Chapter 4

General Climatic Condition
GENERAL CLIMATIC CONDITIONS

Introduction

The role of climate in the hydrological process is very significant. Cohen et al. (1996) indicate that runoff from a river basin can be regarded as being the by-product of two larger processes-precipitation and evapotranspiration. The hydrological cycle is closely connected to the climate, thus there is growing concern that climate change will have significant impacts on water in the hydrological cycles of many regions of the world. Kaczmarek et al. (1996) indicate that the effects of climate variability and climate change on water resources are highly site specific. Watson et al. (1998) indicate that water resources are inextricable like climate, so that prospect of global climate change has serious implications for water resources and regional development. Therefore, hydrologists have recognized the need to create a scientific basis for analyzing the effects on climatic variability in order to plan and operate water resource systems.

In the arid and semi-arid regions, a relatively small decrease in runoff may have dramatic consequences for the provision of water for domestic, agricultural, and industrial use (Kaczmarek et al., 1996). In the study area, effects of climatic changes on water system might be through changes in the hydrological cycle. This chapter briefly analyzes the climatic characteristics of the area under consideration before attempting the quantification of available water resource. Such analysis will focus on variables, such as rainfall, humidity, evaporation, temperature, wind speed, and sunshine duration. However, more concern will be given to the rainfall, particularly, the rainfall analysis in space in order to estimate the areal mean rainfall. For this both the isohyetal and Thiessen polygon methods will be applied in this analysis.
One of the main features of tropical regions is the very high absorption of heat and its low emanation (Balek, 1983). From a meteorological point of view, the area is situated in the tropical region in the northern hemisphere and hence it is under the direct influence of the climatic regimes of the tropics.

Primarily the Inter Tropical Convergence Zone (ITCZ) that tends to follow the seasonal march of the sun controls the summer rainfalls, which are dominant over most of Yemen. According to Balek (1983) changes in the position of the sun throughout the year are mainly responsible for ITCZ fluctuation. The center of the ITCZ tends to move up to 10-20° north of the equator as it follows the sun into the northern summer hemisphere. Greatest movement of ITCZ occurs over Africa and the western parts of the Indian Ocean, where it fluctuates between the Tropic of Cancer (in July) and the Tropic of Capricorn (in January).

The study area is very heterogeneous in terms of climate. The climate varies from arid to semi-arid on the Tihama zone and central zone respectively to sub humid on higher altitudes in the surrounding mountains in the east zone. The main climate-controlling factors are (1) topographic elevation and (2) distance from the Red sea. Prevailing south–Westerly winds carry moisture–laden storms from the Indian Ocean into western slopes of the continental divide during summer season. The catchment area receives large amount of rain. For example, the lbb area receives more than 1000 mm. The Tihama Plain, however, receives less moisture from these storms. As a result, the plain has a semi-arid to arid climate. Rainfall is rare near the coast, but is sufficient to sustain rain-fed agriculture in the areas adjacent to the foothills in the east. In addition, temperatures are high in the Tihama coastal plain, but decline towards east. The cool climate occurs on the peaks and mountain slopes in the eastern part of the study area.
Data concerning long-term annual, monthly variations in rainfall and temperature as well as other meteorological parameters are not adequately available. Climatic observations started with the establishment of the Wadi Zabid Project during the late 1960s and early 1970s. Therefore, most rainfall stations in the study area have short-term records that cannot help to study the long-term variations of annual rainfall totals. Annual and monthly rainfall data and other information on the climate and hydrology of the area are stored in the database of the Tihama Developments Authority (TDA). There is a continuous rainfall record from 1970 for the following stations Zabid Town, Al-Udain, Al Har, Al Dalil, Rihab and Yarim. There are only two meteorological stations, from which information about different variables apart from rainfall are available. These are Al Jerbah and Ibb. These stations have records of sunshine, evaporation, relative humidity and wind speed direction. In the following pages discussion with respect to variables other than rainfall is included. The discussion on rainfall and its spatial temporal variation is included in latter part. Furthermore, there is a stream flow gauge at Al-Kolah (downstream). The following table gives the hydrometeorological network in Wadi Zabid basin.

Table 4.1: Hydrometerological Stations in Wadi Zabid Basin

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Distance from the Red Sea (km)</th>
<th>Type of Data</th>
<th>Unit</th>
<th>Date of installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Zabid Town</td>
<td>14° 11' N</td>
<td>43° 19'E</td>
<td>105</td>
<td>22.22</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Jun. 1969</td>
</tr>
<tr>
<td>2 Al Udain</td>
<td>14° 11' N</td>
<td>44° 03'E</td>
<td>1500</td>
<td>101.48</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Jan. 22, 70</td>
</tr>
<tr>
<td>3 Wadi Al Har</td>
<td>14° 31' N</td>
<td>44° 14'E</td>
<td>2000</td>
<td>113.33</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Jan. 21, 70</td>
</tr>
<tr>
<td>4 Rihab</td>
<td>14° 19' N</td>
<td>44° 05'E</td>
<td>1500</td>
<td>118.54</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Jan. 1, 69</td>
</tr>
<tr>
<td>5 Al-Dalil</td>
<td>14° 09' N</td>
<td>44° 10'E</td>
<td>1800</td>
<td>120.74</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Sep. 22, 69</td>
</tr>
<tr>
<td>6 Yarim</td>
<td>14° 21' N</td>
<td>44° 22'E</td>
<td>2400</td>
<td>140</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Sep. 23, 69</td>
</tr>
<tr>
<td>7 Al Jerbah*</td>
<td>14° 09' N</td>
<td>43° 26'E</td>
<td>240</td>
<td>39.26</td>
<td>All Variables #2</td>
<td></td>
<td>Sep. 12, 69</td>
</tr>
<tr>
<td>8 IBB*</td>
<td>13° 59' N</td>
<td>44° 11'E</td>
<td>1800</td>
<td>120.74</td>
<td>All Variables #2</td>
<td></td>
<td>Sep. 2, 69</td>
</tr>
<tr>
<td>9 Fuleih @</td>
<td>14° 11' N</td>
<td>43° 42'E</td>
<td>900</td>
<td>----</td>
<td>Daily rainfall</td>
<td>mm</td>
<td>Jan. 10, 70</td>
</tr>
<tr>
<td>10 Al-Kolah #1</td>
<td>14° 06' N</td>
<td>43° 32'E</td>
<td>335</td>
<td>60.74</td>
<td>Gauge station</td>
<td>m²</td>
<td>Jan. 1970</td>
</tr>
</tbody>
</table>

Source: Modified from DHV Consulting Engineers, the Netherlands (1983)
# (Bait Al Fatimy) #1 Down Stream #2 Full-fledged Meteorological station* Full fledge Meteorological stations @ Functional only during project period (1969-74).

57
Sunshine

In the study area, average annual sunshine hours in Al Jerbah (Tihama Lowlands) and Ibb (Highlands) stations are approximately 7.6 and 7.9 hours respectively. Seasonally, the area receives more sunshine during post-monsoon and late per-monsoon seasons because of the clear skies during these times. However, the duration of sunshine decreases during the monsoon season due to the density of clouds. Although both the Tihama lowlands and the highlands receive the same amount of sunshine, the Tihama Plain experiences high temperatures and high air humidity. This probably is due to the influence of low altitude and nearness to the Red Sea. Figure 4.2 gives the graph of the mean monthly sunshine at the two stations.

Temperature

The sun in the tropical regions is directly overhead twice a year and the temperature is under the direct influence of the sun (Balek, 1983). The heat balance of land surfaces are largely controlled by the input of solar energy, thus, air temperatures reflect the state of the heat balance of the surface (Lockwood, 1985). Some other factors however, have a significant impact. According to Balek (1983) a positive balance of solar radiation resulting from an excess of incoming radiation all the year is responsible for high air temperature.

In the study area, mean annual temperature varies between approximately 18°C in the highlands (at Ibb station) and 30°C in the Tihama lowlands (at Al Jerbah station). There is a gradual decrease in the mean temperatures from west to east with the rise in elevation. In the west, the Tihama lowlands can be identified as the hottest areas of the Wadi Zabid basin represented by Al Jerbah station, which has a record of maximum temperature as high as 45°C (July, 1976). In the eastern mountainous regions of the Wadi basin, elevation becomes more dominant factor and temperature decreases rapidly. The Ibb
station, at higher altitude (1800 m), experiences low mean annual temperature (18.1°C).

Throughout the Tihama lowlands, the mean maximum temperature ranges between 34°C and 42°C, while in the highlands it ranges between 29.1°C and 32.6°C. The mean annual maximum temperatures of the Tihama plain and the Highlands are 38.8°C and 30.2°C respectively. Figure 4.3 illustrates the monthly temperature in Al Jerbah and Ibb meteorological stations.

The western part (Tihama Plain) of the study area is too hot, particularly in summer. High temperatures start as early as April, and continue through September, whereas low temperatures prevail from October to February. In the month of June, when the sun is overhead over the Tropic of Cancer in the north, the Tihama lowlands experience high mean temperature values. The highlands experience low temperature in comparison to Tihama plain due to nature of terrain. The Ibb station (1800m) records mean annual maximum and minimum of 30.2°C and 5.9°C respectively thus it has a range of 24.3°C. It appears that, at higher elevation, the mean monthly and annual temperatures are low. It is also noted that there is variability with time, which is represented by annual and seasonal variation in temperatures. For example, the Al Jerbah data show that peak mean monthly temperature occurred during June (42.1°C) for the recorded period of 30 years (1970 – 1999), while minimum temperatures occurred during January (16.7°C) for the same-recorded period. It shows that the annual range of temperature is of the order of 25.4°C. In general, temperatures increase during the monsoon season (June – September) and decrease after its withdrawal. Figure 4.4 shows the climatic graphs for Al Jerbah and Ibb stations.
Monthly Sunshine at Ibb and Al Jerbah Stations

Monthly Temperature at Al Jerbah Station

Monthly Temperature at Ibb Station

Fig. 4.2

Fig. 4.3a

Fig. 4.3b
Climatic Graphs for Al Jerbah and Ibb

Al Jerbah

<table>
<thead>
<tr>
<th>Station</th>
<th>Altitude</th>
<th>Mean Temperature (annual °C)</th>
<th>Mean Max. Temperature (Monthly)</th>
<th>Mean Min. Temperature (Monthly)</th>
<th>Curve of the Mean Monthly Temperature</th>
<th>Curve of the Mean Monthly Precipitation</th>
<th>Mean Annual of Precipitation (mm)</th>
<th>Arid Season</th>
<th>Humid Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ibb</td>
<td>1,800 m</td>
<td>18.1</td>
<td>32.6</td>
<td>2</td>
<td>a</td>
<td>b</td>
<td>1979.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Wind Speed

According to Balek (1983) the difference between the temperature of equatorial regions and that of subtropics is one of the main forces of the tropical air circulation. There is a seasonal movement of the ITCZ across the equator. Changes in the position of the sun throughout the year are mainly responsible for the Inter Tropical Convergence Zone (ITCZ) fluctuation; therefore, the center of the ITCZ tends to move up to 10 – 20° north of the equator. The monsoon system is referred to the surface winds of southern Asia, which reverse between winter and summer.

The monsoon dominates the climate conditions during summer over the whole of Yemen and the study area as well. Being a part of the tropical regions, the air movement of the study area is influenced by the mechanism of the air circulation in the tropics, particularly, the trade winds in winter and the monsoon system in summer. In addition, there are wind currents of local nature. In the Tihama coastal areas, it is common to experience sea breezes on summer afternoons and land breezes at nights. In the mountainous areas, it is common to find mountain and valley winds.

In the study area, the systematic observation of the meteorological elements started at Zabid in 1969. According to the data obtained from the Tihama development Authority (TDA) for 19 years (1979 – 1997), mean annual wind speed at Al-Jerbah was 5.7 km/hr). The peak mean monthly value occurred during August (7.4 km/hr). The minimum value occurred during the month of November (3.8 km/hr). There were also seasonal variations in wind speed, for example, the highest seasonal average of the wind speed occurred during the summer months, which is the monsoon season, and the spring months, which is the pre- monsoon season, and ranged between seasons 6.4 km/hr and 6 km/hr, respectively. The minimum season average occurred in the Post-monsoon 4.4 km/hr.
In the mountainous area, represented by the meteorological station Ibb, mean annual wind speed was 6.4 km/hr. The maximum annual average was 11.6 km/hr and the minimum annual average was 1.2 km/hr. Figure 4.5 illustrates the minimum, maximum, and average of wind speed at Al Jerbah and Ibb stations.

Relative Humidity

Air humidity is highly dependent on air temperature and air pressure fluctuation (Balek, 1983). In the study area, a typical feature of Tihama part is the rather high relative humidity. In the Tihama lowlands, compared to the catchment areas, both the temperatures and the air humidity are high throughout the year. Thus, one could assume that there is a high vapor content there, throughout the year. Early measurements of the relative air humidity started at Zabid meteorological station, which constructed in FAO Camp (1969). There have been continuous records of relative humidity since 1970.

According to the available data for the period of 28 years (1970—1997) from Al Jerbah. It may be observed that in the Tihama lowlands the average annual relative humidity is high. The mean annual relative humidity is 64 percent. There are daily, monthly and seasonal variations. According to observations conducted by Tesco (1970), the diurnal variation of relative humidity is rather regular, the maximum value occurs in the early morning between 6 and 7 a.m. and the minimum value between 2 and 4 p.m. (Tesco, 1971). At Al Jerbah station, peak mean monthly relative humidity was during February and March, while mean minimum value occurred during August. Highest mean value relative humidity occurred during the winter months, while the lowest mean value occurred during the summer months. These variations in the relative humidity can be attributed to the seasonal temperatures variations. Figure 4.6 illustrates the mean monthly humidity in Al Jerbah and Ibb stations.
Evaporation

Evaporation is the conversion of water from the liquid state to vapors. According to Cadler (1990) evaporation in the natural environment can be considered to be the result of a balance between externally applied atmospheric demand and the availability of water at the evaporating surface. Evaporation from open surfaces and soil are of great importance in hydrometeorological studies (Raghunath, 1997). The two main factors influencing evaporation from an open water surface are: (1) the supply of energy to provide the latent heat of vaporization, and (2) the ability to transport the vapor away from the evaporative surface (Chow et al. 1988). The incoming solar radiation is the dominant source of heat energy and influences evaporation amounts over the land surface according to latitude and season (Shaw, 1987).

According to Chow et al. (1988) the ability to transport vapor away from the evaporative surface depends on the wind velocity over the surface and specific humidity gradient in the air above it. Other factors effecting evaporation are nature of surface area, barometric pressure, and sensitivity of the water (Raghunath, 1997). According to Shaw (1987), the temperature of both air and the evaporating surface, which is dependent on the main heat energy source (the sun), is important in the processes of evaporation. For instance, the higher the air temperature, the more water vapor it can hold, and similarly, if the temperature of the evaporating water is high, it can be more readily vaporized. Thus evaporation amounts are high in tropical climates and tend to be low in Polar regions (Shaw, 1987).

Being part of the tropical region, the evaporation of the study area, particularly in the Tihama lowlands, is higher than the highlands. It is here that the evaporation is under the direct influence of the high
Mean Monthly Wind speed at Al Jerbah and Ibb

![Graph showing mean monthly wind speed at Al Jerbah and Ibb](image)

Fig. 4.5

Relative Humidity at Al Jerbah Station

![Graph showing relative humidity at Al Jerbah Station](image)

Fig. 4.6a

Relative Humidity at Ibb Station

![Graph showing relative humidity at Ibb Station](image)

Fig. 4.6b

66
temperatures. Class – A pan evaporation data are available at Al-
Jerbah station (Tihama plain). The mean annual total evaporation was
2835 mm during the period of 30 years (1970 – 1999). The highest
mean monthly total was 300 mm (July), while the lowest mean monthly
total was 188.2 mm (January) for the same periods. There is also
seasonal variation in the evaporation values in the Tihama lowlands.
For instance, high values occurred during the summer season months
which start as early as April and continue until September, while low
values of evaporation occurred during the winter months and ranged
between 270 and 206.1 mm in the two seasons, respectively. Generally,
in the Tihama lowlands, it is noted that the high values of evaporation
accompanied by high air temperatures and wind speeds as well as low
values of relative humidities, all of which occurred during the summer
seasons. In this time of the year, the sun is directly overhead (Summer
& Northern hemisphere). Therefore, the area absorbs high amounts of
heat. Tesco (1970) observed that the daily distribution of evaporation,
in the Tihama plain zone, was roughly as follows:

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 06 a.m. to 12</td>
<td>20%</td>
</tr>
<tr>
<td>From 12 a.m. to 06 p.m.</td>
<td>50%</td>
</tr>
<tr>
<td>From 06 p.m. to 06 a.m.</td>
<td>30%</td>
</tr>
</tbody>
</table>

The following table gives the climatic variables in Al Jerbah and Ibb
stations.
Table 4.2: Climatic variables in Al Jerbah and Ibb Stations

<table>
<thead>
<tr>
<th></th>
<th>Al Jerbah</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp (max)</td>
<td>34.06</td>
<td>35.76</td>
<td>39.13</td>
<td>41.10</td>
<td>41.65</td>
<td>42.15</td>
<td>41.67</td>
<td>40.92</td>
<td>40.19</td>
<td>38.55</td>
<td>36.41</td>
<td>34.24</td>
<td>38.81</td>
<td></td>
</tr>
<tr>
<td>Temp (min)</td>
<td>16.66</td>
<td>17.38</td>
<td>19.11</td>
<td>21.23</td>
<td>23.51</td>
<td>24.70</td>
<td>24.74</td>
<td>24.16</td>
<td>22.88</td>
<td>20.63</td>
<td>17.64</td>
<td>17.12</td>
<td>20.81</td>
<td></td>
</tr>
<tr>
<td>Temp (mean)</td>
<td>25.27</td>
<td>26.17</td>
<td>28.62</td>
<td>30.76</td>
<td>32.10</td>
<td>33.52</td>
<td>32.96</td>
<td>32.07</td>
<td>31.05</td>
<td>29.23</td>
<td>26.99</td>
<td>25.83</td>
<td>29.57</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>70.76</td>
<td>69.35</td>
<td>65.63</td>
<td>61.25</td>
<td>60.71</td>
<td>59.81</td>
<td>58.95</td>
<td>60.96</td>
<td>65.38</td>
<td>66.24</td>
<td>66.45</td>
<td>68.87</td>
<td>64.42</td>
<td></td>
</tr>
<tr>
<td>Wind speed (km/hr)</td>
<td>5.00</td>
<td>5.00</td>
<td>7.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>7.00</td>
<td>7.00</td>
<td>5.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>5.90</td>
<td></td>
</tr>
<tr>
<td>Sunshine</td>
<td>7.16</td>
<td>6.83</td>
<td>6.62</td>
<td>7.74</td>
<td>8.31</td>
<td>8.61</td>
<td>5.41</td>
<td>6.08</td>
<td>7.39</td>
<td>8.84</td>
<td>9.34</td>
<td>8.18</td>
<td>7.60</td>
<td></td>
</tr>
<tr>
<td>Evaporation (mean)</td>
<td>6.30</td>
<td>6.80</td>
<td>6.00</td>
<td>9.50</td>
<td>9.60</td>
<td>9.90</td>
<td>9.60</td>
<td>9.60</td>
<td>7.90</td>
<td>7.30</td>
<td>6.90</td>
<td>6.40</td>
<td>8.10</td>
<td></td>
</tr>
<tr>
<td>Evaporation (Total)</td>
<td>188.00</td>
<td>180.20</td>
<td>242.10</td>
<td>264.20</td>
<td>287.60</td>
<td>290.20</td>
<td>303.20</td>
<td>261.80</td>
<td>212.60</td>
<td>221.60</td>
<td>207.60</td>
<td>196.80</td>
<td>2855.90</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>10.06</td>
<td>10.80</td>
<td>9.04</td>
<td>18.99</td>
<td>44.90</td>
<td>9.89</td>
<td>41.92</td>
<td>77.30</td>
<td>96.91</td>
<td>58.43</td>
<td>5.58</td>
<td>1.48</td>
<td>385.29</td>
<td></td>
</tr>
<tr>
<td>Rainy days</td>
<td>1 1</td>
<td>1 1</td>
<td>2 4</td>
<td>2 3</td>
<td>6 8</td>
<td>4 0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Ibb</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp (max)</td>
<td>32.00</td>
<td>29.10</td>
<td>30.50</td>
<td>32.00</td>
<td>32.60</td>
<td>31.20</td>
<td>29.10</td>
<td>29.70</td>
<td>29.20</td>
<td>29.20</td>
<td>28.60</td>
<td>29.60</td>
<td>30.20</td>
<td></td>
</tr>
<tr>
<td>Temp (min)</td>
<td>2.60</td>
<td>3.40</td>
<td>7.10</td>
<td>8.10</td>
<td>9.20</td>
<td>8.80</td>
<td>8.80</td>
<td>9.00</td>
<td>9.00</td>
<td>5.00</td>
<td>5.00</td>
<td>0.60</td>
<td>2.00</td>
<td>5.90</td>
</tr>
<tr>
<td>Temp (mean)</td>
<td>17.30</td>
<td>16.30</td>
<td>18.80</td>
<td>20.10</td>
<td>20.90</td>
<td>20.00</td>
<td>19.60</td>
<td>19.40</td>
<td>17.00</td>
<td>17.00</td>
<td>14.80</td>
<td>15.80</td>
<td>18.10</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>58.00</td>
<td>62.00</td>
<td>59.00</td>
<td>58.00</td>
<td>57.00</td>
<td>66.00</td>
<td>66.00</td>
<td>64.00</td>
<td>60.00</td>
<td>59.00</td>
<td>61.00</td>
<td>61.00</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Wind speed (km/hr)</td>
<td>4.70</td>
<td>5.00</td>
<td>7.60</td>
<td>12.00</td>
<td>4.10</td>
<td>4.10</td>
<td>3.90</td>
<td>3.60</td>
<td>3.10</td>
<td>2.80</td>
<td>2.70</td>
<td>4.60</td>
<td>6.41</td>
<td></td>
</tr>
<tr>
<td>Sunshine</td>
<td>7.22</td>
<td>6.66</td>
<td>8.65</td>
<td>7.65</td>
<td>6.30</td>
<td>7.29</td>
<td>5.01</td>
<td>5.85</td>
<td>6.70</td>
<td>6.45</td>
<td>8.20</td>
<td>8.20</td>
<td>7.01</td>
<td></td>
</tr>
<tr>
<td>Evaporation (mean)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Evaporation (Total)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>15.26</td>
<td>31.42</td>
<td>99.53</td>
<td>173.19</td>
<td>239.55</td>
<td>291.29</td>
<td>365.27</td>
<td>375.54</td>
<td>372.11</td>
<td>88.06</td>
<td>38.96</td>
<td>15.40</td>
<td>1979.24</td>
<td></td>
</tr>
<tr>
<td>Rainy days</td>
<td>4 5</td>
<td>12 17</td>
<td>19 22</td>
<td>23 23</td>
<td>20 11</td>
<td>5 3</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
</tbody>
</table>

Evapotranspiration

The process of evaporation from the land surface and transpiration from vegetation are collectively termed evapotranspiration (EV) (Chow et al, 1988). Evapotranspiration is the total water lost from a cropped (irrigated) land due to evaporation from soil and transpiration by the plants or used by the plants in building up of plant tissue (Raghunath, 1997). It is a key component of the hydrological cycle (Kaczmarek et al, 1996). As previously mentioned, the evaluation evapotranspiration (EV) is important in the study of the impact of climate change on water resources, because evaporation can be considered a key link between the atmosphere and the soil matrix within the hydrological cycle. Chow et al (1988) indicate that the main
factors influencing evapotranspiration (EV) are the supply of heat energy (Solar radiation), the ability to transport vapor away from the evaporative surface (wind velocity) and the supply of moisture at the evaporative surface (Vegetated surface).

According to Sumner (1988), the conditions favorable to high levels of evapotranspiration are: (1) low humidity of the overlying air (2) high temperature of the overlying air; (3) high temperature of the evaporating water surface; (4) high level of air motion to introduce drier air continuity to the evaporating surface; (5) adequate soil moisture to provide water through a plant’s root system; and (6) strong isolation and high air temperatures to stimulate plant growth and transpiration.

In the study area, especially in the Tihama part, the climate conditions are favorable to high levels of evapotranspiration. Based on meteorological data from Al Jerbah (1970 – 88) and Ibb (1988) stations, the potential evapotranspiration was calculated using Penman equation. For example, annual potential crop evapotranspiration (mm), calculated from sunshine data, was 1913 and 1550 mm in the two stations, respectively. Further more, potential annual crop evapotranspiration was calculated from radiation data at Ketab station, near Ibb (catchments zone). It was 1646 mm during the period.

Rainfall

Precipitation is one of the important processes in the hydrological cycle. It may occur in a region in a form of rainfall, snowfalls or in other minor form of precipitation. In whatever way it occurs it has a significant role so far as the availability of water is concerned as it determines the climatic water balance of a given region. Therefore, it is very significant to analyze the rainfall over the basin along with its characteristics, amounts, monthly and seasonal variations, aerial distribution and spatial variability.
In Wadi Zabid basin, rainfall measurements started as early as 1969. Later the measurements were made at several selected sites that represented the entire basin. Data recorded at the different rainfall stations of the basin formed the main source of information for surface water resource assessment during the Wadi Zabid project (1969 – 1972). After the establishment of the Tihama Development Authority (TDA), the meteorological station at Al Jerbah (Tihama part) and the other rainfall stations in the Wadi came under the responsibility of this authority. As far as hydrometeorological data are concerned, Wadi Zabid basin has one of the best hydrometeorological networks in the country. However, the data are still inadequate for planning and integrated management of the area’s water resources. In general a few rainfall stations have continuous records, however, in some cases the continuity is not maintained. For example, the rainfall station of Al Fuleih, in the central catchments area, was closed after few a years of the project operation. Shaw (1987) indicates that, "The need for the continuous recording of precipitation arose from the need to know not just how much rain has fallen but when it fell and over what period". As far as rainfall record frequency is concerned, the study area is lacking in daily rainfall data. On the other hand, monthly and annual rainfall amounts from the stations are available for a period of 30 years.

Causes of Rainfall

Due to the lack of recorded climatic and meteorological data, particularly on the air circulation over Yemen, it has been very difficult to determine the main mechanisms that are behind the cause of rainfall. Many attempts, however, have been made to identify the causes of rainfall. For example, Van Enk and Van der Gun (1984) indicate that there is a general belief that rainfall in Yemen is caused by three main meteorological mechanisms: (1) the Mediterranean
effect, consisting of an ingress of Polar air following a depression which causes the light rainfalls that sometimes occur in the months of December and January; (2) the Red Sea Convergence Zone effect (RSCZ), occurring during winter, spring and fall seasons, causing the first rainy season in April and May and (3) a Monsoon, Inter Tropical Convergence Zone, effect (ITCZ) prevailing during July and August, causing the main rainy season. Shaw (1982) indicates that the seasonal movements of the ITCZ play a large part in the development and characteristics of the weather conditions in the monsoon areas. Monsoon is the main rainy season in the study area. Figure (4.7) shows the rainfall graphs for Wadi Zabid.

**Mean Annual Rainfall**

The monthly records are available for a period of 30 years (1970-1999) from 8 stations in the study area. Mean annual rainfall decreases from east to west. Monsoon is the main rainy season in the study area. The highest and the lowest mean annual rainfall recorded at Ibb and Zabid Town are stations 1917.7mm, 185.5mm respectively during the period of 30 years. Rainfall is higher over the highlands in the catchment area than in the Tihama lowlands. Over the Tihama plain, the rainfall decreases from east to west. From 500 mm/year in the east, near the foothills, to less than 100 mm/year near the coast. At Al Jerbah station, in the middle of the Tihama plain, mean annual rainfall is 385 mm whereas, in Zabid Town to the west, it is 185.5mm. In the highlands the rainfall ranges from 370.1 mm at Al Har to the highest amount mentioned above at Ibb. The annual rainfall distribution over the wadi basin is shown in figure 4.8.

**Seasonal Distribution of Rainfall**

As far as seasonal amounts and distribution of rainfall are concerned, it may be observed that rainfall varies from season to season and from zone to zone across the wadi basin. The following is
RAINFALL GRAPHS - WADI ZABID

Fig. 4.7a: Zabid Town
AA: 188

Fig. 4.7b: Al Har
AA: 376

Fig. 4.7c: Al Jerbah
AA: 385

Fig. 4.7d: Al Dalil
AA: 698

Fig. 4.7e: Rihab
AA: 592

Fig. 4.7f: Yarim
AA: 719

Fig. 4.7g: Al Udain
AA: 846

Fig. 4.7h: Ibb
AA: 1979

AA: Annual Average Rainfall (mm)
an analysis of the pattern of seasonal distribution of rainfall. Since monsoon is the main rainy season in the area. The year has been classified into three seasons such as Pre – monsoon, monsoon, and post monsoon.

**Pre – Monsoon (February to May)**

During this season, rainfall is mainly caused by the Red Sea Convergence Zone effect (RSCZ). This is the first rainy season of the region. The RSCZ rains are most significant in the highlands of the catchments area. During this season, in general, the Wadi Zabid basin receives nearly 32% of its mean annual rainfall. The rainfall decreases from east to west probably due to the topographic effects). The higher the area, the greater is the rainfall it receives. Monthly maximum occurred in April and May. In the highlands, the highest monthly mean occurred in Ibb monthly station in May (239.5 mm). The rainfall records of the two stations (Al- Jerbah and Zabid Town) situated in the Tihama lowlands show that this area received less rainfall than the catchments area during this season. Also the rainfall occurred at these stations in May. It was 44.9 mm and 16.1 mm respectively. Figure 4.9 illustrates the pre-monsoon rainfall distribution.

**Monsoon Season (June to September)**

The monsoon is the most important rainy season. The air circulation, which is associated with the Inter Tropical Convergence Zone (ITCZ), causes the rainfall. Most of the rainfall in the area falls from monsoon systems (Storms) moving in from the Indian Ocean.

The monsoon season starts as early as June and continues through September, while in sometimes continues till the month of October as noted from the rainfall records during the years (1970 – 1999). The heaviest rainfall events are observed in the mountainous areas, where showers and thunderstorm are common in unstable, warm, humid air. The hills and mountains serve as barriers causing the air to raise leading to condensation-cloud formation and rainfall occurrence.
In the highlands, for example, the highest mean monthly rainfall occurred at Ibb station in August (375.5 mm). In the Tihama lowlands, however, the highest mean monthly rainfall occurred at Al Jerbah and Zabid Town stations in September with values reaching 96.9 and 47 mm, respectively. Generally, the study area receives nearly 58 percent of its mean annual rainfall during the monsoon season. Figure 4.10 illustrates the monsoon rainfall distribution over the wadi basin.

Post Monsoon Season (October to January)

Rainfall is caused by: (1) the Mediterranean effect, which causes occasional light rainfalls, occurring in the months of December and January, and (2) the Red Sea Convergence Zone effect (RSCZ). During this season, the area as a whole receives mean seasonal total of 580.9 mm, which is nearly 10 percent of total mean seasonal rainfall received by the area. During this season, the Tihama lowlands received nearly 20 percent of their annual rainfall, whereas the highlands (catchments) received 8.8 percent of their annual rainfall. In the highlands, for example, the highest mean monthly occurred at Ibb station in the month of October (87.2 mm). In the Tihama lowlands, the highest mean monthly (58.4 mm) also occurred at Al Jerbah station in the same month. Figure 4.11 illustrates the post monsoon rainfall distribution over the wadi basin.

It can be concluded that the monsoon season is the most important rainy season in the study area. During the southwest monsoon seasons, the Tihama lowlands and the highlands receive nearly 59 and 58 percent of their mean seasonal rainfall, respectively. In general, the monsoon season contributes about 58 percent of the mean seasonal total rainfall of the Wadi Zabid basin. The second important rainy season is the pre – monsoon season that contributes 32 percent of the mean seasonal totals. Finally the post – monsoon season contributes about 10 percent of the total mean seasonal rainfall.
WADI ZABID BASIN
POST MONSOONAL RAINFALL DISTRIBUTION

Fig. 4.11