CHAPTER IV

WATER BALANCE STUDIES
After the thorough examination of rainfall analysis in the previous chapter it is essential to find out the part played by evaporation and transpiration from the climatic point of view to assess the net amount of water available in the district. Hence in the present chapter water balance studies are carried out as adopted by Thornthwaite (1955).

The term 'Water balance' or 'Water budget' has recently gained much popularity among climatologists, geographers, geologists, hydrologists and the other concerned studies to achieve efficient management of water for the increased crop production especially in dry lands of the semi-arid tropics which are well supplied with radiant energy. So the study about them is important to characterise the variations of temporal availability of water for crop production. It is the quantitative evaluation of water deficiency or the balance between the income of water from precipitation and the outflow of water by evapotranspiration resulting in change of soil moisture and run-off. It is climatic balance since the quantities of precipitation and evapotranspiration are active factors of climate. Water balance studies can contribute significantly to the study of such needed parameters as soil moisture, water deficit, water surplus and run-off. The basic elements of this concept are the water supply of a region
primarily through precipitation and the water loss due to evaporation and evapotranspiration. A knowledge of these parameters is necessary in evaluating risks to dependable crop production in dry land areas and in developing strategies for increasing and stabilising crop production. Rainfall as the primary source of water and its return to the atmosphere by the process of evaporation and transpiration plays a vital role in hydrological cycle. Evapotranspiration is the combined loss of water vapour to the atmosphere in the form of evaporation from the soil and water surfaces and transpiration from vegetation. Both precipitation and potential evapotranspiration play a significant role in agriculture and for the development of water resources of a place. The former one, namely, the precipitation is widely measured at raingauge stations and the later evapotranspiration is rather a difficult problem to do since it depends upon the number of factors like soil moisture, nature and properties of soil and vegetation, air temperature, air humidity and the like. On the other hand, potential evapotranspiration (PE) or the water-need is defined as the total amount of water that would evaporate and transpire if it were always available in sufficient quantity and it should be easier to measure and it has also greater significance than actual evapotranspiration (AE). Thornthwaite (1948),1 to whom this

concept is due, has himself designed an instrument called evapotranspirimeter for the measurement of PE and these instruments are already in operation in some places in the world. This approach is rapidly gaining wide recognition and has been able to solve many practical climatic and other related problems.

**REVIEW OF LITERATURE**

In view of the increasing demand for rational classification of climates on a regional basis from an ecological angle a number of climatic classifications since 1817, Koeppen's scheme appears to be meaningful to some extent and even today it is also popular in many geographical studies. Other attempts at climatic classification (from which the water balance studies are emerged) from time to time did not find the expected favour either because of their elaborate nature or complete lack of rationality or both. Thornthwaite (1948) developed a climatic water balance technique using book-keeping procedure of accounting for increments of water supply and loss on either a daily or monthly basis. However, there is some criticism in the field of hydrology about employing potential evapotranspiration computed by Thornthwaite's formula in climatic water balance studies as it involves only temperature as the parameter. Penman (1948) formulated an equation
for it as a combination of aerodynamic and energy balance terms. Similar studies of computation of evaporation were carried out by Christiansen (1968) and Khosla (1951). A combined model equation was suggested for potential evapotranspiration by Van Bavel (1966) who took into account factors like surface roughness, etc., in the wind function. The actual evapotranspiration is considerably influenced by the soil water supply, plant structure by Hagan and Vadia (1960), Slatyer (1955) in Australia evolved a relationship for decline of evapotranspiration with decreasing soil water shortage. Heilman and Kanemasu (1976) have suggested the use of remote sensing techniques for estimating PE of crops on regional basis.

In India, much of the work has been done by Prof. V.P. Subrahmanyam of Andhra University and the credit of applying the Thornthwaite's climatic classification to regional levels was goes to him alone. The other scholars who contributed much to water balance studies are Subrahmanyam and Umadevi (1981, 1983), Subrahmanyam and Upadhyay (1983), Rammohan (1978, 1980) etc. Sambasiva Rao and Kalavathy (1983) have studied the water balance elements of Madurai District and made an attempt to bring relationship between the distribution of water balance elements and cropping pattern of Madurai District.
M.J. Subrahmanyam and V. Vidyanath (1984) have studied the 'Moisture adequacy and cropping pattern in Andhra Pradesh' and brought out that the expansion of irrigation may invariably result in disturbing the eco-system. Hemamalini, B (1984) brought out some techniques and parameters in water balance analysis. Sambasiva Rao and Rajeswari (1984 and 1985) have also made an attempt to study the water balance elements of Vaigai and Vaippar river basins and brought out the relationship between the distribution of surface and sub-surface water resource.

In the present chapter an attempt is made to study the water balance elements in winter, summer, south-west monsoon season, north-east monsoon season and also on yearly basis; and attempted to classify the climates of Chittoor district. Also an attempt is made to find out the total run-off of the surface water after deducting the evaporation losses.

**METHODOLOGY**

The very important parameters of climatic water balance are the precipitation (P) and potential evapotranspiration (PE) or the combined water loss to atmosphere which needs comparison. Evapotranspiration raises difficult problems in water balance studies particularly in the assessment of drought, owing to uncertain knowledge regarding the rate of loss during the
drying cycle of the soil. A number of methods for estimating evapotranspiration are available, most of which give potential evapotranspiration, those which claim to give actual evapotranspiration are generally more complex and unreliable. These have recently been summarised by Haunam (1971) with particular reference to problems in water balance studies. So it is not surprising to state that a large number of models describing the water balance are available, and these vary mainly in the way in which they handle the evapotranspiration and soil water storage terms. The more popular procedures adopted are:

(a) Fitzpatrick method
(b) Palmer method
(c) Baier-Robertson method
(d) U.S.S.R. methods
(e) Thornthwaite method

In view of the urgent need for data of PE in various fields of investigation since the measured value of PE of the

required nature is not available, empirical formulae were developed to involve determination of \( PE \) from mean monthly temperature with the help of the latitude of the place. The investigator selects the Thornthwaite's book-keeping procedure which yields important information about \( PE \) which plays a double role in water balance, i.e., both as thermal parameter and moisture parameter "it is this feature that makes Thornthwaite's water balance concept and procedure very unique and novel" (Subrahmanyam, V.P., 1982).\(^7\)

The value of \( PE \) can be calculated by

\[
e = 1.6 \left( \frac{10^t}{I} \right)^a
\]

where

\[
e = \text{unadjusted potential evapotranspiration in cms.}
\]

\[
t = \text{mean monthly temperature in } \degree C
\]

\[
I = \text{annual heat index (This value is the sum of the 12 monthly heat indices } i, \text{ when } i = (t/5)^{1.514}
\]

\[
a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239.
\]

The value of 'e' thus obtained is based on a 12 hour-day and 30 day month. Using a series of conversion tables and nomograms prepared by Thornthwaite, it is possible to determine

the PE of Chittoor District and also adjust the same for changing number of days in a month and for changing length of the day in different seasons which varies with the latitude of the place.

Once PE is calculated while P already known the next step is the P-PE, which can be positive, negative or zero. The positive values indicate the amount of excess water which is available for soil storage and run-off, whereas negative values represent a potential deficiency of water. In this case the AE is equal to rainfall plus moisture lost from the soil. The difference between PE and AE gives the water deficit. After the moisture has reached the maximum moisture holding capacity of the soil the difference between precipitation and actual evapotranspiration gives the water surplus.

The moisture stored in the soil can be calculated from the following formula

\[
\text{Storage} = \text{Avc}\exp\frac{\text{Acc}(P-PE)}{\text{AWC}}
\]

where

Acc(P-PE) is the accumulated potential water loss (sum of negative P-PE values) and 'AWC' is the available water capacity. The moisture stored in the soil can be directly

obtained by the tables prepared by Thornthwaite.\textsuperscript{9}

The monthly normals of rainfall and temperature values of 10 raingauge stations of Chittoor District during normal year are carried out. Since the PE values of Penman's formula (1948)\textsuperscript{10} are not available with all the observatories the Thornthwaite's formula is inevitably employed in the present analysis. Field capacity values appropriate to the type of soil present in the study area are taken as 100 mm., and 150 mm.

Actual evapotranspiration equals PE since P is greater than PE which means that the moisture available during the period is more than PE and hence evapotranspiration occurs at its full potential. On the other hand if P is less than PE, soil begins to dryout by giving up its moisture to the atmosphere and hence AE is less than PE. The actual amount by which AE is less than PE gives the value of water deficiency (i.e., PE-AE = WD). WD represents the water deficit which denotes the amount by which P fails to meet the demands of evapotranspiration after all the available soil moisture has been used up. Water Surplus (WS) occurs when P exceeds PE, whenever the soil moisture storage reaches its field

capacity. Generally the soil reaches its field capacity only
during the south-west and north-east monsoon periods.

It is to be understood that the surplus water which is
not needed for evapotranspiration and recharge to the soil
moisture storage is available for run-off and it ultimately
reaches the water courses. Most surplus water does not run-
off from a watershed as soon as it becomes available as
surplus water will flow out of the region but some of it
infiltrates the soil. As a base flow, it takes long time to
reach the water courses. Thornthwaite and Mather have
suggested that one should assume 50 per cent of the surplus
water available to run-off in any month as actual run-off
while the remainder is held over and added to surplus in the
following month. The run-off obtained during summer months
is only from the surplus stored during June to December.
Thus, the climatic water balance provides realistic informa-
tion on an annual run-off of water from a region around the
station under study. These run-off studies are further use-
ful in landuse planning. Basing upon the above criteria
water balance tables were prepared for 10 important stations
which are distributed at random throughout the district and
from those worked out tables Actual Evapotranspiration (AE),
Water Deficit (WD), Water Surplus (WS), Moisture Adequacy (Ima),
Moisture Index (Im) and Aridity Index (Ia) are calculated for
all the seasons in a Normal Year. Water balance graphs have been constructed for all the 10 stations for a Normal Year, Wet Year and Dry Year. Based on the parameters of water balance elements, soil conditions and predominant crops cultivated in the district, the climatic classification of the district has been attempted in the following way:

**Climatic Classification**

By using the water balance parameters, it is possible to specify the climate into 'Thermal Regime' and 'Moisture Regime' i.e., climatic classification based on the 'Thermal Efficiency' of the region respectively. Thermal Efficiency (TE) is nothing but annual potential evapotranspiration; which is a parametric index used to determine the thermal regime since it has been derived from the temperature and the length of the day. In addition to thermal efficiency, however, moisture efficiency of a region has also an equal effect on the vegetation pattern of a region. To understand the moisture regime, it is necessary to compute the indices of aridity, moisture adequacy and moisture index. The ratio between WD and PE constitutes the Index of Aridity (Ia) while the Moisture Adequacy (Ima) is the

11. A normal year is one where the normal rainfall of 85 years has been taken into consideration. A dry year is one, in which the total annual rainfall of that particular year is less than the normal rainfall and a wet year is one in which the total annual rainfall of that particular year is more than the normal rainfall.
ratio between AE and PE. Both are expressed as percentages as laid down below:

\[ Ia = \frac{WD}{PE} \times 100 \]

\[ Ima = \frac{AE}{PE} \times 100 \]

Once these two indices are obtained, the Moisture Index (Im) on which the entire scheme of moisture regime is dependent can be worked out.

\[ Im = \frac{WS}{PE} \times 100 \ (-0.60 \times Ia) \]

The following table gives the climatic classification according to the moisture regime:

<table>
<thead>
<tr>
<th>Climatic type</th>
<th>Symbol</th>
<th>Moisture Index (Im) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perhumid</td>
<td>A</td>
<td>Humid Climates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 and Above</td>
</tr>
<tr>
<td>Humid</td>
<td>B_4</td>
<td>80 - 99</td>
</tr>
<tr>
<td></td>
<td>B_3</td>
<td>60 - 79</td>
</tr>
<tr>
<td></td>
<td>B_2</td>
<td>40 - 59</td>
</tr>
<tr>
<td></td>
<td>B_1</td>
<td>20 - 39</td>
</tr>
<tr>
<td>Moist Subhumid</td>
<td>C_2</td>
<td>0 - 19</td>
</tr>
<tr>
<td>Dry Subhumid</td>
<td>C_1</td>
<td>Dry Climates (Im _0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 33.3 to 0</td>
</tr>
<tr>
<td>Semiarid</td>
<td>D</td>
<td>- 66.5 to 33.4</td>
</tr>
<tr>
<td>Arid</td>
<td>E</td>
<td>- 66.6 and Below</td>
</tr>
</tbody>
</table>
According to Subrahmanyam the following table illustrates the 'Ima' values and the corresponding crops that can be successfully grown under such 'Ima' conditions in the absence of any supplemental irrigation.

<table>
<thead>
<tr>
<th>Ima %</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 - 100</td>
<td>Paddy (high yields)</td>
</tr>
<tr>
<td>60 - 80</td>
<td>Paddy (low yields)</td>
</tr>
<tr>
<td>Below 60</td>
<td>Paddy (uneconomical)</td>
</tr>
<tr>
<td>40 - 60</td>
<td>Millets</td>
</tr>
<tr>
<td>20 - 40</td>
<td>Drought resistant crops</td>
</tr>
<tr>
<td>Below 20</td>
<td>Unsuitable for cultivation</td>
</tr>
</tbody>
</table>

Basing upon the above classification the type of crops that can be successfully grown in Chittoor District was also determined.

WATER BALANCE ELEMENTS IN WINTER SEASON

Precipitation

The areal distribution of rainfall during winter period depicts that the rainfall is low, i.e., less than 10 mm., in the north-western part of the district. It is in the range of 10 mm. to 20 mm., in the south-western and central parts of the district. In the eastern part it is more than 20 mm.
In other words the rainfall has an increasing trend from north-west to east.
Potential Evapotranspiration (PE)

The potential evapotranspiration or water loss owing to evaporation and evapotranspiration during winter period ranges from a minimum of 197 mm., to a maximum of 221 mm., the average of the district is 210 mm. The PE is more than 200 mm., in extreme eastern parts and less than 200 mm., on the western and south-western hilly parts of the district. Similar to precipitation the distribution of PE is also exhibiting an increasing trend from west to east with some minor variations (Table 4.1) (Fig. 4.1).

Actual Evapotranspiration (AE)

Actual evapotranspiration or actual water available for the evapotranspiration in the district during winter period varies from a minimum of 32 mm., to a maximum of 150 mm., the district average is 88 mm. The amount of water available on the eastern part is more than 100 mm., followed by the central and south-western parts of the district where the AE values vary from 50 mm., to 100 mm. It is less than 50 mm., in the north-western corner of the district. The areal distribution of AE also denotes more or less the same picture as that of PE except that AE in north-western pockets of hilly terrain.
TABLE 4.1
WATER BALANCE ELEMENTS IN WINTER SEASON
(Normal Year)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>PE (mm.)</th>
<th>AE (mm.)</th>
<th>WD (mm.)</th>
<th>WS (mm.)</th>
<th>Ima (%)</th>
<th>Ia (%)</th>
<th>Im (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arogyavaram</td>
<td>197</td>
<td>69</td>
<td>128</td>
<td>0</td>
<td>35.02</td>
<td>64.97</td>
<td>-38.98</td>
</tr>
<tr>
<td>2</td>
<td>Chittoor</td>
<td>199</td>
<td>90</td>
<td>109</td>
<td>0</td>
<td>45.22</td>
<td>54.77</td>
<td>-32.86</td>
</tr>
<tr>
<td>3</td>
<td>Kuppam</td>
<td>197</td>
<td>60</td>
<td>137</td>
<td>0</td>
<td>30.45</td>
<td>69.54</td>
<td>-41.72</td>
</tr>
<tr>
<td>4</td>
<td>Palamaner</td>
<td>197</td>
<td>109</td>
<td>88</td>
<td>0</td>
<td>55.32</td>
<td>44.67</td>
<td>-26.80</td>
</tr>
<tr>
<td>5</td>
<td>Piler</td>
<td>199</td>
<td>69</td>
<td>130</td>
<td>0</td>
<td>34.67</td>
<td>65.32</td>
<td>-39.19</td>
</tr>
<tr>
<td>6</td>
<td>Puttur</td>
<td>200</td>
<td>91</td>
<td>109</td>
<td>0</td>
<td>45.50</td>
<td>54.50</td>
<td>-32.70</td>
</tr>
<tr>
<td>7</td>
<td>Satyavedu</td>
<td>221</td>
<td>138</td>
<td>83</td>
<td>0</td>
<td>62.00</td>
<td>38.00</td>
<td>-22.80</td>
</tr>
<tr>
<td>8</td>
<td>Srikalahasti</td>
<td>221</td>
<td>150</td>
<td>71</td>
<td>0</td>
<td>68.00</td>
<td>32.00</td>
<td>-19.20</td>
</tr>
<tr>
<td>9</td>
<td>Thamballapalli</td>
<td>199</td>
<td>32</td>
<td>167</td>
<td>0</td>
<td>16.80</td>
<td>83.91</td>
<td>-50.34</td>
</tr>
<tr>
<td>10</td>
<td>Tirupati</td>
<td>200</td>
<td>85</td>
<td>115</td>
<td>0</td>
<td>42.50</td>
<td>57.50</td>
<td>-34.50</td>
</tr>
<tr>
<td>11</td>
<td>CHITTOOR DISTRICT</td>
<td>210</td>
<td>88.0</td>
<td>122.0</td>
<td>0</td>
<td>41.90</td>
<td>58.09</td>
<td>-34.95</td>
</tr>
</tbody>
</table>

Source: Computed from the data collected.
Water Balance elements of Chittoor District (Winter)

Potential Evapotranspiration

Actual Evapotranspiration

Water Deficit

Moisture Adequacy

Aridity Index

Climatic Classification

Dry

Subhumid

Semiarid

FIG. 41
Water Surplus and Deficit Areas (WS & WD)

Water surplus is not noticed in the district owing to higher water losses in the form of potential evapotranspiration. The water deficit recorded in the winter period varies from a minimum of 71 mm. to a maximum of 167 mm., the district average is 122 mm. The water deficit is high ranging more than 150 mm., in the north-western part of the district. In the south-western and central parts of the district covering Kuppam, Palamaner, Punganur, Madanapalli, Piler, Chittoor, Tirupati and Puttur stations, it is in the range of 100 mm. to 150 mm. On the extreme eastern part covering Srikalahasti and Satyavedu areas it is very low ranging less than 100 mm. From the study of distribution of water deficit it depicts that the district experiences low to moderate water deficit during winter period.

Moisture Adequacy (Ima)

The moisture adequacy is an index to know the amount of moisture available in the district and is the ratio between AE and PE. During winter the moisture adequacy is moderate in the district and varies from a minimum of 16.8 per cent to a maximum of 68.0 per cent, the district average is 41.9 per cent. The availability of moisture is extremely low, i.e., less than 20 per cent in Thamballapalli area, where the water
deficit is very high. The value of 'Ima' has been increasing gradually towards east and reaches its peak of more than 60 per cent in Srikalahasti and Satyavedu areas. In other words, the areal distribution of moisture adequacy depicts that winter period is also a good season for crop culture.

**Aridity Index (Ia)**

The aridity index is the ratio between the water deficit and potential evapotranspiration and it denotes the amount of water shortage in a region. The value of aridity index in the district varies from a minimum of 32.0 per cent to a maximum of 83.9 per cent; the district average is 58.09 per cent. The amount of water shortage is very high in the north-western portion exceeding the district's average percentage and low in the eastern part due to high rainfall and low evaporation. In general, during winter period the water shortage is low to moderate.

**Moisture Index (Im)**

The moisture index is the ratio between water surplus and potential evapotranspiration and this index has been utilised by Thornthwaite and Mather (1955) to bring out the climatic classification of a region. The value of moisture index varies from a minimum of -19.2 per cent to a maximum of -50.34 per cent.
the district average is -34.85 per cent, which means that the district in the eastern and south-eastern parts are enjoying dry subhumid type of climate and the western and south-western part it is showing semiarid type of climate during winter period.

WATER BALANCE ELEMENTS IN SUMMER SEASON

Precipitation

The areal distribution of rainfall during summer period depicts that the hilly terrain on the south-western part receives high amount of rainfall i.e., more than 100 mm. The eastern plains receive the precipitation varying from 50 mm., to 100 mm. The trend of isohyets are irregular which shows that the rainfall in the district during summer period is also irregular.

Potential Evapotranspiration

During summer the potential evapotranspiration varies from a minimum of 470 mm., to a maximum of 522 mm., the district average is 500 mm. The spatial distribution of PE values shows that it has been increasing from west to east (Fig.4.2 and Table 4.2).

Actual Evapotranspiration

The actual evapotranspiration in the district varies from
### TABLE 4.2

**WATER BALANCE ELEMENTS IN SUMMER SEASON**
**(Normal Year)**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>PE (mm.)</th>
<th>AE (mm.)</th>
<th>WD (mm.)</th>
<th>WS (mm.)</th>
<th>Ima (%)</th>
<th>Ia (%)</th>
<th>Im (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arogyavaram</td>
<td>470</td>
<td>123</td>
<td>347</td>
<td>0</td>
<td>26.17</td>
<td>73.82</td>
<td>-44.29</td>
</tr>
<tr>
<td>2</td>
<td>Chittoor</td>
<td>490</td>
<td>110</td>
<td>380</td>
<td>0</td>
<td>22.84</td>
<td>77.55</td>
<td>-46.53</td>
</tr>
<tr>
<td>3</td>
<td>Kuppam</td>
<td>470</td>
<td>155</td>
<td>315</td>
<td>0</td>
<td>32.95</td>
<td>67.02</td>
<td>-40.21</td>
</tr>
<tr>
<td>4</td>
<td>Palamaner</td>
<td>470</td>
<td>136</td>
<td>334</td>
<td>0</td>
<td>28.93</td>
<td>71.06</td>
<td>-42.63</td>
</tr>
<tr>
<td>5</td>
<td>Piler</td>
<td>490</td>
<td>80</td>
<td>410</td>
<td>0</td>
<td>16.32</td>
<td>83.67</td>
<td>-50.20</td>
</tr>
<tr>
<td>6</td>
<td>Puttur</td>
<td>511</td>
<td>99</td>
<td>412</td>
<td>0</td>
<td>19.37</td>
<td>80.62</td>
<td>-48.37</td>
</tr>
<tr>
<td>7</td>
<td>Satyavedu</td>
<td>522</td>
<td>101</td>
<td>421</td>
<td>0</td>
<td>19.00</td>
<td>80.65</td>
<td>-48.39</td>
</tr>
<tr>
<td>8</td>
<td>Srikalahasti</td>
<td>522</td>
<td>111</td>
<td>411</td>
<td>0</td>
<td>21.00</td>
<td>78.73</td>
<td>-47.23</td>
</tr>
<tr>
<td>9</td>
<td>Thamballapalli</td>
<td>490</td>
<td>66</td>
<td>424</td>
<td>0</td>
<td>13.46</td>
<td>86.53</td>
<td>-51.91</td>
</tr>
<tr>
<td>10</td>
<td>Tirupati</td>
<td>511</td>
<td>146</td>
<td>365</td>
<td>0</td>
<td>28.57</td>
<td>71.42</td>
<td>-42.65</td>
</tr>
<tr>
<td>11</td>
<td><strong>CHITTOOR DISTRICT</strong></td>
<td><strong>500</strong></td>
<td><strong>109</strong></td>
<td><strong>391</strong></td>
<td><strong>0</strong></td>
<td><strong>22.86</strong></td>
<td><strong>78.20</strong></td>
<td><strong>-46.92</strong></td>
</tr>
</tbody>
</table>

*Source: Computed from the data collected.*
Water Balance elements of Chittoor District (Summer)

Potential Evapotranspiration

- < 480
- 480 - 500
- 500 - 520
- > 520

Actual Evapotranspiration

- < 70
- 70 - 100
- 100 - 130
- > 130

Water Deficit

- < 350
- 350 - 400
- > 400

Moisture Adequacy

- < 20
- 20 - 30
- > 30

Aridity Index

- < 70
- 70 - 80
- > 80

Climatic Classification

- Semiarid
- Approaching nearer to arid

FIG. 4.2
a minimum of 66 mm., to a maximum of 155 mm., the district average is 109 mm. The value of AE is less than 100 mm., around Thamballapalli and Piler. In the remaining part of the district it is in the range of 100-130 mm. It is concluded from the above results that owing to dry climatic conditions and higher thermal efficiency the water availability on the major portion of the district is definitely low.

**Water Deficit and Water Surplus**

Water surplus is not noticed in the district owing to high water losses in the form of potential evapotranspiration. The water deficit in the district varies from a minimum of 315 mm., to a maximum of 424 mm., while the district average is 391 mm. The spatial distribution reveals that in the south-western part of the district it is less than the average of the district and increases towards east. Overall, the district experiences higher water deficit during summer period without recording any water surplus.

**Moisture Adequacy**

The value of 'Ima' in the district varies from a minimum of 13.46 per cent to a maximum of 32.95 per cent, the district average is 22.86 per cent. The spatial variation of Ima., in the district shows that the north-western and south-eastern parts of the district covering Thamballapalli, Piler, Puttur
and Satyavedu areas it is less than 20 per cent. It is only in the central part of the district covering Palamaner, Madanapalli, Vayalapadu, Chittoor, Tirupati and Srikalahasti it is in the range of 20-30 per cent.

From the study of moisture adequacy it depicts that the crop culture on the plains is not advisable owing to low moisture availability and higher thermal efficiency. However, the crops could be cultivated by supplementing water either from reservoirs or extracting water from sub-surface zones.

**Aridity Index**

The aridity index in summer season varies from a minimum of 67.02 per cent to a maximum of 86.53 per cent, the district average is 78.2 per cent. The spatial variation of aridity index in the district shows that except in the extreme southwestern portion covering Kuppam, the aridity index is more than 70 per cent. Overall, the district experiences higher water shortage during summer period owing to low precipitation, high thermal efficiency, low water availability and high water deficit.

**Moisture Index**

The value of moisture index vary from a minimum of -40.21 per cent to a maximum of -51.91 per cent, whereas the district average is -46.92 per cent. The above values of the district
depict that climatologically the district is categorised under 'semiarid' type of climate.

WATER BALANCE ELEMENTS IN SOUTH-WEST MONSOON SEASON

Precipitation

The distribution of precipitation during south-west monsoon season depicts that Thamballapalli area bordering Anantapur district receives low amount of rainfall i.e., less than 300 mm. But the central upland tract covering Madanapalli, Vayalapadu, Piler, Palamaner and Tirupati receives the rainfall in the range of 300 mm. to 400 mm. The general trend of rainfall is that it has been decreasing from east to west.

Potential Evapotranspiration

The potential evapotranspiration during this season varies from a minimum of 556 mm., to a maximum of 685 mm., the district average is 615 mm. The spatial variation reveals that it is decreasing from east to west similar to precipitation. In general the PE value is high during south-west monsoon period owing to high temperature, low rainfall, high wind velocity etc. (Fig.4.3)(Table 4.3).

Actual Evapotranspiration

The actual evapotranspiration in the district in south-west monsoon season varies from a minimum of 318 mm., to a
### TABLE 4.3

WATER BALANCE ELEMENTS IN SOUTH-WEST MONSOON SEASON
(Normal Year)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>PE (mm.)</th>
<th>AE (mm.)</th>
<th>WD (mm.)</th>
<th>WS (mm.)</th>
<th>Ima (%)</th>
<th>Ia (%)</th>
<th>Im (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arogyavaram</td>
<td>556</td>
<td>318</td>
<td>238</td>
<td>0</td>
<td>57.19</td>
<td>42.80</td>
<td>-25.68</td>
</tr>
<tr>
<td>2.</td>
<td>Chittoor</td>
<td>622</td>
<td>404</td>
<td>218</td>
<td>0</td>
<td>64.95</td>
<td>35.04</td>
<td>-21.02</td>
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<tr>
<td>3.</td>
<td>Kuppam</td>
<td>556</td>
<td>340</td>
<td>216</td>
<td>0</td>
<td>61.15</td>
<td>38.84</td>
<td>-23.30</td>
</tr>
<tr>
<td>4.</td>
<td>Palamaner</td>
<td>556</td>
<td>355</td>
<td>201</td>
<td>0</td>
<td>63.84</td>
<td>36.15</td>
<td>-21.69</td>
</tr>
<tr>
<td>5.</td>
<td>Piler</td>
<td>622</td>
<td>333</td>
<td>289</td>
<td>0</td>
<td>53.53</td>
<td>46.46</td>
<td>-27.70</td>
</tr>
<tr>
<td>6.</td>
<td>Puttur</td>
<td>685</td>
<td>446</td>
<td>239</td>
<td>0</td>
<td>65.10</td>
<td>34.89</td>
<td>-20.93</td>
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<tr>
<td>7.</td>
<td>Satyavedu</td>
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<td>417</td>
<td>247</td>
<td>0</td>
<td>62.80</td>
<td>37.19</td>
<td>-22.31</td>
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<td>357</td>
<td>307</td>
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<td>46.23</td>
<td>-27.73</td>
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<td>9.</td>
<td>Thamballapalli</td>
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<td>52.09</td>
<td>47.90</td>
<td>-28.74</td>
</tr>
<tr>
<td>10.</td>
<td>Tirupati</td>
<td>685</td>
<td>376</td>
<td>309</td>
<td>0</td>
<td>54.89</td>
<td>45.10</td>
<td>-27.06</td>
</tr>
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<td>11.</td>
<td>CHITTOOR DISTRICT</td>
<td>615</td>
<td>376</td>
<td>239</td>
<td>0</td>
<td>61.13</td>
<td>38.86</td>
<td>-23.31</td>
</tr>
</tbody>
</table>

Source: Computed from the data collected.
Water Balance elements of Chittoor District (S-W Monsoon)

Potential Evapotranspiration
- □ < 600
- □ 600 - 650
- □ > 650

Actual Evapotranspiration
- □ < 350
- □ 350 - 400
- □ > 400

Water Deficit
- □ < 200
- □ 200 - 250
- □ 250 - 300
- □ > 300

Moisture Adequacy
- □ < 55
- □ 55 - 60
- □ > 60

Aridity Index
- □ < 40
- □ 40 - 45
- □ > 45

Climatic Classification
- Dry subhumid □

FIG. 4.3
maximum of 446 mm., while the district average being 376 mm. The spatial pattern of AE shows that on the western hilly terrain it is less than 350 mm., and on the eastern part it is more than 400 mm.

**Water Surplus and Water Deficit**

Though it is one of the principal monsoon seasons of the district, water surplus is hardly noticed in the district owing to high water losses by high range of daily temperatures. Water deficit varies from a minimum of 201 mm., in the western part of the district to a maximum of 309 mm., in eastern part of the district. Overall, the plain region experiences high water deficit during this season than on hilly terrain.

**Moisture Adequacy**

The moisture adequacy in the district varies from a minimum of 52.09 per cent to a maximum of 65.10 per cent the district average is 61.13 per cent. The value of moisture adequacy is more than 60 per cent on the southern part of the district and less than 55 per cent in the northern part of the district. It can be depicted from the above analysis that the southern part of the district is more suitable for crop culture and gradually unsuitability increases towards north. Therefore, careful water management practices must be adopted during this
period on central and northern regions.

**Aridity Index**

The index of aridity in the study area varies from a minimum of 35.04 per cent to a maximum of 47.9 per cent, the district average is 38.86 per cent. The spatial variation of this index shows that the isohyets are exhibiting the same pattern as in the case of Ima but the values are reversed. In other words, the water shortage is high on the northern part and low in the southern part. Overall, during the south-west monsoon period the district experiences high water shortage in the northern region.

**Moisture Index**

The Moisture Index in the district ranges from a minimum of -20.93 to a maximum of -28.74 per cent, the district average is -23.31 per cent. As the above results are in the range of 0 to -33.3 per cent, the entire district in this season exhibits 'Dry subhumid' type of climate.

**WATER BALANCE ELEMENTS IN NORTH-EAST MONSOON SEASON**

**Precipitation**

The spatial distribution of rainfall in this season depicts that the rainfall is very high in the eastern part due to its proximity to Bay of Bengal coast and has been showing a decreasing
trend towards west.

**Potential Evapotranspiration**

The potential evapotranspiration in this season varies from a minimum of 266 mm., to a maximum of 342 mm., and the district average is 307 mm. There are four distinct zones in which the PE values are showing an increasing trend from west to east. The potential evapotranspiration values seem to be much lower during this season than south-west monsoon and summer seasons. The lowest values are noticed in the district during winter period (Fig.4.4)(Table 4.4).

**Actual Evapotranspiration**

The value of actual evapotranspiration or the availability of water for evaporation and transpiration is more or less similar to that of PE and ranges from a minimum of 252 mm., to a maximum of 338 mm., while the district average is 302 mm. It has been presenting an increasing trend from west to east due to depressions formed in the Bay of Bengal.

**Water Deficit and Water Surplus**

Water surplus is noticed in this season and it varies from a minimum of 44 mm., to a maximum of 372 mm., the district average is 56 mm. The spatial pattern of water surplus shows that the eastern part is showing the surplus water more than
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>PE (mm.)</th>
<th>AE (mm.)</th>
<th>WD (mm.)</th>
<th>WS (mm.)</th>
<th>Ima (%)</th>
<th>Ia (%)</th>
<th>Im (%)</th>
</tr>
</thead>
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<td>255</td>
<td>11</td>
<td>0</td>
<td>95.86</td>
<td>4.13</td>
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<td>2</td>
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<td>100.00</td>
<td>0</td>
<td>14.47</td>
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<td>94.73</td>
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<td>-3.15</td>
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<td>4</td>
<td>Palamaner</td>
<td>266</td>
<td>266</td>
<td>0</td>
<td>96</td>
<td>100.00</td>
<td>0</td>
<td>36.09</td>
</tr>
<tr>
<td>5</td>
<td>Piler</td>
<td>304</td>
<td>294</td>
<td>10</td>
<td>0</td>
<td>100.00</td>
<td>3.28</td>
<td>-1.96</td>
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<td>6</td>
<td>Puttur</td>
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<td>342</td>
<td>0</td>
<td>111</td>
<td>92.98</td>
<td>0</td>
<td>32.45</td>
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<td>Satyavedu</td>
<td>338</td>
<td>338</td>
<td>0</td>
<td>372</td>
<td>100.00</td>
<td>0</td>
<td>109.76</td>
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<td>Srikalahasti</td>
<td>338</td>
<td>338</td>
<td>0</td>
<td>336</td>
<td>100.00</td>
<td>0</td>
<td>99.40</td>
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<td>264</td>
<td>40</td>
<td>0</td>
<td>86.84</td>
<td>13.15</td>
<td>-7.89</td>
</tr>
<tr>
<td>10</td>
<td>Tirupati</td>
<td>342</td>
<td>342</td>
<td>0</td>
<td>87</td>
<td>98.83</td>
<td>0</td>
<td>25.43</td>
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<td>11</td>
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<td>307</td>
<td>302</td>
<td>7.5</td>
<td>56</td>
<td>98.37</td>
<td>2.44</td>
<td>18.24</td>
</tr>
</tbody>
</table>

Source: Computed from the data collected.
Water Balance elements of Chittoor District (N-E Monsoon)

Potential Evapotranspiration
- < 300
- 300-320
- 320-340
- > 340

Actual Evapotranspiration
- < 300
- 300-325
- > 325

Water Deficit / Surplus
- < 50
- 50-100
- > 100

Moisture Adequacy
- < 90
- 90-95
- > 95

Aridity Index
- < 5
- 5-10
- > 10

Climatic Classification
- Humid
- Per humid
- Wet subhumid
- Dry subhumid

FIG. 4.4
100 mm. In the central belt it is noticed in the range of 50-100 mm. In Chittoor station it is less than 50 mm. Water deficit was also noticed which varies from a minimum of 10 mm., to a maximum of 40 mm., the district normal is 7.5 mm. The areal distribution of water deficit depicts that on the north-western corner it is more than 30 mm., and the south-western belt, it is less than 15 mm. The water surplus is due to high amount of rainfall received by depressions/cyclonic storms formed in the Bay of Bengal and Arabian Sea and low thermal efficiency as the eastern part is very nearer the coast, the water surplus has been more on the eastern part and considerably reduced towards west and with the result the north and south-west portions of the district is fallen under 'water deficit zone'.

**Moisture Adequacy**

The moisture adequacy in the district varies from a minimum of 86.84 per cent to a maximum of 100 per cent, the district normal is 98.37 per cent. Climatologically viewing, the above values show that there is high moisture content for crop culture. In major portions of the district the moisture adequacy is more than 95 per cent. It is in the north-western part covering Thamballapalli area, it is less than 90 per cent. In Puttur area it is in the range of 90 per cent.to 95 per cent.
The availability of moisture is highest during this period because of high precipitation received and low potential evapotranspiration and high water surplus.

**Aridity Index**

The water shortage during north-east monsoon season is very low ranging from 0 to 13 per cent while the normal of the district is only 2.44 per cent. In the major part of the district, i.e., on the central and eastern parts the shortage of water is less than 1 per cent. In the south and western belt it is in the range of 1 to 5 per cent. In Thamballapalli area of the district a maximum shortage is observed ranging more than 10 per cent.

**Moisture Index**

The moisture index values of central and eastern portions of the district reveal the positive values ranging from a minimum of +14.47 per cent to a maximum of +109.76 per cent, the district normal is +18.24 per cent. The western and south-western parts of the district reveal the negative values ranging from a minimum of -1.96 per cent to a maximum of -7.89 per cent. The climatic classification of the area shows that the extreme eastern portion is exhibiting 'Perhumid' and the neighbouring belt towards west exhibiting the 'Humid' climate. In Chittoor area, the climate is 'Moist Subhumid'. The entire
western and south-western part shows 'Dry Subhumid' type of climate.

**ANNUAL WATER BALANCE ELEMENTS**

**Precipitation**

The areal distribution of annual rainfall in the district reveals that the north-western part covering Thamballapalli, P.T.M., receives low amount of rainfall, i.e., less than 700 mm. In the central upland region the rainfall is varying from 700-900 mm. In the eastern plains covering Srikalahasti, Satyavedu, Puttur, it is more than 900 mm. The general trend of rainfall is increasing from north-west to east.

**Potential Evapotranspiration**

The annual PE varies from a minimum of 1489 mm, to a maximum of 1745 mm, the district average is 1620 mm. The spatial distribution of PE denote that it has been increasing from south-west to east (Fig.4.5)(Table 4.5).

**Actual Evapotranspiration**

Actual evapotranspiration or water need of the district varies from a minimum of 686 mm, in Thamballapalli to a maximum of 994 mm, in Satyavedu, while the district's average is 780. The spatial distribution reveals that in the eastern part the AE values are more than in the western part. In
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>PE (mm.)</th>
<th>AE (mm.)</th>
<th>WD (mm.)</th>
<th>WS (mm.)</th>
<th>Ima (%)</th>
<th>Ia (%)</th>
<th>Im (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arogyavaram</td>
<td>1489</td>
<td>765</td>
<td>724</td>
<td>0</td>
<td>51.40</td>
<td>48.62</td>
<td>-25.10</td>
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<td>2.</td>
<td>Chittoor</td>
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<td>908</td>
<td>707</td>
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<td>56.22</td>
<td>43.77</td>
<td>-26.26</td>
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<td>3.</td>
<td>Kuppam</td>
<td>1489</td>
<td>807</td>
<td>682</td>
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<td>54.20</td>
<td>45.80</td>
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<td>58.20</td>
<td>41.84</td>
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<td>5.</td>
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<td>58.67</td>
<td>45.13</td>
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<td>54.89</td>
<td>45.10</td>
<td>-27.06</td>
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<td>7.</td>
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<td>994</td>
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<td>43.03</td>
<td>-25.81</td>
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<td>1745</td>
<td>956</td>
<td>789</td>
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<td>54.78</td>
<td>45.21</td>
<td>-27.12</td>
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<td>-34.50</td>
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<td>945</td>
<td>793</td>
<td>0</td>
<td>54.37</td>
<td>45.62</td>
<td>-27.37</td>
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<td>780</td>
<td>755</td>
<td>0</td>
<td>48.14</td>
<td>46.60</td>
<td>-27.96</td>
</tr>
</tbody>
</table>

Source: Computed from the data collected.
other words the water need is more on the eastern part than on the western part.

**Water Deficit and Water Surplus**

The whole district is experiencing the water deficit owing to less precipitation and more evapotranspiration. The deficit in the district varies from a minimum of 623 mm., to a maximum of 929 mm. The south-western part covering Kuppam and Palamaner it is less than 700 mm. On the north-western part covering Thamballapalli area it is more than 900 mm. In the remaining part of the district it is varying from 700 to 900 mm. Overall, in the district, the north-western part experiences high water deficit.

**Moisture Adequacy**

The annual values of moisture adequacy in the district range from a minimum of 42.47 per cent to a maximum of 58.2 per cent, while the district's average is 48.14. Subrahmanyam et al (1963) mapped the distribution of this index over the Indian sub-continent and concluded that the regions with index values higher than 40 per cent are favourable for crop culture. As the Moisture Adequacy values of the study area are in the range of 42 per cent to 58 per cent this district is somewhat good for crop culture in climatic point of view.
Aridity Index

The value of aridity index varies from a minimum of 41.84 per cent to a maximum of 52.57 per cent, denoting that there is an acute water shortage in the study area. In the eastern plain regions the value of water shortage is less than 45 per cent and in the south-west and central part it ranges from 45-50 per cent. The aridity index of more than 50 per cent is noticed in the north-western part covering Thamballapalli area which indicates that there is very high shortage of water. Overall, the district experiences high shortage of water.

Moisture Index

The negative values of 'Im' index indicates that the district experiences dry climatic condition. The value from 0 to -33.3 shows 'Dry Subhumid' climate and -33.3 to -66.7 shows 'Semiarid' climate. The north-western part covering Thamballapalli area it is showing 'Semiarid' climate. The remaining part of the district is showing 'Dry Subhumid' climate.

From the study and critical examination of seasonal water balance elements it is supposed that the entire district on both hilly terrain and plains experiences water deficit during winter, summer and south-west monsoon periods. The water deficit is very high during summer period and hence the aridity index
of the district also records high i.e., 78.2 per cent. The water supply by rainfall in winter, summer and south-west monsoon (522.14 mm.) is not sufficient to the water needs (1320.8 mm.) of the district. But during the north-east monsoon period the district records some surplus owing to high rainfall, low variability, cool winds and low temperature. The water deficit is increasing towards north-west, reaching its maximum values of 40 per cent in Thamballapalli area. As the north-east monsoon season experiences water surplus, it is highly suitable for crop culture. During summer and south-west monsoon the crops could be cultivated either by canal or tank irrigation since most of the wells are dry during these two seasons. Careful water management practices must be strictly adopted to distribute the limited water available in the reservoirs. Micro climatic changes could be noticed from one season to the other (For example, during winter, the district experiences 'Dry Subhumid' type of climate in the eastern plain portion and 'Semiarid' type of climate in the western hilly terrain). In summer the entire district experiences 'Semiarid' type of climate and during south-west monsoon season, it is experiencing 'Dry Subhumid' type of climate, irrespective of hilly terrain and plain regions. Majority of the plain regions during different seasons experience 'Dry Subhumid' type of climate due to high rainfall,
WATER BALANCE GRAPHS
(NORMAL YEAR)

THAMBALLAPALLI

AROYAVARAM

PLIER

TIRUPATI

PUTTUR

SRIKALAPASTI

PALAMANER

CHITTOOR

KUPPAM

SATYAVEDU

0  30 KM

POTENTIAL EVA. TRANSPARATION
RAINFALL
ACTUAL EVA. TRANSPARATION
WATER DEFICIT
SOIL MOISTURE USE
SOIL MOISTURE RECHARGE
WATER SURPLUS

FIG. 4.6
low water deficit, low potential evapotranspiration and high water availability. In the north-east monsoon period the 'Humid' and 'Dry Subhumid' types of climate prevail over major parts of the district. The micro climatic changes noticed in the study area are due to variation in the precipitation received during different seasons, variations in water loss, water availability, water deficit and water surplus. Thus, the water balance elements not only help to study the amount of water deficit and water surplus in the district but also bring out the micro-climatic variations that are likely to prevail over a year.

**WATER BALANCE GRAPHS**

The water balance graphs have been constructed using the parameters of precipitation, potential evapotranspiration and actual evapotranspiration for 10 important stations* in the district and are represented graphically for a 'normal year', 'wet year' and 'dry year' to study the water surplus and water deficit periods over a year on monthly basis and the results were shown graphically for each year and at each station.

**Water Balance Graphs During Normal Year**

During normal year the water balance graphs depict that on the plain region in the eastern part, there is water deficit from January to September (Fig.4.6)(Annexure 8A to 8D). In the

* The ten important stations are shown in the Water Balance Graphs.
months of October, November and December, the surplus water available goes in the form of run-off to the down stream. The run-off exceeds more than 300 mm., in the months of October, November and December (North-east monsoon season). On the hilly terrain of the western part of the district there is water deficit from January to September. In the months of October, November and December, the surplus water goes in the soil moisture use and soil moisture recharge. Table 4.6 shows the annual water balance of the district in which all the stations show the deficit of water owing to increase in water need (The water supply of the district is 866.4 mm., and water need is 1627.3 mm., thereby showing a deficit of 760.9 mm).

**TABLE 4.6**

**ANNUAL TOTALS OF WATER BALANCE ELEMENTS**

(Normal Year)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>Annual water supply (mm.)</th>
<th>Annual water need (mm.)</th>
<th>Deficit/Surplus (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arogyavaram</td>
<td>695</td>
<td>1489</td>
<td>-794</td>
</tr>
<tr>
<td>2.</td>
<td>Chittoor</td>
<td>895</td>
<td>1615</td>
<td>-720</td>
</tr>
<tr>
<td>3.</td>
<td>Kuppam</td>
<td>766</td>
<td>1489</td>
<td>-723</td>
</tr>
<tr>
<td>4.</td>
<td>Palamaner</td>
<td>894</td>
<td>1489</td>
<td>-595</td>
</tr>
<tr>
<td>5.</td>
<td>Piler</td>
<td>690</td>
<td>1615</td>
<td>-925</td>
</tr>
<tr>
<td>6.</td>
<td>Puttur</td>
<td>1015</td>
<td>1738</td>
<td>-723</td>
</tr>
<tr>
<td>7.</td>
<td>Satyavedu</td>
<td>960</td>
<td>1745</td>
<td>-785</td>
</tr>
<tr>
<td>8.</td>
<td>Srikalahasti</td>
<td>1142</td>
<td>1745</td>
<td>-603</td>
</tr>
<tr>
<td>9.</td>
<td>Thamballapalli</td>
<td>592</td>
<td>1615</td>
<td>-1023</td>
</tr>
<tr>
<td>10.</td>
<td>Tirupati</td>
<td>1015</td>
<td>1738</td>
<td>-723</td>
</tr>
<tr>
<td>11.</td>
<td>CHITTOOR DISTRICT</td>
<td>66.4</td>
<td>1627.3</td>
<td>-760.9</td>
</tr>
</tbody>
</table>
Water Balance Graphs During Wet Year

The monthly water balance graphs in the district during wet year shows that there is surplus water owing to high rainfall received throughout the district more than the normal rainfall. Except the station Puttur, in all other stations there is considerably some amount of rainfall which has gone in the form of run-off into the down streams. In other words, owing to high rainfall after the soil has reached water holding capacity the excess of rainfall goes in the form of run-off to down streams (Annexure 7A to 7D)(Fig.4.7). In Srikalahasti and Satyavedu stations the surplus water exceeds more than 900 mm., which flows in the form of run-off and in Tirupati and Chittoor stations the surplus ranges from 300-350 mm. In Kuppam, Arogyavaram and Thamballapalli (on the western part) the surplus water is in the range of 200-250 mm. The annual water balance (Table 4.7) shows that except Palamaner, Satyavedu and Srikalahasti, all the stations exhibit the water deficit of 193.2 mm.

Water Balance Graphs During Dry Year

The monthly water balance graphs during dry year reveal that the plain region in the eastern part of the district experiences water surplus during October, November and December in the form of run-off (Annexure 9A to 9D). On the hilly terrain: all the stations except Arogyavaram experience water deficit
TABLE 4.7

ANNUAL TOTALS OF WATER BALANCE ELEMENTS
(Wet Year)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>Annual water supply (mm.)</th>
<th>Annual water need (mm.)</th>
<th>Deficit/Surplus (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arogyavaram</td>
<td>1340</td>
<td>1489</td>
<td>-149</td>
</tr>
<tr>
<td>2.</td>
<td>Chittoor</td>
<td>1401</td>
<td>1615</td>
<td>-214</td>
</tr>
<tr>
<td>3.</td>
<td>Kuppam</td>
<td>1169</td>
<td>1489</td>
<td>-320</td>
</tr>
<tr>
<td>4.</td>
<td>Palamaner</td>
<td>1655</td>
<td>1489</td>
<td>+166</td>
</tr>
<tr>
<td>5.</td>
<td>Piler</td>
<td>828</td>
<td>1615</td>
<td>-787</td>
</tr>
<tr>
<td>6.</td>
<td>Puttur</td>
<td>1243</td>
<td>1738</td>
<td>-495</td>
</tr>
<tr>
<td>7.</td>
<td>Satyavedu</td>
<td>2292</td>
<td>1739</td>
<td>+553</td>
</tr>
<tr>
<td>8.</td>
<td>Srikalahasti</td>
<td>2342</td>
<td>1745</td>
<td>+597</td>
</tr>
<tr>
<td>9.</td>
<td>Thamballapalli</td>
<td>780</td>
<td>1615</td>
<td>-835</td>
</tr>
<tr>
<td>10.</td>
<td>Tirupati</td>
<td>1290</td>
<td>1738</td>
<td>-448</td>
</tr>
<tr>
<td>11.</td>
<td>CHITTOOR DISTRICT</td>
<td>1434.0</td>
<td>1627.2</td>
<td>-193.2</td>
</tr>
</tbody>
</table>

ranging from 50 mm., to 250 mm., per month throughout the year except in November and December, where a little amount of surplus water goes in the form of soil moisture recharge. This is due to low rainfall and high potential evapotranspiration. This deficit is very high from April to September. In
WATER BALANCE GRAPHS
(DRY PERIOD)

All Values in mm.

- POT. EVAPOTRANSPIRATION
- RAINFALL
- ACTUAL EVAPOTRANSPIRATION
- WATER DEFICIT
- SOIL MOISTURE USE
- SOIL MOISTURE RECHARGE
- WATER SURPLUS

0 30 KM.

FIG. 4.8
Arogyavaram, water surplus occurs in August, which goes in the form of soil moisture recharge. The annual water balance elements during dry year (Table 4.8) shows that the water need is more in the district (1628.2 mm.) than the water supply (593.7 mm.), thereby showing a deficit of 1034.5 mm.

**TABLE 4.8**

ANNUAL TOTALS OF WATER BALANCE ELEMENTS
(Dry Year)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Station</th>
<th>Annual water supply (mm.)</th>
<th>Annual water need (mm.)</th>
<th>Deficit/Surplus (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arogyavaram</td>
<td>378</td>
<td>1491</td>
<td>-1113</td>
</tr>
<tr>
<td>2.</td>
<td>Chittoor</td>
<td>568</td>
<td>1615</td>
<td>-1047</td>
</tr>
<tr>
<td>3.</td>
<td>Kuppam</td>
<td>456</td>
<td>1489</td>
<td>-1033</td>
</tr>
<tr>
<td>4.</td>
<td>Palamaner</td>
<td>518</td>
<td>1489</td>
<td>-971</td>
</tr>
<tr>
<td>5.</td>
<td>Piler</td>
<td>391</td>
<td>1615</td>
<td>-1224</td>
</tr>
<tr>
<td>6.</td>
<td>Puttur</td>
<td>844</td>
<td>1738</td>
<td>-894</td>
</tr>
<tr>
<td>7.</td>
<td>Satyavedu</td>
<td>960</td>
<td>1745</td>
<td>-785</td>
</tr>
<tr>
<td>8.</td>
<td>Srikalahasti</td>
<td>730</td>
<td>1745</td>
<td>-1015</td>
</tr>
<tr>
<td>9.</td>
<td>Thamballapalli</td>
<td>357</td>
<td>1617</td>
<td>-1260</td>
</tr>
<tr>
<td>10.</td>
<td>Tirupati</td>
<td>735</td>
<td>1738</td>
<td>-1003</td>
</tr>
<tr>
<td>11.</td>
<td>CHITTOOR DISTRICT</td>
<td>593.7</td>
<td>1628.2</td>
<td>-1034.5</td>
</tr>
</tbody>
</table>
As stated earlier, in Water Balance computations precipitation (p) is compared with Potential Evapotranspiration (PE). On a monthly basis, P-PE can be zero, positive or negative. When P-PE is positive, actual evapotranspiration (AE) is equal to Potential Evapotranspiration (PE) as evapotranspiration can proceed unhindered with no water shortage. Negative P-PE values mean potential loss of moisture from the soil. The actual loss of moisture from the soil will be at potential rate or at a lesser rate as detailed above. Actual evapotranspiration in this case is equal to precipitation plus moisture actually lost from the soil.

The difference between Potential Evapotranspiration and Actual Evapotranspiration is water deficiency of the month. After the soil has attained the field capacity the difference between precipitation and actual evapotranspiration which equals to PE is the water surplus of the month. This surplus is the amount of water that is available for deep drainage as well as for run-off into streams, rivers and lakes. A part of this surplus only does actually run-off in the month. This has been taken as 50 per cent of the surplus, the value is generally considered to hold good for large water sheds. The rest of the surplus is detained in the water-shed and becomes run-off during the subsequent month.
Basing upon the above assumptions, the surface run-off has been evaluated using the formula

\[
\text{Total run-off in cu.m.} = \frac{\text{District area in sq.meters}}{\text{Run-off in meters}}
\]

The estimated total run-off after all the evaporation losses is 759.85 mcum.

**Conclusion**

The water balance worked out by using Thornthwaite and Mather (1955) show that hardly a few of the stations in the district has water surplus even on a monthly basis. Contributions to the groundwater reservoir from this region are thus normally absent. In certain years, however, when the precipitation during the rainy season is much greater than the normal, local water supplies occur for brief periods only, and these surpluses not only produce enormous surface flow resulting in inundation but also significantly contribute to the groundwater resources.

Overall, 60-70 per cent of the area in the district suffers from severe water deficit (which ultimately leads to drought) in the bordering taluks of Anantapur. Therefore, this district has been rightly identified as 'drought prone area' by the Irrigation Commission (1972).