mean of 49.73%; where as in the pre-monsoon samples, it varied from 11 to 92% with a mean of 53.81%.

In post-monsoon water samples, the sodium absorption ratio (SAR) varied from 0.7766 to 25.9029 with a mean of 4.63; while in the pre-monsoon samples, it varied from 0.2604 to 16.2422 with a mean of 4.35.

In post-monsoon water samples, the residual sodium carbonate (RSC) varied between 0 and 11.5930 with a mean of 3.49; while in the pre-monsoon samples, it varied from 0 to 9.1110 with a mean of 2.49.

CONCLUSIONS

The computation and analysis of the climatic water balance indicates that the annual *WD* of the basin is 821 mm. The maximum *WD* is observed during March and June, and its minimum occurs in September. The analysis also revealed that there is no *WS* in any of the months. The *Ia* values show that drought conditions prevail in the basin area. During the study period the basin experienced 24 drought years with different severities. The climatic water balance study also demonstrated that the climate of the river basin is arid to semiarid type. The *Ima* values indicate the poor moisture status for agricultural development in the basin. Based on the water balance parameters, the area of the basin is only suitable for cultivation of drought crops, such as *Sorghum bicolor*, *Eleusine coracana*, *Pennisetum typhoides*, etc. However, with the exploitation of groundwater the farmers are cultivating both wet and dry crops. This reveals that the quantity of extraction of groundwater from the wells is more than the annual recharge of the basin area.

The geochemical characteristics of the water samples reveal slight seasonal variations. The waters of the region are generally alkaline. The majority of the groundwater samples in the study area showed that it is useful for drinking and irrigation purposes.

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