CHAPTER V

HYDROMETEOROLOGY

GENERAL

In the evaluation of the hydrological characteristics of a region, climatic and meteorologic parameters play a vital role, as the quantitative assessment of groundwater reserves is totally based on them. Hydrologic characteristics of an area are determined largely by its geology and geography, climate playing a dominant role. Among climatic factors that establish the hydrologic features of a region are the amount and distribution of precipitation; the effects of wind, temperature and humidity on evapotranspiration.

Geographically the study area lies in the tropical zone (i.e. between the tropics of Capricon and Cancer) and hence it is marked by three distinct seasonal variations viz. summer, monsoon and winter. As the location of Inter Tropical Discontinuity (ITD) falls in the vicinity of study area, the climatic and meteorologic phenomenon are influenced by ITD.

As alluded earlier, the temperature, humidity, insolation, precipitation, run-off and evaporation with evapotranspiration are the basic parameters to be considered for carrying out water balance studies. These are individually discussed herewith in detail.

CLIMATIC FACTORS

TEMPERATURE

The meteorological observatory in the district headquarter at Baroda posseses very well maintained records, and the observations of this station have been taken as representatives of the conditions prevailing in the study area in general.

Due to the location of the study area in the tropical zone and the position of ITD, temperature are normally high round the year. Seasonal and latitudinal variations of ITD affect the extremes, seasonal and diurnal ranges. The monthly temperature records (Table 5.1) reveal that the period from March to May is one of continuous increase in temperatures. The day temperatures during May are the highest, being about 40.5°C. The heat particularly in the later part of the summer season is intense and on individual days temperature may go upto as much as 45°C. With the onset of the monsoon early in June there is appreciable drop in the day temperatures but nights are as warm as during the summer. After the withdrawal of the monsoon by about the end of September there is slight increase in day temperatures and secondary maximum in day temperatures is reached in October. However, the night temperature decreases after the withdrawals of the monsoon. After mid November both day and night temperatures decreases rapidly till January which is the coldest month. The mean daily maximum temperature in January is 30°C and the mean daily minimum 10.6°C. The study area is sometimes affected by cold waves in association with weather disturbances passing across north India and the minimum temperature may reach the freezing point of water.

The highest maximum temperature recorded at Baroda was 46.7°C on 20th May, 1955 and the lowest minimum was 1.1°C recorded on 15th January, 1955.

The seasonal course of mean monthly temperature (Fig. 5.1) suggest a typical continental type of annual variation. The curve shows two maxima and two minima. The minima quite properly fall in the centre of the respective winters. Then temperature rises sharply through the spring months and ascends the first maximum in the early summer i.e. May. Then temperature drops under the influence of the increased cloud cover even though the precipitation may be quite small. This is the secondary minimum. At the end of the rainy season i.e. October while the sun is still high in the sky the temperature rises again and the secondary maximum develops.

Table 5.1. Average Monthly Normals of Temperature & Relative Humidity

Month	Mean Monthly temperature Minimum °C	Mean Monthly temperature Maximum °C	Mean Monthly temperature °C	Relative Humidity 08.30hr %	Relative Humidity 17.30 hr %	Mean Monthly Humidity %
JAN	10.6	30.1	20.3	69	36	52.5
FEB	12.3	32.3	22.3	63	29	46.0
MAR	16.1	36.5	26.3	53	23	38.0
APR	21.5	39.5	30.5	56	22	39.00
MAY	25.9	40.5	33.2	67	33	50.00
JUN	27.1	37.5	32.3	74	52	63.00
JUL	25.3	32.1	28.7	87	77	82.00
AUG	24.8	31.7	28.2	86	72	79.00

Table 5.1 (Contd.)

Month	Mean Monthly Temperature Minimum °C	Maximum °C	Mean Monthly Tempera -ture°C	Relative Humidity 08.30 hr %	17.30hr %	Mean Monthly Humidity %
SEP	24.0	32.5	28.2	85	67	76.00
OCT	19.4	35.3	27.3	75	50	62.5
NOV	14.0	33.3	23.6	68	47	57.5
DEC	10.7	30.9	28.8	72	41	56.5
Mean Annual	19.3°C	34.3°C	27.5°C	71 %	46 %	52.1 %

HUMIDITY AND CLOUDINESS

Water content in atmosphere, is expressed as relative humidity which varies directly with the rainfall and is expressed as the ratio of two vapor pressures, the actual and the saturation. The actual vapor pressure changes with the pressure and the saturation vapor pressure varies with temperature. Therefore, relative humidity changes markedly in an adiabatic process and in all other processes involving a change in temperature or pressure. Relative humidity has a wide diurnal variation, changing inversely with the temperature.

The trend of relative humidity in the study area (Table 5.1) indicates that during the south-west monsoon

SEASONAL VARIATION OF TEMPERATURE AND EVAPORATION

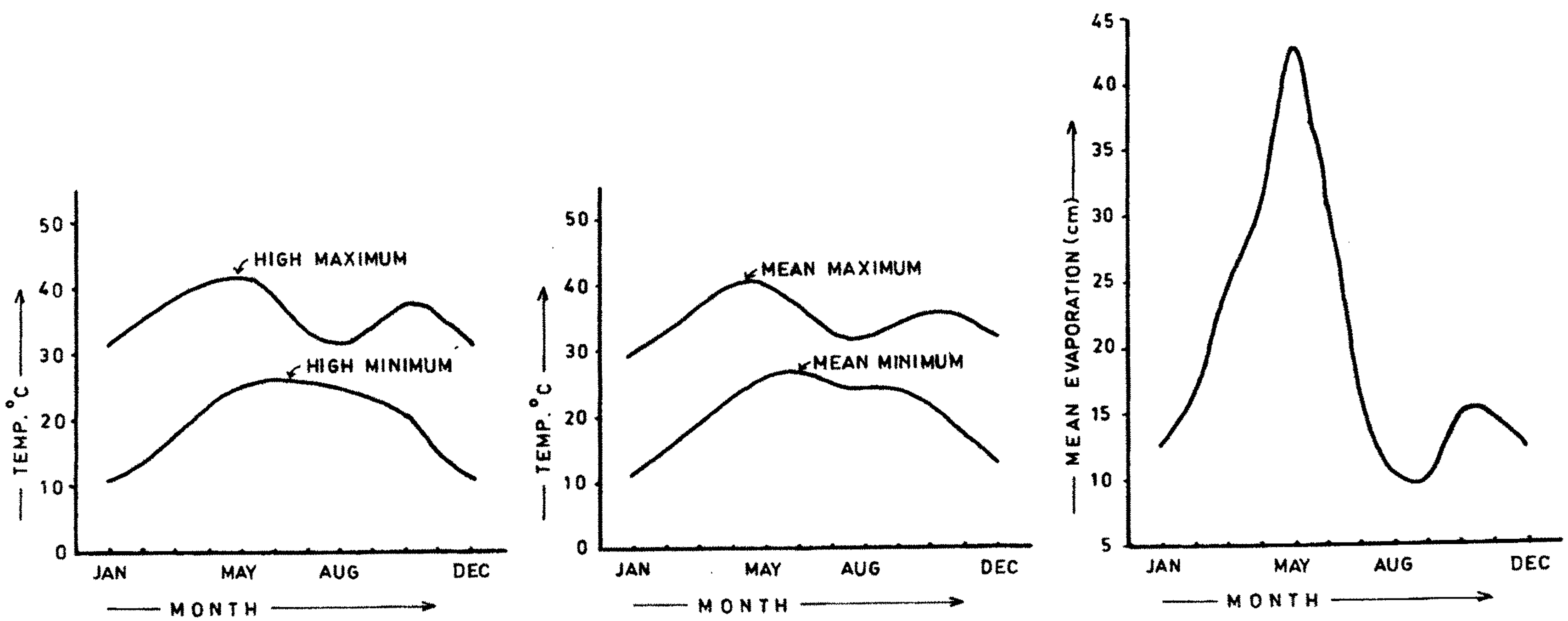

FIG. 5.1

season it is high, generally exceeding 70 %. In the rest of the year the air is dry. The driest part of the year is the period from February to April with relative humidity less than 30% in the afternoon.

Skies are generally heavily clouded or overcast in the south-west monsoon season. Cloudiness rapidly decreases in the post monsoon season. Skies are mostly clear or lightly clouded during the period December to May.

WINDS AND INSOLATION (SUNSHINE)

Winds are generally of the nature of breeze with some strengthening during the late summer and early part of the south-west monsoon season. However, wind speeds upto 80 km/hr have been observed during storms. Winds blow mostly from the south-westerly and westerly directions during the period from May-September while, it blows from the north or north-east during the post monsoon and early winter months (Table 5.2). In the later half of the cold season and the first two months of summer, winds are mostly from west direction.

Table 5.2 Mean Monthly Wind Velocity

Month	Wind speed km/hr.	Direction
January	4.0	Westerly
February	3.7	
March	4.0	
April	5.5	
May	9.2	South-westerly to Westerly
June	10.6	
July	8.7	
August	7.4	
September	5.0	
October	2.7	
November	2.7	North & North-East
December	3.2	
Mean Annual	5.6 km/hr.	

Sunshine in the study area varies from 9.35 hours to 7.20 hours/day. There is a great local difference in the duration of sunshine in areas among hills. One reason is that the astronomically determined time of sunrise or sunset is influenced by topographical features, and the duration of sunshine is reduced; another reason is the frequent occurrence of clouds particularly in winters. The monthly pattern of insolation shows marked variations. Between January and March, the area has a mean of 7.74 hours of sunshine. During the wet season, the situation becomes more distorted with increasing cloud cover, and minimum sunshine hours are experienced in the month of August.

The mean monthly hours computed by the standard solar radiation table is depicted in Annexure III.A.

RAINFALL

Luckily, the rainfall data in and around the basin is well documented. There are 14 numbers of rain gauge stations in the study area and its surroundings. The daily and monthly rainfall records are maintained by meteorological units of Irrigation Department, Gujarat Government.

The mean monthly rainfall records of 12 stations have been collected for rainfall analysis and are appended in Appendix 5.1/A-K.

The annual rainfall has been tabulated for the recharge and water balance studies purpose. (Table 5.3). But as the density of rain gauge stations in the study area and their locations are not adequate to monitor the effects of altitude, exposure and other factors that cause precipitation to differ from one part of the area to another, the determination of

Table 5.3 Stationwise Annual and Mean Rainfall (mm)

YEAR / STATION	1975	1976	1977	1978	1979	1980	1981	1982	1984	Total	Mean (mm)
Alirajpur	560.5	581.9	743.7	670.3	845.8	1400.0	1072.3	458.7	-	6333.2	791.65
ChhotaUdepur	764.0	1778.0	1459.0	1105.0	866.0	718.0	1956.1	792.0	-	9438.1	1179.76
Jetpur Pavi	837.10	-	1585.2	991.6	824.6	705.22	1404.3	452.0	-	6800.02	947.43
Kalarani	846.0	-	2352.4	1235.6	747.0	-	1189.1	452.7	-	6822.8	1137.13
Kawant	856.5	1778.0	788.0	1214.0	873.7	718.0	599.30	374.9	-	7202.4	900.30
Lalpur	-	-	-	-	-	-	1053.33	800.2	1404.0	3257.53	1085.84
Palasani	1069.8	1833.4	1335.0	1090.4	923.0	-	1049.49	6880	-	7989.09	1141.29
Rajwasana	1129.5	-	1254.02	1277.9	521.8	-	974.65	726.5	-	5884.37	980.72
Rangpur	894.0	-	1425.0	1512.1	1036.40	-	-	541.8	-	5409.3	1081.86
Rampur	-	-	1282.0	1076.0	-	-	-	858.1	-	3216.1	1072.03
Sankheda	1067.9	1928.0	1407.0	1206.0	725.5	718.0	-	759.9	-	7832.3	1118.90
Timberva-Nava	1049.2	-	1425.0	1217.6	1126.5	-	1156.3	759.9	-	6734.5	1122.41
Vora	948.8	1853.0	1400.2	1013.3	710.4	718.0	706.9	555.8	-	7906.4	988.3
Wasna	1085.0	-	1173.6	1098.4	904.1	-	462.02	801.8	-	5524.92	920.82

the amount of precipitation has been attempted by an alternative strategy. The weighted average precipitation has been determined with the Thiessen's Polygon method. The precipitation stations in and adjacent to the study area have been plotted on a map and the lines have been drawn between adjacent stations. Perpendicular bisectors have been next drawn on the connecting lines. Polygons centred on each precipitation station have been formed by joining these bisectors. The area of each Polygon has been determined and the weighted precipitation at the central station has been applied to the area. Figure 5.2, shows the locations of rain gauge stations and their weighted area with histograms of annual rainfall.

The average annual rainfall in the basin area is 974.78 mm. (Table 5.4) The rainfall in study area increases generally from the west towards north-east. About 95 % of the normal rainfall is received in the monsoon months June to September, July being the rainiest month. The variation in the annual rainfall from year to year is large.

Regarding rainfall the following points are significant:

(i) There is more rainfall in the north eastern part of basin area i.e. Chhota Udepur area. This is due to combined effects of the western ends of

Table 5.4 Weighted Area Precipitation in Heran Basin (By Thiessen's Polygon Method)

Serial number	Station	Weighted area (Sq.Km) A	Rainfall (mm) R	Precipitation A. R
1.	Alirajpur	85.90	791.65	68002.73
2.	Chhota Udepur	101.25	1179.76	119450.70
3.	Dabhoi	9.00	885.00	7965.00
4.	Kalarani	45.00	1137.13	51170.85
5.	Kawant	596.25	900.30	536803.88
6.	Lalpur + Rangpur+ Nava Timberva	146.25	1096.70	160392.38
7.	Palasani	18.00	1141.29	20543.22
8.	Sankheda	56.25	1118.90	62938.12
9.	Wasna + Rajwasana	141.75	950.77	134771.65
10.	Vora + Rampura	126.00	1030.16	129800.16
Total		1325.25	10231.66	1291838.16

Total mean precipitation over entire river basin -

$$P = \frac{R_1A_1 + R_2A_2 + R_3A_3 + R_4A_4 \cdots\cdots\cdots}{A_1 + A_2 + A_3 + A_4 \cdots\cdots\cdots\cdots}$$

$$\text{i.e.} = \frac{1291838.16}{1325.25}$$

$$= 974.78 \text{ mm/year}$$

Satpura and Vindhyan ranges.

(ii) Disturbance lines which are belts of intense thunderstorms moving east-west producing heavy rains of short duration.

(iii) On an average there are 42 rainy days (i.e. days with rainfall of 2.5 mm to 100 mm or more) in a year. The number varies from 28 in the central part of the basin to 53 at Chhota Udepur.

RUNOFF

Runoff is the sum of stream flow and groundwater flow that reaches the streams. Stream flow or surface runoff is a function of precipitation intensity, type of vegetation, area of drainage basin, distribution of precipitation, stream channel geometry, depth to water table, and the slope of the land surface.

The Heran river discharge is monitored at three gauge stations viz. (i) Lalpur i.e. site for the proposed Heran dam, (ii) Rajwasana Weir downstream of Lalpur gauge station and (iii) Bhilodiya near the confluence of Heran and Orsang. Unfortunately river discharge data at Bhilodiya is not available and hence it has made difficult for the author to utilise the available data to arrive at any definite conclusion for the lower reaches of the basin.

The run off has been computed by applying various standard theoretical formulae namely Barlow's Ingli's, Lacey's and Strange's. The mean runoff has been calculated for the computation of recharge and water balance.

Katsumi (1956) has carried out experimental studies in a small watershed area in Hokkaido, Japan. The annual runoff (R) and precipitation (P) were measured before and after cutting down the forests. Katsumi, established an equation for the relation before the cutting.

$$R = 0.704\ P - 297 \ \ldots\ldots\ (A)$$

and that after the cutting

$$R = 01.105\ P - 740 \ \ldots\ (B)$$

Where, R and P are expressed in mm. The present author has utilised the above two equations in a slightly different manner to suit his studies. He has applied equation A for the upper part of the basin which is forested, whereas equation B has been used for the middle part which is free from vegetation and comprises plain agricultural land. It has been found that the derived run-off values from above equations are very much close to the values derived from other formulae as under:

Sr.No.	Method	Formula	Runoff (cm)
1.	Barlow's formula	$R = K \times P$	33.41

2.	Ingli's formula	$R = \frac{(P-17.8)}{254} \times P$ (For non-ghat areas)	29.16
3.	Lacey's formula	$R = \frac{P \times PS}{1 + 304.8\ F}$	33.16
4.	Strange's formula	$R = \frac{(P-T)}{100} \times P$	29.17
5.	Katsumi's equation	(a) R = 01.105 P-740 (Non forest areas)	37.53
		(b) R = 0.704 P-297 (Forest areas)	35.38
6	Observed Runoff at Rajwasana	$Q = C.L.H.^{3/2}$	47.58

For carrying out water balance studies separate run-off has been computed for all the three parts of the basin viz. Upper, middle and lower basins. The observed run-off at Rajwasana gauge stations have been critically evaluated (Table 5.6).

The annual mean observed discharge at Rajwasana gauge stations is 474 Mm^3. The observed run-off values at Rajwasana has been adopted as total runoff from the upper and middle part of the basin, while for the lower part of the basin, the total annual runoff has been computed by theoretical formulae. The mean value derived from all methods has been taken as 93.0 Mm^3. After taking into consideration the computed discharge in three parts of the basin separately the total annual run-off of entire Heran basin 567 Mm^3 has been adopted, which forms 43.90 % (say 44 %) of the total precipitation in the study area.

EVAPORATION AND EVAPOTRANSPIRATION

Whereas a substantial portion of precipitation drains into rivers and streams as run-off, evaporation from free water surfaces and enclosed water bodies as well as from bare soil, vegetative cover accounts for the depletion of remaining rainfall accumulation. In order to assess evaporative and transpiration loses, a survey of the composition of soil, crop and water surfaces becomes necessary.

EVAPORATION

It is an atmospheric process by which water vapour escapes from the evaporating medium into the overlying air layers. Evaporative losses from any medium are principally governed by environmental factors such as solar radiation, temperature of the evaporating surface, wind-speed. In addition, factors such as (i) size, depth, purity and state of surroundings in the case of water bodies (ii) depth of water table and pattern of rainfall moistening of the soil in the case of bare soil surfaces and (iii) foliar ground coverage, depth of active root zone and watertable, (iv) physical properties, chemical composition and moisture characteristics of soils in the case of vegetative surfaces, also affect the process. The evaporative losses records in the study area are inadequate to make any conclusive assessment. Only one years monthly pan-evaporation data are available with Heran River Valley Development Authority, Government of Gujarat at Kosindra. These have been utilised for the calculation of consumptive use of water by Pan 'A' Evaporation method. The evaporative losses in the study area have been computed by standard theoretical formulae namely Christiansen's and Blaney-Criddle's methods for computing the potential and actual evapotranspirations.

For entire basin mean losses due to evaporation has been taken as 207.97 cm. The monthly break shows (Table 5.5) that the heightest mean evaporation rate 29.63 cm is recorded towards the end of the dry season in May-June, while, the lowest values 13.96 cm recorded in the wet season in July-August. This may be attributed to the considerable increase in cloud cover and greatly reduced amounts of insolation.

Table 5.5 Monthly Evaporation Losses in Study Area

Month	Pan 'A' Evaporation	Christiansen's Method	Blaney-Criddle Method	Mean E_p
JAN	12.70 cm	9.80 cm	13.17 cm	11.89 cm
FEB	15.24	11.05	13.18	13.15
MAR	25.40	18.44	16.92	20.25
APR	30.48	22.00	18.82	23.76
MAY	43.18	24.40	21.32	29.63
JUN	30.48	21.61	20.36	24.15
JUL	15.24	14.78	19.60	16.54
AUG	10.16	15.18	18.64	14.66
SEP	10.16	14.52	17.21	13.96
OCT	15.24	10.96	16.44	14.21
NOV	15.24	11.94	13.96	13.71
DEC	12.70	10.11	13.21	12.06
Total	236.22	184.79	202.83	207.97

A correlation between relative humidity, temperature and class 'A' pan evaporation suggests that the temperature and evaporation go side by side, while humidity is having an inverse relationship with temperature and evaporation.

EVAPOTRANSPIRATION

Estimation of evapotranspiration (ET) constitutes a major input in a hydrological analysis. The evapotranspiration is a broad term and it is further divided into two categories (i) Potential Evapotranspiration (PET); (ii) Actual Evapotranspiration(AET).

Potential evapotranspiration means, the maximum rate at which plants transpire when there is unlimited supply of water and favourable conditions of growth. Since PET gives the maximum rate of evapotranspiration and is not necessarily the true input for the water balance equation. The true input is the Actual Evapotranspiration which has a maximum value equal to PET. AET is dependent on the water supply, vegetation (type of agriculture crops and forestry) and soils. AET is calculated by applying respective crop factors 'K' in the agriculture land, forest etc. in relation to their percentile area coverage.

There are two methods by which PET & AET can be calculated. One is direct measurement by Lysimeter; and other, meteorological formulae e.g. Blaney-Criddle's Christiansen's class 'A' pan evaporation, Thronthwaite and Penmand etc. Since no data on direct measurement are available, author has calculated PET & AET by meteorological formulae (Annexure I to III) for all the three segments of the basin area and also for entire basin. A comprehensive details of computed AET are as under:-

Method Adopted	Upper Basin	Middle Basin	Lower Basin	Entire Heran Basin
Hargreaves class 'A' pan-evaporation	39.46 cm	49.48 cm	49.42 cm	43.54 cm
Christiansen's	33.26 cm	42.92 cm	44.77 cm	37.62 cm
Blaney-Criddle	40.25 cm	51.11 cm	56.65 cm	46.04 cm
MEAN 'AET'	37.65 cm	47.83 cm	50.28 cm	42.40 cm

Computed values of AET forms 43.5 % of total precipitation received by the basin area. These values have been used in the recharge and water balance studies for calculating the groundwater potential of the basin.