CHAPTER : VIII

CLIMATE OF BARODA CITY

This aspect of the environment, though, falling outside the perspective of geology "sensu stricto', nevertheless, has been dealt with very fleetingly, with an aim to possibly establish a relationship, if any, between the changing land-use pattern and meteorological parameters.

Cities, because they are cities, have climates different from the surrounding countryside. In fact, the city reaches out and influences the region beyond the inner city - the suburbs and often the hinterlands many miles from the city [Bryson and Ross, 1972]. We now know that man has unwittingly changed such fundamental things as temperature, air circulation and the heat budget. In short, the cities that man builds, profoundly affect climate in the short run and almost certainly will produce significant long-term climatic effects as well.

The evidence is mounting that these climatic changes can make life unpleasant. Table : 36 shows the average changes in various climatic elements caused by urbanization.

Urbanization alters the city climate in various ways. First, urbanization changes the physical surface of the land, notably by constructing many buildings and paving much of the ground, in the process water-proofing the land, increasing its thermal admittance, and increasing its roughness and hence its effect on wind. Second, urban man and his activities produce climatically important amounts of heat in several ways. Third, by their functions cities introduce great quantities of fine particles into the air which in turn affect the temperature.

TABLE : 36

AVERAGE CHANGES IN CLIMATIC ELEMENTS CAUSED BY URBANIZATION
[FROM LANDSBERG 1970]

Element	Comparison with Rural Environment
Radiation	
global	15 to 20% less
ultraviolet, winter	30% less
ultraviolet, summer	5% less
sunshine duration	5 to 15% less
Temperature	
annual mean	0.5 to 1.0°C more
winter minima [average]	1 to 2°C more
heating degree days	10% less
Contaminants	
condensation nuclei & particulates	10 times more
gaseous admixtures	5 to 25 times more
Wind speed	
annual mean	20 to 30% less
extreme gusts	10 to 20% less
calms	5 to 20% more
Precipitation	
totals	5 to 10% more
days with less than 5 mm	10% more
snowfall	5% less
Cloudiness	
cover	5 to 10% more
fog, winter	100% more
fog, summer	30% more
Relative humidity	
winter	2% less
summer	8% less

TABLE : 37

VARIATION OF RAINFALL [mm] IN BARODA CITY BETWEEN THE YEARS 1898-1988

YEAR	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1898	230.37	596.90	170.94	188.46	1,186.67
1899	83.05	2.28	3.04	19.05	107.42
1900	0.00	296.92	272.28	146.55	715.75
1901	55.62	365.76	154.68	17.52	593.58
1902	52.83	185.42	283.21	271.27	792.73
1903	2.03	658.11	199.89	216.40	1,076.43
1904	79.50	81.53	36.83	145.28	343.14
1905	7.11	473.96	11.68	110.99	603.74
1906	226.82	332.99	312.67	162.56	1,035.04
1907	67.05	267.70	429.76	6.85	771.36
1908	56.44	494.28	228.09	108.20	887.21
1909	97.53	284.48	136.14	108.45	626.60
1910	321.81	436.88	320.04	21.84	1,100.57
1911	124.20	79.75	67.81	55.37	327.13
1912	94.48	508.50	340.36	8.12	951.46
1913	534.41	492.25	256.03	288.79	1,571.48
1914	225.29	531.62	86.36	303.27	1,146.54
1915	192.78	282.95	165.10	20.66	661.49
1916	166.37	323.08	164.59	165.86	819.90
1917	294.13	235.96	647.44	446.02	1,623.55
1918	49.02	22.60	124.20	0.76	196.58
1919	90.17	429.76	346.20	13.20	879.33
1920	90.17	163.83	72.64	39.62	366.26
1921	10.41	444.24	190.75	501.39	1,146.79
1922	193.54	210.31	57.65	278.38	739.88
1923	.	168.65	114.30	179.83	462.78
1924	118.87	239.26	147.32	187.19	692.64
1925	296.41	374.39	70.86	2.03	743.69
1926	5.33	390.90	564.13	133.60	1,093.96
1927	245.11	1,585.97	134.87	99.31	2,065.26
1928	141.47	384.55	337.56	60.42	924.00
1929	302.76	362.96	98.29	7.62	771.63
1930	137.92	372.36	196.59	243.58	950.45
1931	111.50	416.81	679.45	121.92	1,329.68
1932	145.28	487.42	163.32	310.13	1,106.15
1933	90.17	353.31	740.91	232.41	1,416.80
1934	260.35	207.01	445.77	74.42	987.55
1935	119.35	367.03	92.71	259.08	838.17
1936	291.56	125.22	25.40	158.75	600.93
1937	133.35	301.24	10.13	368.80	813.52
1938	258.31	589.01	49.78	.	817.10
1939	42.67	194.31	330.70	68.07	635.75
1940	131.06	169.92	115.57	50.03	466.58
1941	44.70	740.41	182.11	28.19	995.41
1942	114.04	412.49	418.33	74.42	1,019.28
1943	107.44	300.73	40.89	205.23	654.29

Table : 37 [Contd.]

YEAR	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
1944	68.58	483.87	438.91	63.24	1,054.60
1945	113.03	405.63	253.23	575.31	1,347.20
1946	218.18	281.38	482.09	25.90	1,007.55
1947	.	269.24	205.48	217.93	692.65
1948	20.82	166.11	84.07	51.30	322.30
1949	20.32	281.17	1.52	203.45	506.46
1950	1.77	885.44	47.24	333.50	1,267.95
1951	26.92	160.78	150.36	1.77	339.83
1952	144.78	454.91	121.41	5.33	726.43
1953	193.29	110.23	593.59	76.20	973.31
1954	151.63	281.17	247.14	408.94	1,088.88
1955	127.76	88.54	470.73	193.54	880.57
1956	49.02	525.27	485.64	44.95	1,104.88
1957	203.02	452.03	108.07	0.00	763.12
1958	231.08	231.01	205.02	450.02	1,117.13
1959	73.09	630.01	280.09	348.00	1,331.19
1960	75.04	153.09	183.03	126.05	537.21
1961	203.03	247.04	277.01	150.02	877.10
1962	7.04	280.66	123.08	165.01	575.79
1963	84.09	309.08	410.07	148.05	951.29
1964	98.08	428.01	163.05	116.00	805.14
1965	0.00	465.00	168.06	4.04	637.18
1966	196.07	329.00	94.08	143.06	762.21
1967	144.05	523.07	183.00	118.08	968.20
1968	3.06	208.08	293.63	39.07	543.84
1969	180.09	343.06	221.01	314.09	1,058.25
1970	201.04	178.01	565.09	367.07	1,311.21
1971	134.02	369.02	204.04	209.04	916.12
1972	94.01	159.00	112.08	21.09	386.18
1973	200.00	247.03	326.03	359.06	1,132.12
1974	30.03	64.04	42.02	100.06	236.15
1975	131.08	103.08	465.00	139.08	838.24
1976	437.07	530.07	476.66	113.02	1,556.82
1977	271.08	456.00	202.09	139.06	1,068.23
1978	130.00	232.04	605.60	30.30	997.94
1979	124.01	119.03	301.02	76.50	620.56
1980	319.01	216.03	363.02	41.80	939.86
1981	120.03	282.07	359.01	86.70	847.81
1982	15.01	128.09	315.00	6.30	464.40
1983	136.80	601.08	454.03	134.04	1,325.95
1984	62.60	230.70	335.00	78.40	706.70
1985	0.80	300.80	113.00	6.10	420.70
1986	158.50	70.40	68.20	2.70	299.80
1987	33.80	141.10	217.40	2.50	394.80
1988	79.80	388.40	212.40	269.40	950.00

Source : Meteorological Office, Baroda

METHODOLOGY :

Meteorological data between the years 1898-1988 was collected from the Meteorological Observatory in Baroda. Temperature [Table : 40 and Fig. 35] and rainfall data [Table : 37 and Fig. 33].

For this purpose, the previously cited and explained 3 land-use maps prepared from Survey of India Toposheet Nos. 46 F/3, 4, 7 [1876-78, 1959-60] and SPOT-1 HRV_2 MLA band $B_1G_2R_3$ satellite imagery dated 15.1.1988, were used for comparison with meteorological data.

CHANGES IN THE PHYSICAL SURFACE :

[a] **Waterproofing :**

On an average, man has waterproofed about 50% of the surface in cities. Roofs, streets, and parking lots increase the run-off of even gentle rain, and drain systems are required to transport the run-off away from settled areas quickly and efficiently; otherwise every minor storm would bring a barrage of phone calls because of filled basements and flooded underpasses. Thus, we put gutters on roofs and along streets, and we build storm sewers as the waterproofed areas increase the run-off. Contrast this with the situation in rural areas, where much more water soaks into the soil, eventually to return to the atmosphere by evapotranspiration or to seep slowly away in the groundwater.

The enhanced run-off in Baroda during the monsoon can be deduced from the water discharge data from the Water Resource Investigation Division [Gujarat]. Hydrogeological data from the gauging stations [Fig. 32] at A [Vishwamitri] and B [Pilol] which are given in Table : 38.

Discharge data for the four monsoon months of June, July, August

FIG. 32-VISHWAMITRI RIVER SAMPLING STATIONS FOR WATER DISCHARGE VOLUME ASSESSMENT IN THE STUDY AREA.

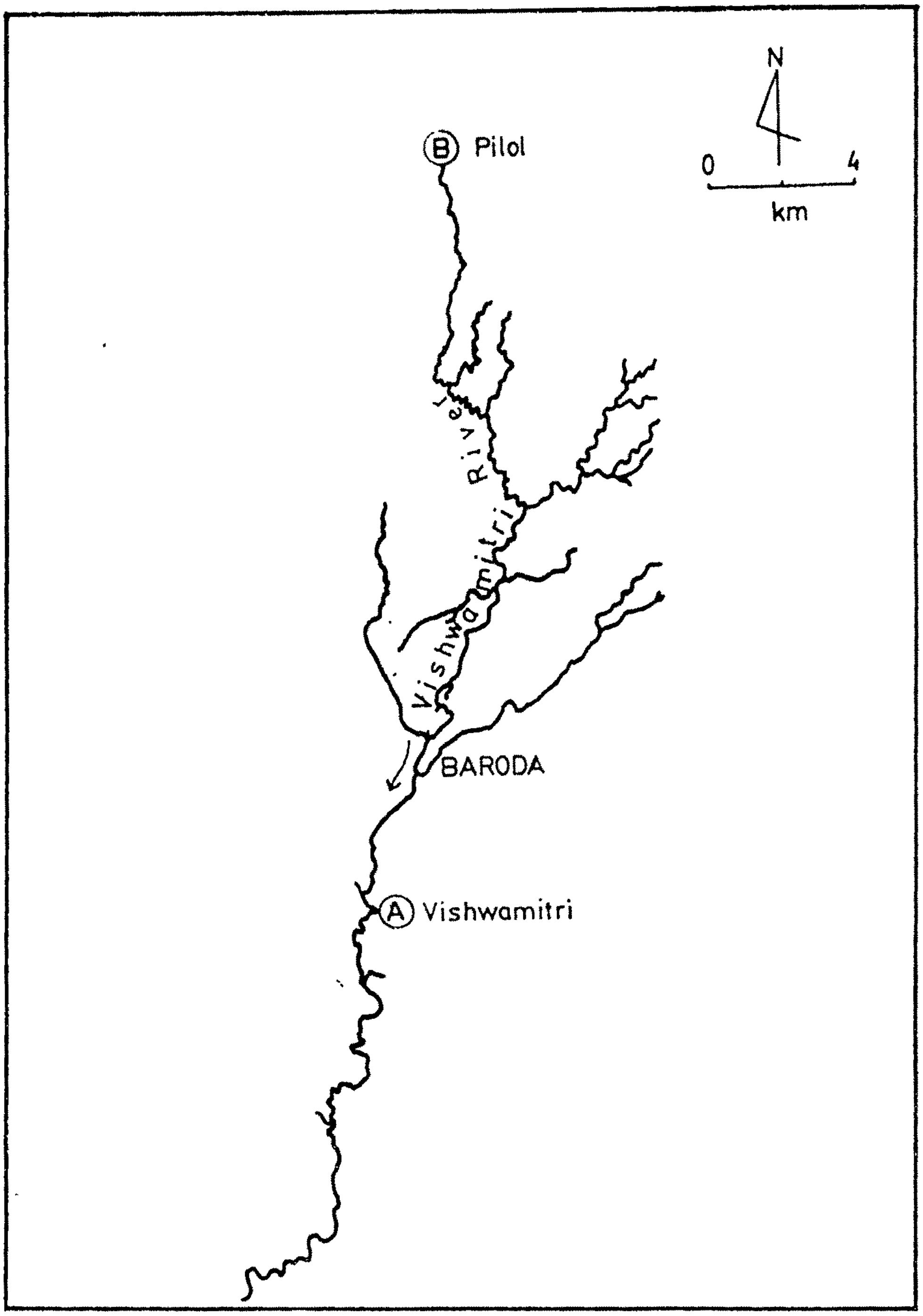


TABLE : 38

WATER DISCHARGE DATA FOR THE VISHWAMITRI RIVER WITHIN THE STUDY AREA

		YEAR								
		1967			1978			1988		
Total Rainfall (mm)		968.20			997.94			950.00		
	MONTHS	STATION		DIFFERENCE	STATION		DIFFERENCE	STATION		DIFFERENCE
		A	B	[A-B]	A	B	[A-B]	A	B	[A-B]
Discharge	June	11.61	10.31	1.30	10.94	9.09	1.85	13.04	12.63	0.41
Volume	July	23.31	21.61	1.70	13.56	11.16	2.40	18.14	16.08	2.06
$[Mm]^3$	August	11.61	9.90	1.71	23.18	21.06	2.12	24.91	23.80	1.11
	September	8.09	7.40	0.69	14.40	14.09	0.31	12.93	9.17	3.76
Total Discharge				5.40			6.68			7.34

SOURCE : Rainfall = Meteorological Office, Baroda
Discharge = Water Resource Investigation Division
Volume Hydrogeological Data Report Part II [B] [1967, 1978, 1988]

STATION : A = Vishwamitri, B = Pilol

and September for the years 1967, 1978 and 1988, clearly show that from 1967 onwards, there is an increased run-off, leading one to conclude that less water was infiltrating into the surface of the earth as it was covered with roads and buildings. The increase in run-off [A-B] is significant, as the rainfall data for the last 20 years show a decrease in mean annual rainfall.

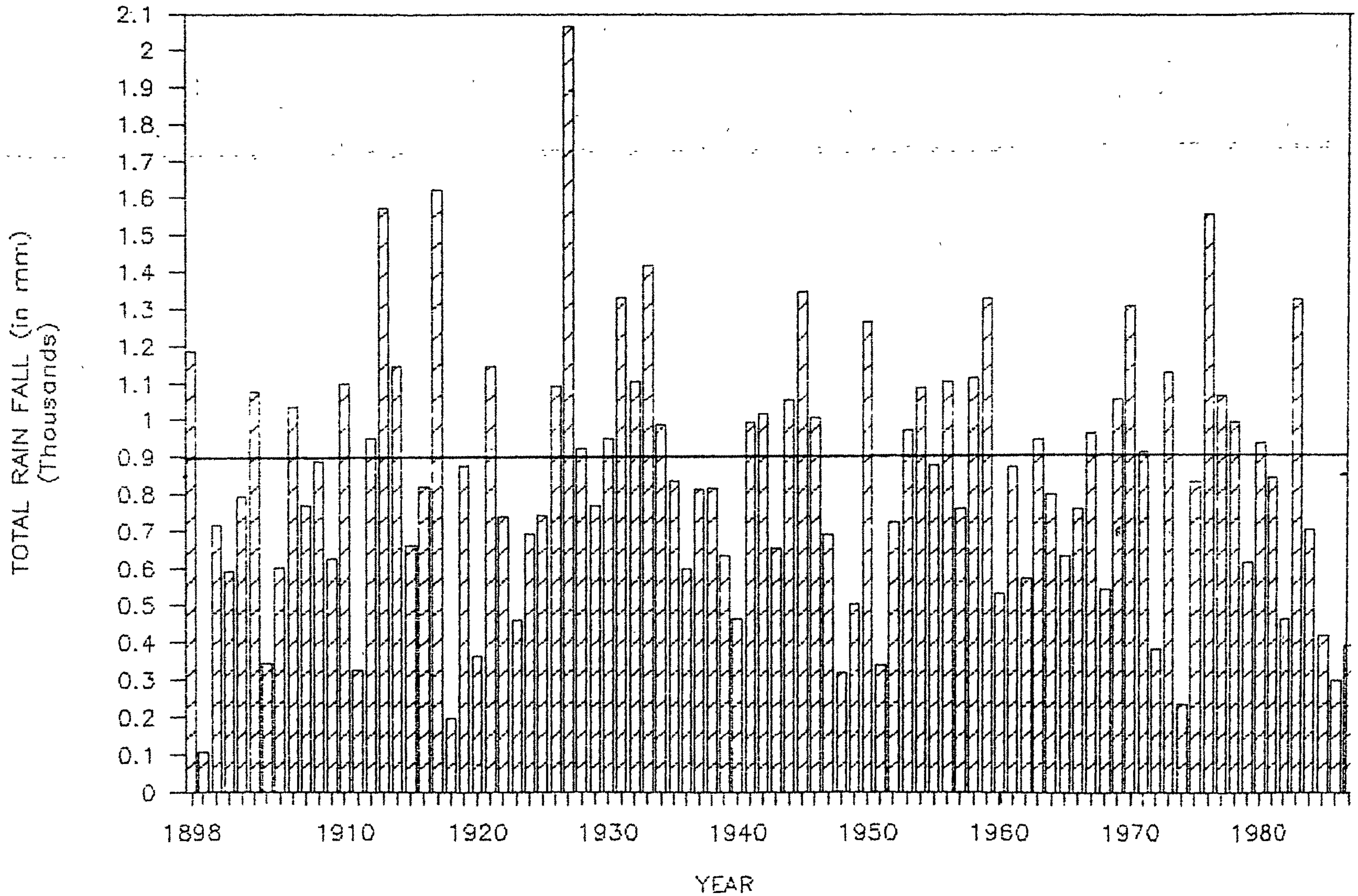
This waterproofing involves a hydrologic change with climatic consequences. Since in the city rapid run-off leaves paved surfaces dry most of the time between rainfalls, less moisture is available for evaporation than in the country side. This is significant because the evaporation process removes heat from the air [approximately 600 calories for every gram of water evaporated] and hence has a cooling effect at the earth's surface. Paved and roofed city surfaces simply do not have this mode of heat loss [Bryson and Ross, 1972].

This is very striking in the case of Baroda, as there is a distinct change in the amount of annual rainfall before and after industrialization [with 1960 as the cut-off year]. From Table : 37 and Fig. 33, it can be seen that in the pre-industrial period [i.e. before 1960], 51% of the total years recorded below normal rainfall, whereas after 1960, within a short span of 28 years, 62% of the total years showed below normal rainfall. This indicated an 11% increase in the number of years having below normal rainfall, and can be directly attributed to the 'waterproofing' effect caused by extensive urbanization and industrialization, whereby natural earth is covered by masses of concrete and roads.

Further proof of the change in climate due to rapid urbanization/ industrialization can be discerned by the evapo-transpiration figures.

Evapo-transpiration is the combined loss of water vapour to atmosphere from soil, water surfaces and transpiration from the plants. This loss is controlled by two factors, namely the availability of moisture

FIG : 33 VARIATION OF TOTAL RAINFALL IN BARODA CITY (1898 - 1988)



at the earth's surface and the ability of the atmosphere to supply energy to vaporize water and transport the vapour. If supply of water is unlimited, loss of water in the form of evaporation and transpiration will depend on the atmospheric conditions, and this loss is termed as potential evapo-transpiration [PE] [Rao et al, 1971].

The concept of potential evapo-transpiration was first formulated by Thornthwaite [1948]. It is now widely used in many fields of study like soil water balance, irrigation assessment, agroclimatology and hydrology.

In the present study, the concept of potential evapo-transpiration is used to evaluate the soil water balance of the study area. Data of evapo-transpiration for the study area [Baroda] has been taken from the report giving potential evapo-transpiration [PE] over the whole of India [Rao et al 1988].

For the evaluation of the complete soil water balance of any area, it is necessary to compare rainfall [P] with potential evapo-transpiration [PE], making allowance for the storage of water in the soil and its subsequent utilization for evapo-transpirational purposes. For a few months, especially in the monsoon, rainfall [P] is always greater than the potential evapo-transpiration. So that the soil remains full of water, and a water surplus "S" occurs. While for a few months, precipitation [P] is less than potential evapo-transpiration [PE], as there is not enough moisture for the vegetation to use, a negative value will be seen [Subramanyam, 1982].

The moisture holding capacity of a soil depends on the depth of the soil layer considered and the type and structure of the soil medium. It can vary from just a few millimeters on a shallow sand bed to well over 400 mm on a deep, well aerated silt loam. The roots of the plant compensate some what for the variable nature of the soil, for on sandy soils plants will be deep-rooted while on silt and clay, the plants tend to be more shallow-rooted.

The actual steps involved in the soil water balance computation for Baroda are shown in Table : 39. To determine the periods of moisture excess and deficiency, the difference between rainfall [P] and potential evapo-transpiration [PE] is obtained. A negative value for [P-PE] indicates the amount by which the rainfall fails to supply the potential water need of a vegetation covered area. A positive value of [P-PE] indicates the amount of excess water which is available for soil moisture replenishment and perhaps also for run-off.

Discussion :

The parameters of soil water balance as obtained from the above mentioned procedure [after Subramanyam, 1982], when graphically plotted against the months of the year [Fig. 34] present a clear picture of the trend of water surplus and deficiency between 1931-1960 and 1961-1988, which correspond to the pre- and post-industrial phases of the growth of Baroda city respectively.

For the period 1931-1960, the water surplus of 458 mm occurred during the monsoon months of July, August and September. This water surplus was completely depleted during the months between October - June, resulting in an annual deficit of 588 mm.

During 1960-1988 [post-industrial phase], the water surplus during the months of July, August and September dropped to 301 mm, a decrease of 157 mm, as compared to the 458 mm value for the period 1931-1960. This 301 mm surplus was completely depleted between the months October - June, resulting in an annual deficit of 278 mm as compared to 1931-1960.

Hence, it can be seen that there is a deficit soil-moisture water balance which is on the increase.

FIG. 34 - VARIATION OF RAINFALL VERSUS POTENTIAL EVAPO-TRANSPIRATION FOR THE PERIODS 1931-60 AND 1961-88.

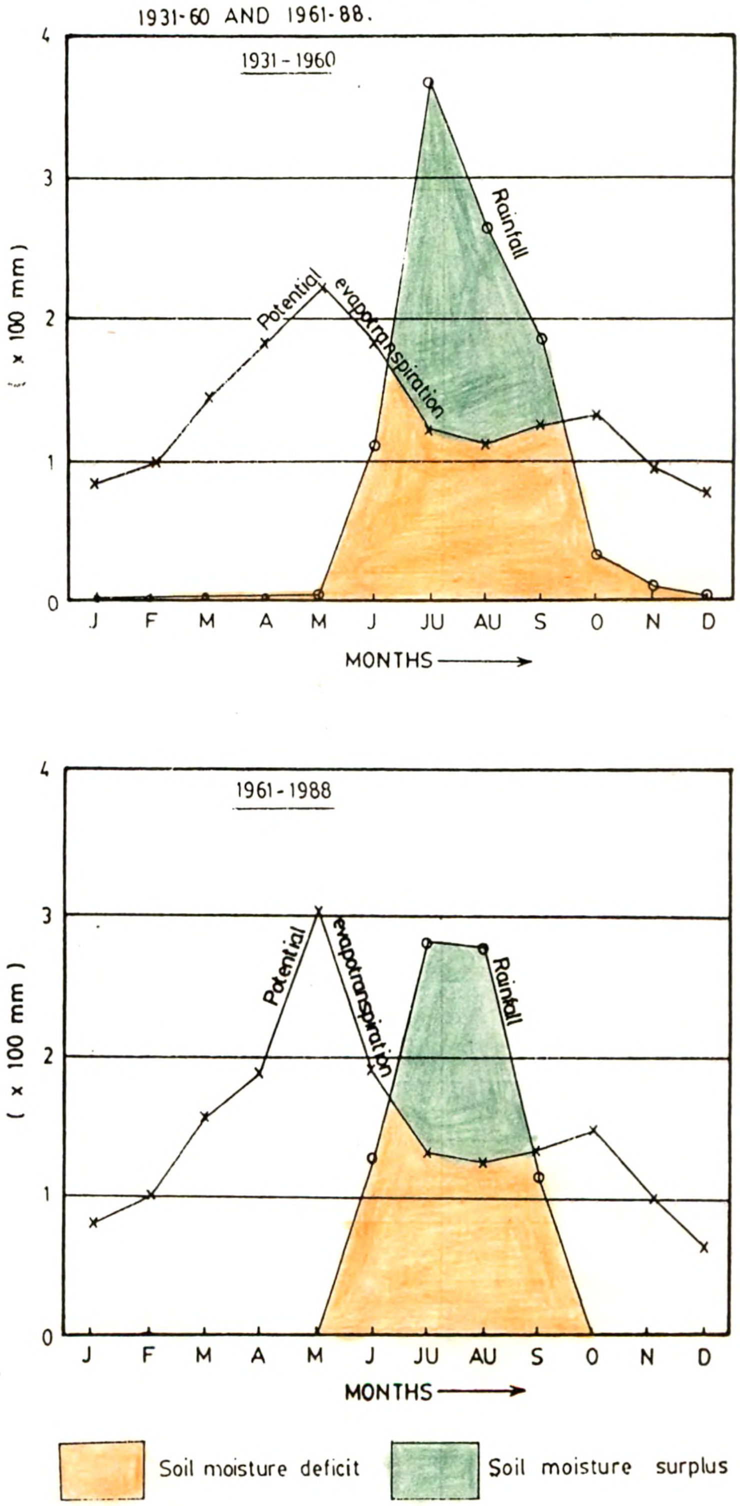


TABLE : 39

SOIL WATER BALANCE OF THE STUDY AREA [BETWEEN 1931 TO 1960 AND 1961 TO 1988]

YEAR	ITEM	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	ANNUAL
1931 to 1960	P [in mm]	2	2	1	3	4	115	366	264	186	35	9	0	987
	PE [in mm]	82	98	145	181	227	185	120	114	124	130	93	76	1575
	P - PE [in mm]	-80	-96	-144	-178	-223	-70	+246	+150	+62	-95	-84	-76	-588
1961 to 1988	P [in mm]	1	1	1	2	0	130	280	279	115	25	7	0	841
	PE [in mm]	80	101	159	190	300	190	132	126	135	149	80	65	1707
	P - PE [in mm]	-79	-100	-158	-188	-300	-60	+148	+153	-20	-124	-73	-65	-866

SOURCE : Potentioevapotranspiration [PE] = Report on ICRISAT [1988]
Rainfall [P] = Meteorological Office, Baroda

One of the reasons for this increase in deficit soil-moisture water balance, could be attributed to the Albedo effect. Much of the energy that converts surface moisture into water vapour comes from the Sun's radiational heating of the land surface. The energy thus depends on surface, Albedo or relevant degree of reflectant "Shininess" of the land surface [Sagan et al, 1979; Pinker et al, 1980]. In turn the Albedo depends upon the vegetation, which absorbs more heat than does bare soil. Over thick vegetation, there are vigorous thermal currents taking moisture [provided by the same plant cover] up into the atmosphere, where it condenses as rain. Because of its influence on convection patterns and wind currents, and hence on rainfall regimes, the Albedo effect constitutes a basic factor in controlling climate.

When vegetation is removed from the earth's surface in large quantities, the result is often a self-promoting cycle of Albedo enhancement, leading to a new stable state if less worm soil, lower rainfall and sparser vegetation. These ensures a significant decrease in ranfaill and increase in evapo-transpiration, as also in cloud cover.

[b] Thermal admittance :

The city has higher thermal admittance than the surrounding country side. To understand this, let us look first at a rural field covered with grass. The ground receives heat during the day and cools off at night, but vegetation acts as an insulating blanket [in large part trapping still air, through which heat moves slowly]. The flow of heat both into and out of the soil therefore is reduced. During the day, the grass blanket keeps heat from flowing into the ground as rapidly as it otherwise would, so there is less heat stored in the soil. This would leave more at the surface to heat the air, except that evapo-transpiration from the vegetation helps to lower temperatures. At night, the temperature at the top of grass drops owing to reradiation back to the atmosphere, but the insulating blanket prevents considerable heat flow from the soil below. In short, the vegetation [when growing] tends to reduce surface temperatures during both day and night.

In contrast, the city, with its acres of concrete, has high thermal conductivity and heat capacity. Heat flows easily into the concrete during the day and is stored. At night, as the surface cools, there is a flow of heat upward to balance the surface loss. The effect of this is to maintain relatively higher temperatures at the surface. Thus the city, with high thermal admittance, stores more heat during the day and lets out more at night. For these reasons, night temperature in the city a few inches over concrete may be 5-6°C warmer than temperature over rural fields [Bryson and Ross, 1972].

[c] Heat Production :

Not only has man, through his urban constructions, dramatically affected the exchange of energy and moisture within the system by altering the physical qualities and materials of the earth's surface, he also has become a primary source of heat production within the system. The heat man produces has led to even more radical changes in the heat balance than result from construction. These changes are manifested in many ways, ranging from the heat release of fossil fuel combustion to that of the human metabolism.

A typical automobile, operating in a city, burns about 13.65 litres of fuel per hour. The combustion in most automobile engines produces about the same amount of heat as the typical home furnace in winter: indeed one can easily heat a house with an automobile running in the garage given the appropriate exhaust system and heat exchanger. All this heat is added to the city's heat system.

Human beings themselves are another contributor to the city's heat budget. A man produces heat at a rate of between 100 and 300 watts

TABLE : 40

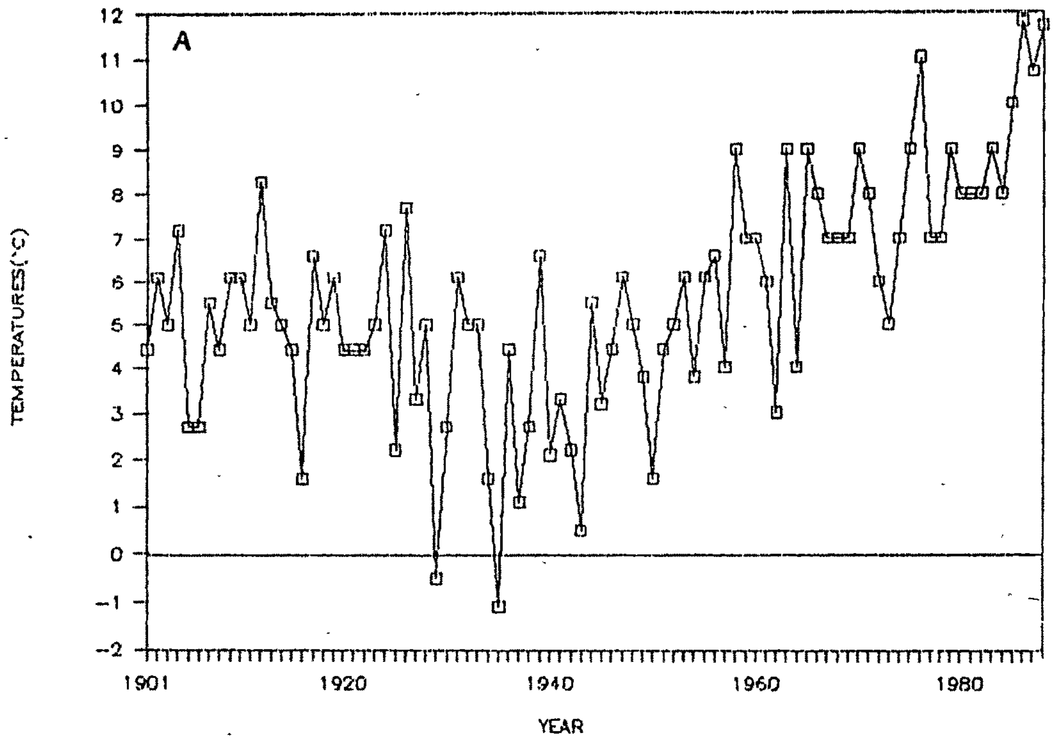
VARIATION OF TEMPERATURE FOR 88 YEARS IN BARODA CITY [1901-1988]

YEAR	°C		YEAR	°C		YEAR	°C	
	MAX.	MIN.		MAX.	MIN.		MAX.	MIN.
1901	46.0	4.4	1931	40.0	6.1	1961	45.0	6.0
1902	45.0	6.1	1932	43.8	5.0	1962	46.0	3.0
1903	46.0	5.0	1933	43.0	5.0	1963	45.0	9.0
1904	43.0	7.2	1934	43.0	1.6	1964	45.0	4.0
1905	45.0	2.7	1935	44.4	1.1	1965	44.0	9.0
1906	45.0	2.7	1936	43.8	4.4	1966	46.0	8.0
1907	43.0	5.5	1937	44.4	1.1	1967	45.0	7.0
1908	43.0	4.4	1938	43.8	2.7	1968	43.0	7.0
1909	44.4	6.1	1939	37.7	6.6	1969	45.0	7.0
1910	43.0	6.1	1940	44.4	2.1	1970	46.0	9.0
1911	43.0	5.0	1941	43.8	3.3	1971	44.0	8.0
1912	44.4	8.3	1942	43.8	2.2	1972	45.0	6.0
1913	44.4	5.5	1943	45.0	8.5	1973	45.0	5.0
1914	46.0	5.0	1944	45.0	5.5	1974	44.0	7.0
1915	45.5	4.4	1945	45.5	3.2	1975	44.0	9.0
1916	46.0	1.6	1946	43.8	4.4	1976	42.0	11.0
1917	37.7	6.6	1947	43.8	6.1	1977	44.0	7.0
1918	42.7	5.0	1948	44.0	5.0	1978	43.0	7.0
1919	43.0	6.1	1949	46.0	3.8	1979	46.0	9.0
1920	43.8	4.4	1950	45.0	1.6	1980	44.0	8.0
1921	43.8	4.4	1951	45.0	4.4	1981	45.0	8.0
1922	45.0	4.4	1952	45.0	5.0	1982	43.0	8.0
1923	43.8	5.0	1953	45.0	6.1	1983	43.0	9.0
1924	45.0	7.2	1954	44.4	3.8	1984	44.0	8.0
1925	46.6	2.2	1955	46.6	6.1	1985	44.0	10.0
1926	43.8	7.7	1956	45.5	6.6	1986	43.5	11.8
1927	44.4	3.3	1957	43.0	4.0	1987	43.5	10.7
1928	43.0	5.0	1958	46.0	9.0	1988	45.5	11.7
1929	45.5	0.5	1959	46.0	7.0			
1930	46.0	2.7	1960	47.0	7.0			

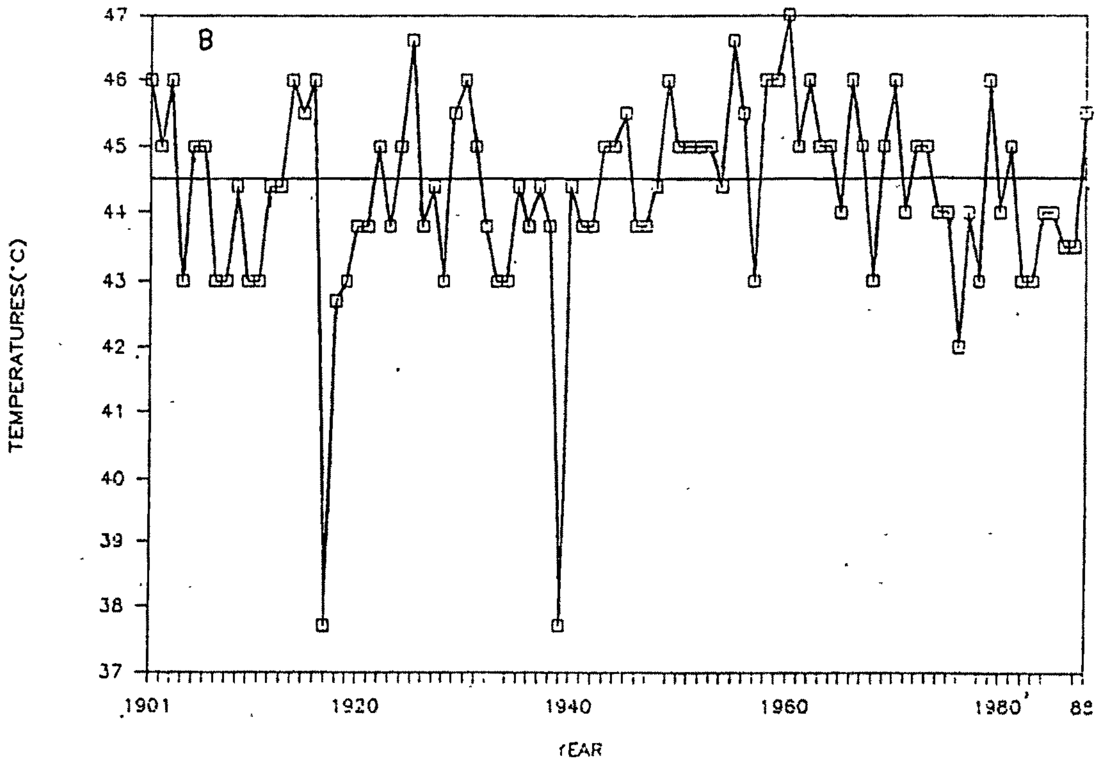
Source : Meteorological Office, Baroda

FIG : 35

VARIATION OF MINIMUM TEMPERATURES IN BARODA CITY
(1901 - 1988)



VARIATION OF MAXIMUM TEMPERATURES IN BARODA CITY
(1901 - 1988)



depending on his activities; a person produces about 100 watts at rest and about 200-300 watts while working. Some heavy work produces even more [Bryson and Ross, 1972]. That's not insignificant with 1-10 million people in a city. In crowds, the heat generated is equal to summer sunshine.

The net contributions of combustion, heating and metabolism can produce an impressive adjustment of the earth's heat budget in urban places and urban areas. The combined effects of thermal admittance and heat production are very evident in the case of Baroda from Table : 40 and Fig. 35.B, it can be seen that in the pre-industrial phase, 44.82% of the total years recorded above normal temperature [with 44.5°C as normal summer temperture], whereas from 1960 onwards, 48.27% of the total years showed above normal temperture, thus indicating a rise of nearly 4%. Further, from Fig. 35.A it is very clear that, the minimum temperature variation is also on the rise.

[d] **Roughness :**

In cities man has also altered the roughness of the earth's surface. This [aerodynamic] roughness modifies the movement of the air at the surface. What happens depends primarily upon the smaller features, such as trees, bushes, less upon the spaces between them. The city in most situations, is rough compared to the open country side.

Increased surface roughness affects the wind structure and causes a major adjustment in the vertical wind profile so that wind speeds near the surface are reduced. The structural features of cities, because they interfere with laminar flow, also increase the number of local eddies and thus increase the turbulence. The decrease of wind speed over cities is poorly documented [Bryson and Ross, 1972]. Reasonable interpretations of available records suggest that wind speed in cities is about 25% less than in rural areas. This is not unreasonable in the light of measurable increases in aerodynamic roughness.

Experiments show that the aerodynamic roughness is proportional to the height of the buildings [h] squared times their width [w] and inversely proportional to the size of the lot the building occupies, that is, to the square of the average distance between buildings [D] [Bryson and Ross, 1972].

$$Z_0 = \frac{I\ h^2\ W}{2\ D^2}$$

This roughness length Z may be 5 cm in the country side and 1000 cm in city. Given this figures, the reduction of wind in the city at 30 m above the ground may be 80% of more. This reduction proportionately lengthens the time required for the wind to flush air pollutants from the city. At greater heights the reduction of the wind speed is much less.

[e] Turbidity : Particles in the air :

In addition to alterations of the physical surface and variation in heat production, a third factor distinguishing the city from the countryside is a difference in combustion and properties of the atmosphere. The measure of dust, smoke and other particulate matter in the air is referred to as turbidity. All air is turbid to some degree. Nature contributes dust from sparsely vegetated land, for example, but man has greatly increased the turbidity by his agriculture, fuel combustion, industrial emissions, and other activities.

Atmospheric dust has a number of effects. Among these is interference with solar radiation by the suspended particles. Although this interference affects the whole spectrum, it is most pronounced in the short wavelengths, resulting in a reduction of about 15% of total direct radiation over most major cities. This reduction is generally greater in winter and less in summer.

The result of all this is that cities become 'heat islands' characterised by temperatures 5° to 10°C higher than the surrounding country side [Valdiya, 1987].