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SURFACE RUNOFF OF RIVER TAPTI UNDER A WARMER CLIMATE

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CERTIFICATE

Certified that the work embodied in this dissertation entitled **"Surface runoff of river Tapti under a warmer climate"** has been carried out by me under the supervision of Prof. V. Asthana in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. The work is original and has not been submitted in part or in full for any other degree or diploma in this or any other University.

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ERRATA

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INTRODUCTION

It is now established that man's activities can bring about changes in climate in addition to those due to natural forces. Before the nineteenth century industrialization, anthropogenic activities were too small to affect weather or climate. Fast industrial development, resulting in greater energy use, loss of carbon-dioxide stored in the soil and rocks, due to extensive agricultural development and deforestation are the several ways which release carbon in the atmosphere. Once released, carbon forms atmospheric CO_2, one of the most important heat trapping gases.

The subject of anthropogenic climate change is not more than 50 years old when Callendar (1938) showed that man by burning of fossil fuel could change the climate of the planet. Intensive study of the subject began during the late 1960s. The results suggested that CO_2 is not solely responsible, but other gases eg. methane, nitrous oxide, ozone and chloroflourocarbons taken together are of comparable importance in changing the atmospheric thermal balance. Thus in future, the problem becomes twice as severe.

Measurements have shown that the earth's surface temperature has increased between 0.5 and 0.7 °C since 1860. At the present rate of emissions of the greenhouse gases, the earth is committed to an additional warming of at least 0.15 °C and perhaps as much as 0.50 °C each decade, resulting in a mean global warming of at least 3 °C and as much as 5 °C by the year 2030 (Abrahamson,1989). There is, however, considerable uncertainty about parameters influencing global climate change because of incomplete scientific understanding or because of unknown future releases of greenhouse gases.

associated with changes in the timing of precipitation and spring runoff and increased soil moisture supplies during the summer months.

Resolution of GCMs is found to be coarse compared to many hydrologic events. To make realistic estimate of actual changes in water availability, state-of-the-art estimates of actual climatic changes, as well as hypothetical scenarios should be incorporated with hydrological models. To determine the effects of climate changes on the regional watersheds, water balance method is a good tool. The technique provides broad spatial and temporal resolution. The model is easy to understand and can be modified to fit the characteristics of available data.

Water balance models provide accurate estimates of surface runoff, relative changes in soil moisture, evapotranspiration estimates under different climatic regimes and estimates of ground water discharge and recharge rates. Snow melt can also be incorporated into such models.

The region under study is first characterized by water balances and then the effect of climatic changes can be evaluated in three ways : first, after verifying the model accuracy , long term historical data is used to assess the effect of fluctuation in temperature and precipitation on runoff and soil moisture, second, by determining the sensitivity of runoff and soil moisture to changes in temperature and precipitation, sensitivity of watershed to hypothetical climatic changes can be evaluated, and third, by incorporating changes in temperature and precipitation predicted by GCMs, their impacts on regional hydrology can be evaluated. The water balance model, though traditional, offers several advantages over other methods for assessing the regional hydrologic effects of large scale climatic changes.

One of the most important impacts of future climatic changes may be alterations in regional hydrologic cycles and subsequent changes in the quality and quantity of regional water resources. Greater evaporation and precipitation, earlier snowmelt and reduced water availability in summer is the likely outcome of higher temperature (Glieck, 1986b). Soil moisture and water level, volume and flows are to decline rapidly during dry periods. The distribution pattern of precipitation is to change in unexpected ways, while some regions will be benefited others will experience losses. Water is so much important for every aspect of society and ecology that an understanding of how a change in global climate would affect regional water supplies is very much necessary.

Currently, evaluation of the effect of human activities on global climate are based on results from GCMs. These models have been undergoing development and refinement for many years (Manabe 1969,a,b ; Schlesinger and Gates,1980 ; Manabe and Stouffer,1980 ; Weatherald and Manabe,1981 ; Ramnathan,1981 ; Manabe et al.,1981 ; Hansen et al.,1983 ; Washington and Meehl,1984). The models evaluate carbon-dioxide-induced changes in climatic variables such as temperature, eddy kinetics, cloud and ice cover, radiative fluxes, water-vapour distribution, precipitation, evapotranspiration, changes in soil moisture and runoff.

The recent results from GCMs suggest that possible changes in some hydrologic variables-especially precipitation and evapotranspiration- may lead to major water supply problem, including changes in runoff and soil moisture in a region. For example, Manabe et al. (1981); Manabe and Stouffer (1980); have suggested that reductions in summer soil moisture in middle latitudes is a possible outcome of a doubling of CO_2 in the atmosphere. Washington and Meehl (1984) show different changes in zonal-mean-soil-moisture values

India lies in the monsoon climatic belt where more than 75% of the rainfall occurs in four months of the south west monsoon season. A very small fraction of the annual rainfall is received in the winter months. During the post monsoon season, the south peninsula, Assam and some parts of Kashmir receive rains. The annual rainfall in India is about 105 cm, the largest anywhere in the world for a country of comparable size. However, the amount is widely variable, the coefficient of variability lying between 15 and 30. Over Gujrat and Rajasthan the coefficient is larger than 40% (Rao, 1979).

The temporal and spatial variability in Indian rainfall should be kept in mind while planning for better utilization of water resources of the country. Problem of conservation and management of water becomes even more important for India, as a large population of the country depends on agriculture. While it is important to augment the efficiency of water use, it is equally important for planners and managers of water resource systems to make assessment of future hydrologic changes as a consequence of greenhouse warming.

The present study is intended to have an understanding of future climate changes and how this affects the hydrologic systems. Tapti river basin on the west coast of India is chosen for the study. Using temperature, precipitation, evaporation and discharge data for the past 20 years water balance study is done. Statistical analysis of the data gives an idea of the effect of hypothetical changes in temperature on hydrologic parameters especially the possible changes in runoff of the basin.

LITERATURE REVIEW

Greenhouse Gases and Changes in Global Climate :

Global climate is changing because of the build-up of the heat trapping gases-carbon dioxide, methane, nitrous oxide , the CFCs, and the other greenhouse gases in the atmosphere. The atmospheric concentration of the greenhouse gases are increasing because their release rates exceed the rate of removal by natural processes. The greenhouse gases, their pre-industrial and present concentrations and their growth rates are summarised in Table 2.1. Table 2.2 gives the sensitivity of mean global temperature to changes in concentration of greenhouse gases.

Table 2.1 : Growth rate of greenhouse gases

Gases	Concentration in Air Preindustrial	1986	Present rate of increase(per year)
Carbon dioxide (CO_2)	275 ppm	346 ppm	1.4 ppm (0.4%)
Methane (CH_4)	0.75 ppm	1.65 ppm	17 ppb (1%)
Fluorocarbon-12 (CCl_3F_2)	Zero	400 ppt	19 ppt (5%)
Fluorocarbon-11 (CCl_3F)	Zero	230 ppt	11 ppt (5%)
Nitrous Oxide (N_2O)	280 ppb	305 ppb	0.6 ppb (0.2%)
Ozone (O_3) Tropospheric	15 ppb?	35 ppb	0.3 ppb? (1%) N.Hemisphere only
Other Fluorocarbons	Zero		(5 to 15%)

Source : Cicerone (1989)

Table 2.2 : Sensitivity of temperature to change in concentration of greenhouse gases

Gas	Change in concentration	Warming °C
CO_2	100 ppmv	0.5-1.6
CH_4	doubling	0.2-0.7
N_2O	+50%	0.2-0.6
Ozone(trop.)	+50%	0.5-1.7
CFC-12	1 ppbv	0.1-0.4
CFC-11	1 ppbv	0.1-0.4
H_2O(strat)	doubling	0.6

Source : Cibororowski (1989)

As a result of these changes in atmospheric concentration, the mean global temperature will rise between 0.8 and 2.4 °C (Dickinson and Cicerone ,1986). Jones et al. (1986b) carried out a detailed analysis of sea surface temperature and marine air temperature and found a long-term warming trend. The magnitude of warming agrees with theory; it is about 0.5 °C over the last 100 years.

Global temperature trends since 1880 to 1988 have been given in fig 2.1. It is seen that present global temperatures are the highest in the period of instrumental record. The rate of global warming is higher than earlier time. Fig 2.2 compares recent global temperature change with climate model simulations of temperature changes which will result from the greenhouse effect. In both the observations and the model results the warming is close to 0.4 °C by 1987 (Hansen, 1989).

Early estimates during the late 1960s predicted that a doubled CO_2 concentration should raise the average temperature 1.5-3 °C (Manabe and Wetherald, 1967). Numerous other estimates using energy balance, RCMs and GCMs lie in the range 1.5-4.5 °C, with values near 3 °C most favoured (Schlesinger and Mitchell, 1985). Ramanathan et al.(1985) assuming a stable

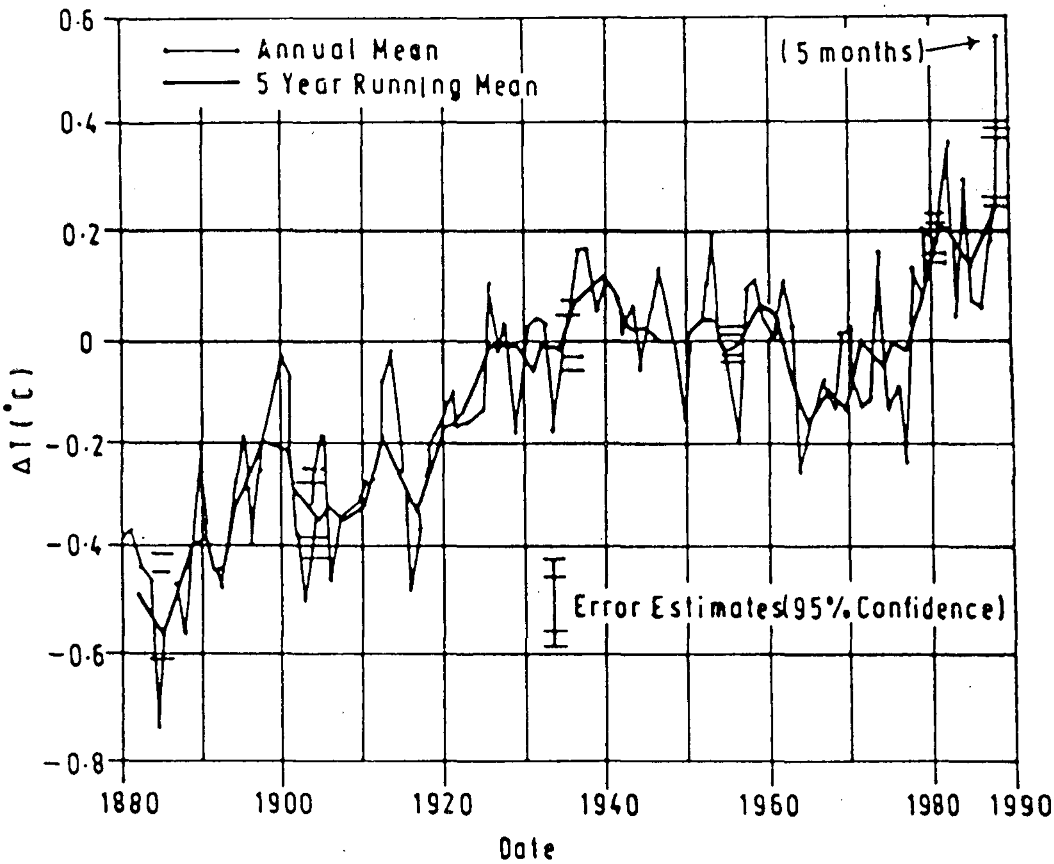


Fig. 2.1 Global temperature trends: 1880–1988

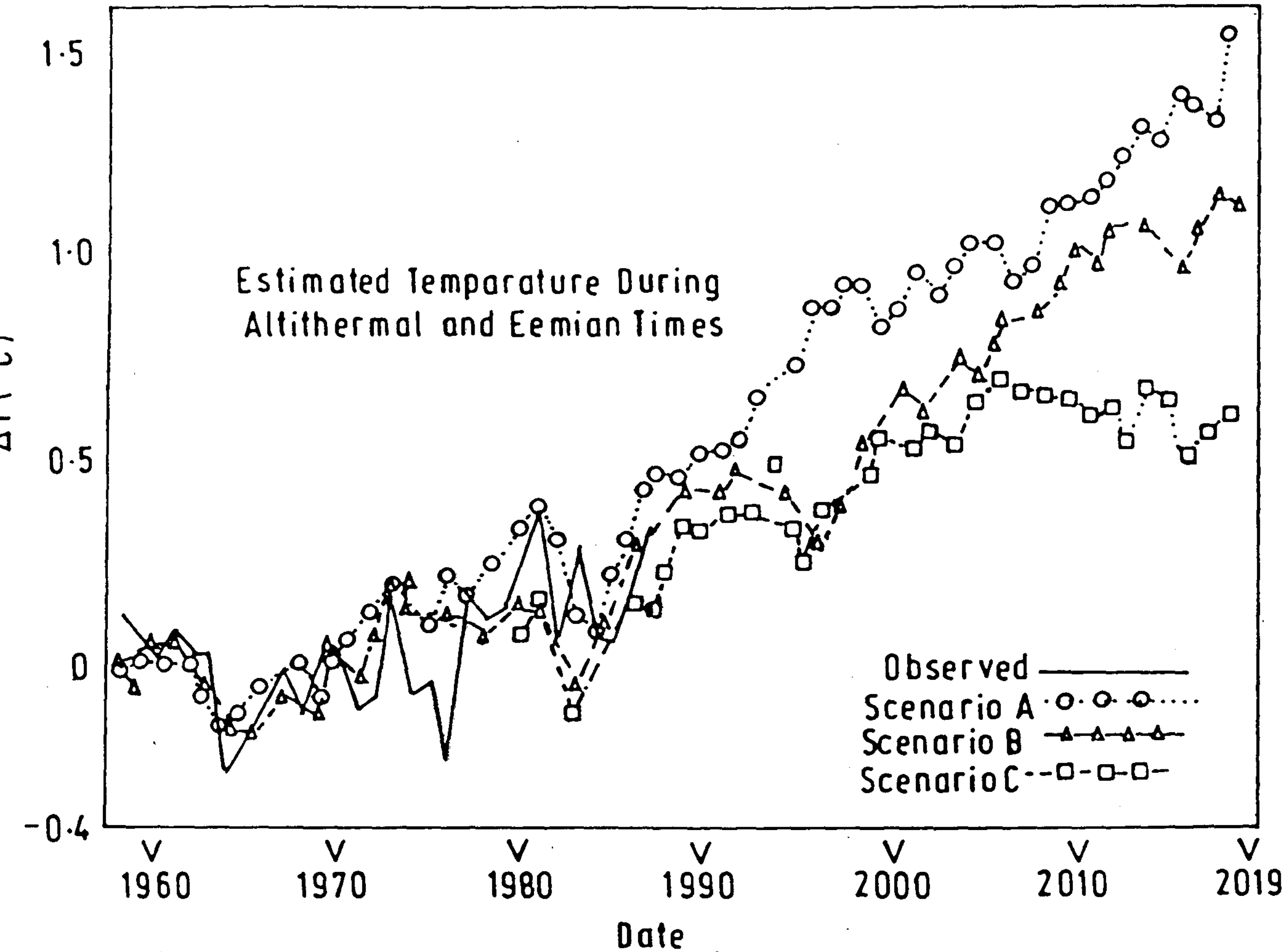


Fig. 2.2 Comparision of recent global temperature changes

projection of current energy use, predicted a warming of 1.5 °C between 1980 and 2030. Macdonald (1985) using the energy budget model calculated the change in temperature assuming concentration changes as given in Table 2.3. The calculated surface warming is 1.8-2.2 °C as shown in the Table 2.3.

Table 2.3 : Changes in concentration of greenhouse gases and consequent warming

Species	Mixing ratio (ppbv) 1980	estimated 2030		Change in T °K
CO_2	340×10^3	450×10^3		1.0
N_2O	300	350-450		0.2
CH_4	1650	2500-3000		0.3-0.4
CCl_2F_2	0.30	0.6-1.2		0.1-0.2
CCl_3F	0.18	0.5-1.0		
O_3(Trop.)	20-70	30-100		0.2-0.4
			Total	1.8-2.2

Source : Macdonald (1989)

Increase in temperature will result in higher evaporation which in turn will give more precipitation. Seasonal and geographical distribution of precipitation will also change. Precipitation should increase in low-latitude regions and during the winter in high latitudes. Mid-latitudes may have reduced summer precipitation. Long period precipitation data of different countries of the world have been studied by a number of workers. Most of the records from both the hemispheres show small effects but no clear trends emerge on a hemispherical basis. Reduced precipitation and increased water loss through evaporation and transpiration may result in summer soil moisture reduction in many of the world's agricultural regions.

Trend of temperature over Indian Region :

Pramanik and Jagannathan (1954) studied the annual maximum and minimum temperatures of 30 meteorological observatories in and around India and found no general tendency of increase or decrease in temperature. Hingane et al.(1985) studied the trends of temperature of different regions of India as a whole and suggested a slight but definite warming trend in the mean annual temperature from 1901 to 1982. The mean annual temperature, the smooth anomaly obtained by applying 9 point Gaussian filter and a fitted trend line given in fig. 2.3 show a warming of 0.4 °C during recent eight decades. About 41 per cent of the stations show warming trends and 8 per cent cooling trends of annual temperature. Northwestern regions give significant cooling trends while eastern regions give warming trends.

It was noted that Indian mean annual temperature does not show the post 1940 cooling which was observed for the northern hemisphere. On the contrary Indian temperatures have shown steadily increasing trends over past 8 decades (Sarkar and Thapaliyal, 1988).

Trend of Indian Rainfall :

Blanford (1886), first analysed 19 year (1867-1885) annual rainfall data for India as a whole but found no significant oscillation or systematic trend. The second study by Walker (1910), concluded that summer monsoon rainfall over India from 1841 to 1908, showed no perceptible climate change. Rao (1936), Agarwala (1952), Pramanik and Jagannathan (1953), made systematic study of some part or the whole of the country but found no significant trend or short period cycle. Recently, some investigators like Koteswaram and Alvi (1969,1970) ;Parthsarathy and Dhar (1974) ;Raghavendra (1973,1974,) ;Rao (1958) ;Chowdhary and Abhyankar (1979) ;Parthsarathy and Mooley (1981) and Dhar et al.(1982) for some or the other meteorological subdivisions have found evidence for the presence of different cycles ranging from very high frequency to very low frequency. Some of the results suggest quasi-biennial-oscillations,

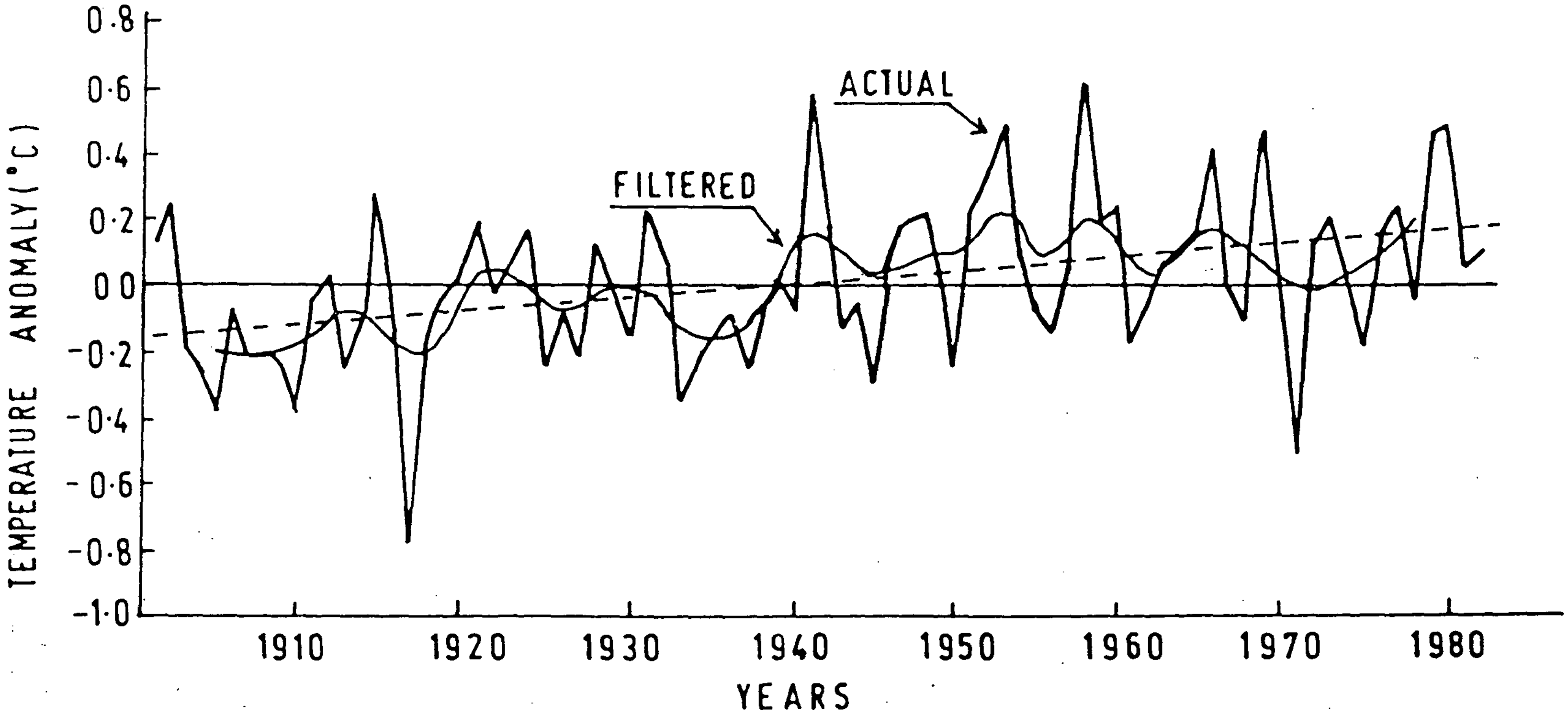


Fig. 2 3 Trend line temperature anomalies in India others a 14 year cycle and still others existence of 6 to 6.5-year cycle in different studies. Detailed analysis of long period rainfall, however, do not indicate any long term climate change but only year to year random fluctuations during last 100 years (Sarkar and Thapaliyal, 1988).

Effect of Changing Climate on Water Resources :

Climate change will affect both the supply and demand of water. If climate warms, there will be greater evaporation and in turn greater precipitation and earlier snowmelt. This will lead to reduced water availability in summer and during dry periods and rapid declines in soil moisture. Small changes in regional temperature, precipitation and evaporation patterns can change scenario of water availability significantly especially in arid areas (Nemec and Shaake, 1982 ; Klemes and Nemec, 1985). Precipitation is more variable in arid than in humid areas. More vulnerability to interruptions in water availability may be observed under a warmer and drier climate.

To evaluate the effects of global climate changes on hydrology of any region water balance models developed by C.W.Thornthwaite and Mather in 1940s and 1950s (Thornthwaite, 1948 ; Thornthwaite and Mather, 1955,1957) were used . Standard methodologies have been developed over the last 40 years (Thornthwaite and Mather, 1955 ; Sokolov and Chapman, 1974) . Modifications and extensions of the original formulations can be used for assessing climatic impacts.

Recent attempts to evaluate the regional hydrologic implications of climatic change (Schwarz, 1977 ; Stockton and Bogges, 1979 ; Nemec and Schaake,1982 ; Revelle and Waggoner,1983 ; U.S. Environmental Protection Agency,1984 ; Flaschaka, 1984) have shown that relatively small changes in precipitation and evaporation pattern might result in significant changes in regional water availability. The results of some of the earlier studies have been summarized in Table 2.4

Table 2.4 : Results of early studies estimating runoff in a changed climate

Author	Region	Climatic change	% change in runoff
Stockton and Boggess 1979	Average for seven western U.S. regions	+2°C, -10% ppt	-40 to -76
Nemec and Schaake 1982	Arid basin	+1°C, +10% ppt	+50
		+1°C, -10% ppt	-50
	Humid basin	+1°C, +10% ppt	+25
		+1°C, -10% ppt	-25
Revelle and Waggoner 1983	Colorado river basin	+2°C, +10% ppt	-18
		+2°C, -10% ppt	-40 ± 7.4
Flaschaka 1984	great basin	+2°C, -10% ppt	-17 to -38
U.S.EPA 1984	Central U.S.	doubled atmospheric carbon dioxide	-26
	New U.S.		+20 to +60

Source : Gleick (1986,b)

Note : Different authors use different methods to make the assessment. All changes in runoff are annual average changes.

Schwarz (1977), in one of the earliest studies, attempted to evaluate the effect of hypothetical changes in climate on water supply. He followed three approaches in his study. 1) A review of the individual water-supply system and their response to previous climatic anomalies. 2) Speculation of the effects of climatic changes on hydrologic criteria and 3) use of synthetic streamflows to evaluate the effect on water supply of hydrologic variations resulting from climatic changes. Schwarz concluded that the variability of streamflows, are very sensitive to change in climate. He stressed to have a full understanding of the relationship between climatic change and water supply.

Stockton and Bogges (1979), evaluated the hydrologic effects of hypothetical changes in temperature and precipitation using the well known empirical relationship between temperature, precipitation and runoff developed by Langbein (1949). They analyzed four climate scenarios-involving changes of plus and minus 2°C in temperature and changes of plus and minus 10% in total annual precipitation and estimated the average annual runoff of major water basins throughout the U.S.. According to them a march towards warmer and drier climate would have the greatest impact nationwide. The most severe effects will be observed in the water limited regions. A change to cooler and wetter conditions will produce beneficial effects, although in some cases flooding may result on river systems.

Nemec and Schaake (1982) using hypothetical climate change scenarios, evaluated the runoff of an arid and a humid watershed. They found significant changes in runoff resulting from only moderate variations in climate. For example, an increase in temperature of only 1 °C and a decrease in precipitation of 10% in a humid basin reduced average annual runoff by approximately 25%. The same changes in an arid basin reduced runoff by approximately 50 %. Runoff was found to increase with increase in precipitation. According to Nemec and Schaake the serious impact of change in runoff advocate that the effects of climate change on the design and operation of water-resource- systems in different climatic regions of the world should be fully understood.

Following Nemec and Shaake, Klemes (1985) reviewed the role of hydrologic models in climate impact assessment. They provided an excellent review and discussion of the type studies that should provide the most useful information on the sensitivity of water resources to variations in climate. He also outlined some tests that are applied to hydrologic models to make sure that significant results are obtained and insignificant results are discounted.

Revelle and Waggoner (1983), used the empirical relation found by Langbein et al. (1949) to assess the effect of probable climatic change on the United States' water resources . This was based on representative data from 22 drainage basins distributed over climates from warm to cold and from humid to arid. Using their relation they estimated annual runoff for different values of mean annual precipitation and weighted mean annual temperatures. They found that for any given annual precipitation , runoff diminishes rapidly with increasing temperature. Similarly for any given temperature, the proportion of runoff to precipitation increases rapidly with increasing precipitation.

They computed the approximate percentage decrease in runoff for a 2 °C increase of temperature and for a 10% decrease in precipitation. They concluded that percentage decrease in runoff from warming diminishes with increasing precipitation and becomes greater for successively higher values of initial temperature. In case of per cent decrease in precipitation, reduction in runoff is larger with higher average annual temperatures and there is relatively small difference in the percentage decrease in runoff at a given temperature over the range of initial precipitaion. Comparision of the two results shows that below an initial mean annual precipitation of 500 mm, the effect of a 2 °C warming are larger than those caused by a 10% decrease in precipitation. The reverse is true when mean annual precipitation is 500 mm or more. Their study also support the previous suggestions of a nonlinear relationship between changes in precipitation and changes in runoff.

The U.S. E.P.A.(1984) using data from large scale GCMs examined the changes in the hydrologic cycle under steady-state doubled atmospheric concentration of carbon dioxide. In spite of the coarse resolution of the GCMs and the poor reproduction of actual hydrologic and climatic characteristics in many areas -the study reaffirmed earlier suggestions that climatic changes may cause substantial changes in runoff and soil moisture patterns in the northern hemisphere.

Flaschaka (1984), to evaluate the hydrologic effects of climatic changes in the Great Basin of the U.S., used regional hydrologic technique, like that of Nemec and Schaake (1982), although her modeling methods differed from that of Nemec and Schaake in some important respect. She applied water balance technique to four water-sheds in Great Basin to evaluate the consequences of the same type of climatic change scenarios studied by Stockton and Bogges (1979) and Revelle and Waggoner (1983). She concluded that such changes could result in decrease in annual average runoff of over 50% for precipitation decreases of 25% together with temperature increases of 2 °C.

Gleick, in order to determine the effects of changing climate on the water resources developed a water balance model and applied it to Sacramento basin in California. He developed a series of ten purely hypothetical climate change scenarios involving increase in temperature of 2 and 4 °C and changes in precipitation of plus and minus 0, 10, and 20% , and another series of eight scenarios (involving changes in temperature and precipitation) predicted for that region by three state-of-the-art GCMs.

The scenarios were used to evaluate the effects on monthly average soil moisture and runoff. Large decreases in summer soil moisture levels were observed in all the eighteen scenarios. Major shift in the timing of average monthly runoff was found throughout the year, runoff in summer months decreased for all 18 scenarios. Large increases in winter runoff were observed for fifteen scenarios, the other three scenarios involving precipitation decreases of 10 to 20% showed small decreases in winter runoff (Gleick, 1987). The results of Gleick's analysis are in agreement to that of Manabe, Mitchell, Wetherald etc.

The major river systems over the Indian subcontinent are largely unregulated and vulnerable to hydrometeorological changes associated with greenhouse warming. Numerous studies have been carried out to estimate temperature and rainfall under changing climate, in different parts of India or the whole country but studies regarding impacts of climate change on water resources are still meager.

S.D.S.Abbi applied Sacramento river model for water balance studies and river forecasting, for different river systems. He studied Yamuna catchment for runoff simulation at Kalanur outlet point, to explore the possibility of applying Sacramento model to Indian catchments. The model enables the calculation of water transfer (interception, evapotranspiration, percolation etc.) of different phases of water cycle and of flow at the outlet (direct runoff, surface runoff, interflow and baseflow). The study found a good correlation between the observed and the estimated discharge values. The results suggested that the model has requisite potential for streamflow simulation, based on hydrometeorological data (Gosain and Abbi,1981a). Encouraged by the results of this study, further studies have been taken up.

M. Lal (1994), in his studies used the data generated by Hamburg general circulation models to assess the impacts of future climate changes on water resources of Indian subcontinent and the south Asian region. The results indicated increase in summer soil moisture over central India, Bangladesh and south China but a significant decrease in soil moisture in winter was expected over Central China (Lal, 1994). A moderate decrease in surface runoff was expected over large areas of Central China during cold months whereas the flood prone areas of N.E.India, Bangladesh and South China were to experience increased runoff by the end of next century (Lal, 1994) .

In another study by Lal (1994), it was found that under IPCC's scenario A, the model predicted an increase of about 18 cm per year in total annual precipitation. During winter a decrease in precipitation was expected over southern India but no substantial change was simulated over much of the India. Evaporation in monsoon period was simulated to increase over parts of north and central India but for southern India no substantial change in evaporation was suggested during winter and premonsoon months. Except a marginal decline in extreme south, annual mean soil moisture was simulated to increase over India. Mean annual increase in surface runoff over India by the year 2080, was found around 25% , much of this increase is confined to northeast and central plains. No significant change in surface runoff was simulated by the model. A marginal decline was, however, possible over the southern extremes (Lal, 1993).

Global warming is now confidently ascribed to greenhouse effect. Projection of future warming are, however, uncertain since future levels of use of carbon fuels and the budget of other greenhouse gases are not known. Current estimates of impacts of global warming on regional scale have low confidence as GCMs results are not in agreement. Simulations of climate models still contain a number of systematic errors in comparison to the observed climate (Lal, 1994). The issue requires further consideration.

STUDY AREA

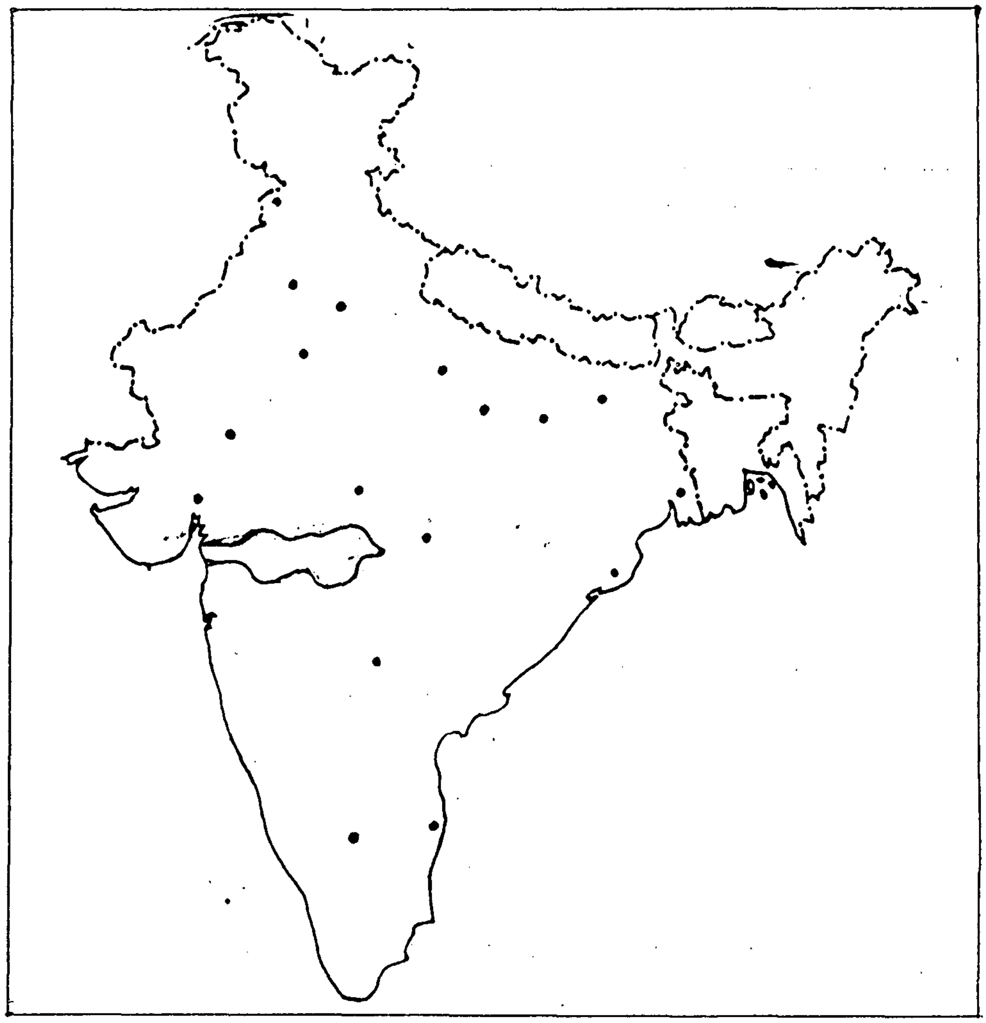
Basin characteristics

River Tapti is the second largest west flowing river of the Indian Peninsula. It rises near Multai in Betul district of Madhya Pradesh at an elevation of 752 m. The drainage area of the basin is 65,145 sq.km. and it lies between longitude 72°38' to 78°17' east and latitude 20°5' to 22°3' north. The location of the basin is shown in fig 3.1. The basin is situated in the Deccan plateau country and covers large areas of the states of Madhya Pradesh , Maharashtra and Gujrat. The statewise distribution of drainage area is shown in Table 3.1 :

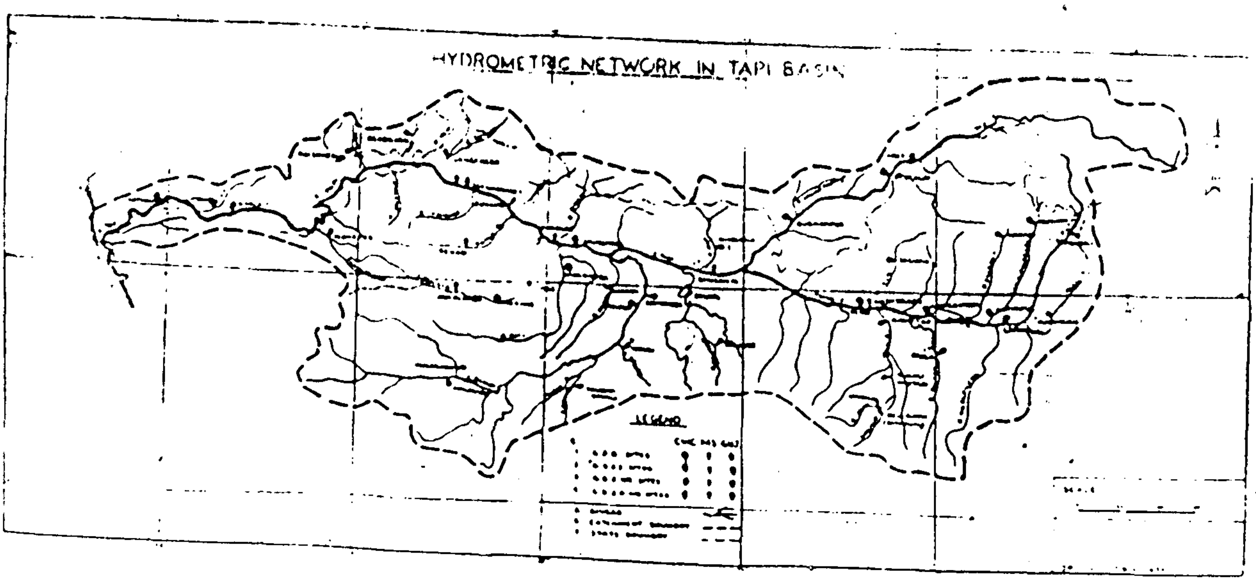
Table 3.1 : Drainage area in the basin statewise

State	Area
Madhya Pradesh	9,804 sq.km.
Maharashtra	51,504 sq.km.
Gujrat	3,837 sq.km.
Total	65,145 sq.km.

The basin is bounded on the north by Satpura ranges, on the east by the Mahadeo hills, on the south by the Ajanta range and on the west by the Arabian sea. The basin has an elongated shape. The maximum length of the basin from east to west is 587 km. and the maximum width from north to south is 201 km. It has two well-defined physical regions, the hilly region which covers the Satpura, the Satmala, the Ajanta, and the Gavilgarh hills and is well forested and the Khandesh and the Gujrat plains which are broad and fertile areas suitable for cultivation.



LOCATION MAP OF BASIN



DRAINAGE PATTERN

FIG. 3.1

The total length of the river is 724 km.,of which 228 km.are in Maharashtra, 214 km.are in Gujrat and the remaining 54 km.form the common boundary between Madhya Pradesh and Maharashtra. In the head reach covering a distance of about 241 km. the river traverses an open and partially cultivated plain and then plunges into a rocky gorge in the Satpura hills. In the next reach of 290 km. the river enters the Khandesh district of Maharashtra. After receiving the tributary Purna from the left it flows through the broad fertile Khandesh plains which are bounded on the north by the Satpura and on the south by the Ajanta ranges. In the next reach of around 80 km.,it passes through wild and almost uninhabited country. In the last reach of 113 km.,the river passes through the Gujrat plains and after flowing past Surat city empties into the Arabian sea.

Fig. 3.1 shows the drainage pattern of the river Tapti. The river receives several tributaries on both banks. The right bank tributaries have their origin in the Satpura ranges and flow generally south-west. The left bank tributary except the Vaghur, originate from the eastern slopes of the Sahyadris and the Galna hills, which are spurs of the Western Ghats. These flow eastward for considerable distances at right angles to the main line of the ghats and then change their direction of flow to northward to join the Tapti. The source, flow direction and drainage area of different tributaries is given in Table 3.2 :

CLIMATE :

There are four distinct seasons in the basin cold weather, hot weather, south-west monsoon and post-monsoon. The cold weather commencing in December continues till the end of February, December being the coldest month. In this season the days and nights are bright and cloudless, frost and hail are unknown. In the upper reaches of the basin slight precipitation occurs. The hot

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weather starts in March and continues upto middle of June, May usually is the hottest month. The season is generally dry except for occasional thunder-storms. The south-west monsoon sets in by the middle of June and withdraws by the first week of October, heaviest rainfall occurring in the period June to September. In the areas adjoining the river the weather is somewhat sultry and oppressive. A few thunder-storms occur in the post-monsoon season especially in October. Thereafter, the weather clears up and it is dry and pleasant throughout the valley.

Table 3.2 : Tributaries of river Tapti

Tributary	Source	Flow-dir	Confluence
Left bank			
Purna (18,929)	Gawilgarh hills	Southwesterly, then turns to west	
Vaghur (2,592)	Ajanta hills	Northerly dir	N-W of Bhusaval
Girna (10,061)	Western Ghats	first east then turns north	near Nanded
Bori (2,580)	Malegaon	first easterly then in northerly dir	east of Betavad
Panjhara (3,257)	Sahyadri hills	first east then turns to north	south of Thalner
Buray (1,419)	Satmala hills	easterly dir for 64km then to north-east	N-E of Sindkheda
Right bank			
Aner (1,702)	Satpura hills	south westerly dir	south of Hol
Arunavati (935)	---do---	---do---	east of Virdel
Gomai (1,148)	---do---	---do---	near village Prakash

Rainfall :

There are about 78 rain-gauge stations inside the basin, evenly distributed and adequate in number. In addition to the reporting rain-gauge stations there are also a number of non-reporting rain-gauges. The monthly and annual normals of rainfall in the district lying in the basin are given in the Table 3.3 :

Table 3.3 : Monthly Normal Rainfall

Months	Rainfall (mm)	% of annual rainfall
June	136.1	16.4
July	252.9	30.5
August	168.4	20.3
September	160.9	19.4
October	43.2	5.2
Dry months	68.3	8.2

The normal annual rainfall in the basin is 830 mm, about 90% of which is received during the monsoon months. Although the monsoon withdraws during the first week of October, 5.2% of rainfall is received during this month and in the wake of a wet September, this amount of rainfall is likely to produce a comparatively higher runoff.

Temperature :

In the cold weather season the mean minimum temperature varies from 11.1 °C to 14.4 °C. In several areas temperatures below freezing point have also been observed. The mean maximum temperature ranges from 38 to 42 °C in the hottest month. As we go inland from the coast and from the hills towards the plains the temperature rises. The Purna sub-basin in the upper half of the Tapti basin is one of the hottest regions in India during summer. The maximum temperature recorded at different places in the basin are shown in Table 3.4.

Table 3.4 : Maximum temperature in the basin

Places	Maximum temperature recorded °C
Surat	45.6
Akola	47.2
Amaravati	46.7
Malegaon	43.3

During the south-west monsoon season the mean temperature in the basin varies from 25 to 30 °C.

Evaporation :

There are no departmental observatories of the I.M.D. within the basin, there are three agrometeorological observatories of the department located at Surat, Jalgaon and Akola.

Lithology :

The basin rests on the Deccan traps. The traps are principally made up of rocks of basaltic and doleritic composition. They are dark coloured fine to medium grained basic igneous rocks and are mainly composed of plagioclase, pyroxene, iron-ore, primary glass and some secondary minerals. The rocks though very hard, tough and compact are susceptible to weathering which commences on the exposed surfaces and along joints cracks and fissures. The black cotton soil of Deccan and the laterite deposits of Madhya Pradesh are some of the useful products of prolonged weathering of the Deccan traps.

The Deccan traps are intercalated with sedimentary intertrappean horizons made up of shale, chert impure limestone, pyroclastic materials etc., ranging in thickness from a few inches to around 100 feet. The geological formations lying below the traps range in age from Upper Cretaceous to Paleocene or even Eocene. The trap rocks are commonly used as road and building materials. They have also yielded deposits of high grade bauxite and semiprecious stones. The vesicular and highly jointed lava flows serve as suitable aquifers in some parts of the Deccan country.

Soils :

Central Water and Power Commission in connection with the Ukai and Kakrapar projects has done soil surveys. These surveys and the general data regarding the soils of India indicate that the Tapti basin consists mainly of black soil. The coastal plains in Gujrat are composed of aluvial clays with a layer of black soil in the surface. The principal soil types found in different districts lying in the basin are described below 3.5 :

Table 3.5 : Soils in Tapti basin-districtwise

District	State	Type of soil
Betul	M.P.	Shallow black
Hosangabad	-do-	Medium and deep black
East Nimar	-do-	Medium black
West Nimar	-do-	--do--
Akola	Maharashtra	--do--
Amaravati	-do-	--do--
Buldana	-do-	Deep black
Dhulia	-do-	Medium and deep black
Jalgaon	-do-	--do--
Nasik	-do-	Medium black
Broach	Gujrat	Black and coastal alluvium
Surat	-do-	Medium black, deep black

Land use and agricultural practices :

Statewise land use details have been given in the Table 3.6

Table 3.6 : Land use details in Tapti basin (thousand hectares)

Item	M.P.	Maharashtra	Gujrat	Total
	Name of State			
Gross area	980	5,150	384	6,514
Area under forest	403	1,189	55	1,647
Culturable area	515	3,608	169	4,292
Uncultivated culturable area	128	344	20	492
Total cropped area	405	3,406	155	3,966
Net area irrigated	17	144	17	178

Source : Table 3.1 to 3.6 from Report of Irrigation Commission 1972 Vol3 part1.

The culturable area in the basin is about 2.2% of the total culturable area in the country. The total cropped area in the basin forms 2.4% of the total cropped area in the country.

Water resources :

The first assessment of the Tapti river system (Narmada and Tapti taken together) was made in (1901-1903) by the Indian Irrigation Commission. The estimates derived by this method were only a rough approximation as no direct measurement of runoff was made.

In 1949 the assessment of the basin water resources was worked out on the basis of Khosala's empirical formula. In 1960 the irrigation potential studies of the country were made by the CWPC. River gauging in the basin started at a few stations as early as 1902 but the operation was brought to an end on all sites in the basin in 1926 with the exception of Thengoda and Jamda. Till 1947, all hydrological activities remained suspended. Toward the later part of 1946, a number of gauge and discharge measurement stations were set up

In the Tapti basin the gauging operation have been fairly extensive and almost all important reaches of the Tapti and its tributaries are being gauged. Normally two observations a day are taken. In the monsoon season when the discharges are found to vary rapidly during the day, as many as eight observations a day are made. The runoff data in respect of gauge and discharge sites in the basin are available for only a short period, whereas the precipitation records are available for a much longer period.

Like other peninsular rivers, the Tapti swells during monsoon months of July, August and September and flow reduces during the post-monsoon period. The major part of the surface runoff occurs in the monsoon months.

METHODOLOGY

Data

Data for the study are all from secondary sources. Mean monthly temperature and rainfall values from 1970-1989 for the stations shown in fig 4.1 were taken from India Meteorological Department, Pune. Using Thornthwaite's formula potential evapotranspiration values were calculated and modified water balance procedure was then applied to get the values of moisture parameters viz. actual evapotranspiration (AE) water surplus, water deficiency, soil moisture change and runoff.

Methodlogy

The basic equation governing the water balance concept is

$$P = E + \Delta S + RO$$

where P is precipitation,

E is evapotranspiration,

ΔS is change in soil moisture storage, and

RO is runoff.

For evaluation of water balance of a station water supply ie. precipitation is compared with water demand ie. potential evapotranspiration (PE) . The calculations yield above moisture parameters. Soil acts as a medium for storing water (upto a limit) in times of excessive rainfall and releasing the same in a restricted manner at the other times for the purpose of evapotranspiration. For working out the water balance three parameters - 1) potential evapotranspiration, 2) precipitation, and 3) available water capacity (Awc) are required.

Direct measurement of PE involves various practical difficulties. Thornthwaite (1957) gave an empirical relation for its estimation, using the mean air

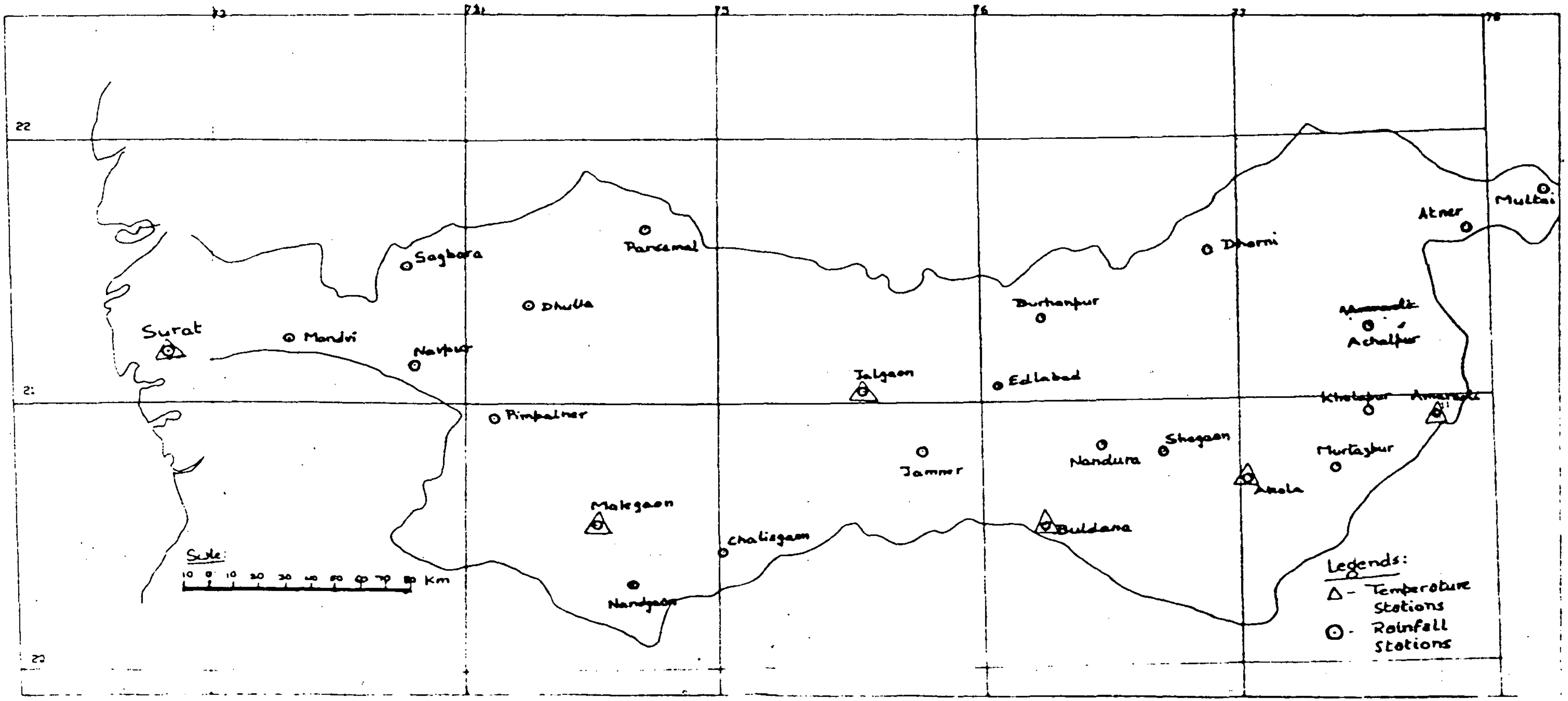


Fig.4.1 Location of recording stations

temperature data and length of the day which depends upon latitude of the station and season. The formula is given as

$$e = 1.6\ (10 \times T / I)$$

where e = monthly thermal efficiency in cm. ,

T = mean monthly temperature in °C,

I = Annual Heat Index being equal to $\sum_{n=1}^{n=12} i_n$

where i_n = mean heat index of the n^{th} month given as $i_n = (t_n/5)^{1.514}$

where t_n = mean temperature of the n^{th} month,

$a = 6.75 \times 10^7\ I^3 - 7.71 \times 10^5\ I^2 + 1.79 \times 10^2\ I + 0.49239$

The values of thermal efficiency thus obtained are adjusted for the length of the day and the actual number of days in the month. Correction factors are available for this purpose.

Penman (1948) on the other hand gave a formula based on sound physical and mathematical consideration including the radiation balance and aerodynamic energy processes. The values obtained by this method correspond more to realistic values of PE.

Some empirical relations have also been suggested by Hassan et al. (1987) and Gangopadhyay et al. (1965) to calculate PE from pan evaporation values which is easier to record. The relation is given as

$$PE = \beta \times \text{Pan evaporation}$$

where ß is a conversion factor and standard values for this have been given by the authors. The values have been given for Iraq and South England but are in general use at different locations.

Mean monthly precipitation values were taken for the 25 stations shown in fig. 4.1. The stations were chosen such that they cover the whole basin, have sufficient length of records and are fairly uniformly distributed. The monthly values were then cumulated to seasonal and annual averages. The 12 months have been grouped into three seasons of four months each -premonsoon (October through January), monsoon (February through May) and postmonsoon (June through September). The average precipitation for the basin was calculated using Theissen Polygon method.

Any excessive rainfall, left over after meeting the requirements of PE goes into the soil to charge it till the soil attains field capacity. Further addition of rain water goes as surplus and flows out of the region as surface runoff or sub-surface or underground flow.

Available water capacity of a place depends on the type of soil and the depth of root zone of the crop. It can vary just from a few mm of water on shallow sand to well over 400 mm in deep well aerated silt loam. Tables are available for values of soil field capacities for different combinations of soil and vegetation (Subrahmanyam V.P.,1982).

According to Thornthwaite and his associates, the release of soil moisture, for evapotranspiration during dry periods, is according to an exponential function given by

$$S = Awc.\ Exp.\ (Acc(P\text{-}PE)/Awc)$$

where S is the moisture remaining in the soil as storage, Acc.(P- PE) accumulated potential water loss. With the help of the value of soil storage parameters AE, water deficit, water surplus and runoff were calculated.

When precipitation is greater than PE , AE equals PE. For months when precipitation is less than PE, AE is equal to precipitation plus any change in soil storage. The difference of PE and AE is the water deficiency and the amount by which precipitation exceeds AE, when the soil is at field capacity, is defined as water surplus. Two third of the surplus for any month goes as river discharge and one third alone remains in the soil during that particular month and contributes to the subsequent months surplus. Again the monthly averages of these parameters were cumulated to seasonal and annual averages.

Model fitting

The next step done was regression analysis to find the kind of relation between the parameters that is how a parameter is affected by a change in another parameter. The analysis also gives the strength of association between the parameters.

A set of hypothetical climate change scenarios,involving changes in temperature of +1,+2,+3 and +4 °C and changes in precipitation of plus and minus 10, 20 % have been constructed and putting these values in regression results effect of climate change of such a magnitude on AE, runoff and change in soil storage have been estimated. The regression results have been given in the next chapter.

The water balance equation suggests that runoff is mainly a function of precipitation, AE and any change in soil moisture storage. Multiple regression analysis ,therefore, was done taking runoff as dependent variable and the remaining three variables as independent variables. A linear model was fitted between the variables in case of all the three seasonal and annual means. The results of model fitting have been discussed in the next chapter.

Results and Discussions

5.1. Trends of temperature and moisture parameters based on previous data :

Temperature and moisture parameters were analysed for annual mean conditions as well as for the three seasons for assessment of climatic changes and its impacts on water resources of Tapti river. Annual and seasonal averages of temperature, precipitation, actual evapotranspiration (AE), soil storage, changes in soil storage and runoff are plotted for past 20 years (1970-1989). A linear fit has been given to the plots and the trends of these parameters are given in fig. 5.1 .

Temperature trends :

From the figure it can be seen that temperature is continuously increasing in coming years except in premonsoon season. In premonsoon season temperature shows slight decrease. Trend of temperature is positive in postmonsoon season and changes are the most significant during this period. Significant warming in postmonsoon and winter season has been reported by Pant et al. also (1993). The studies so far conducted on the long term temperature changes have shown an increasing trend over last 8 decades (Sarkar and Thapaliyal, 1988).

Variation in trends have also been reported by Hingane et al. (1985), in their study on long series of temperature data of different regions of the country. They found that west coast, interior Peninsula, north central India and northeast India show a pronounced warming in mean annual temperature. They repoted the trend to be 0.7 °C in postmonsoon and winter season, 0.4 °C in premonsoon

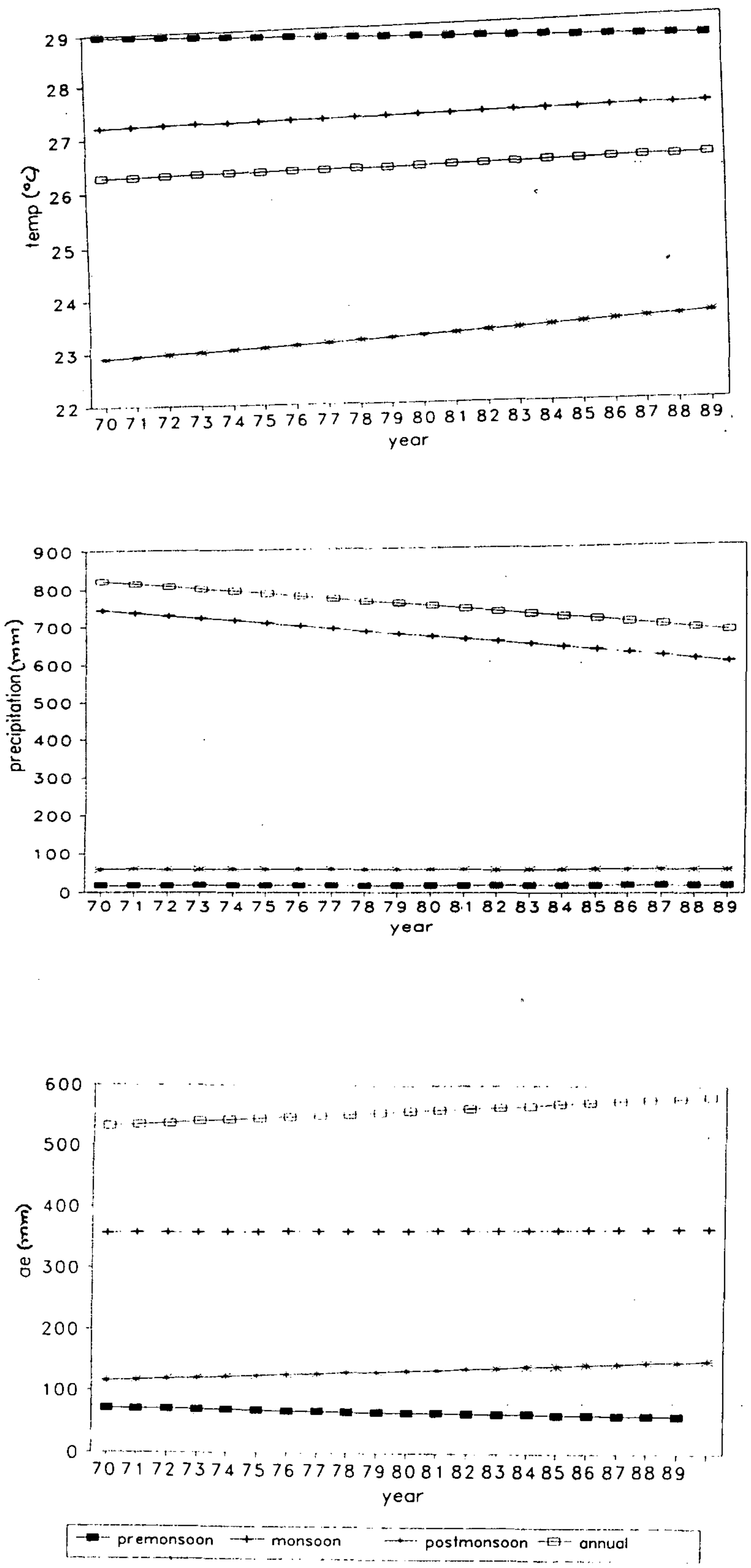


Fig 5.1 a: Linear fit in temperature and moisture parameters for the period 1970-1989

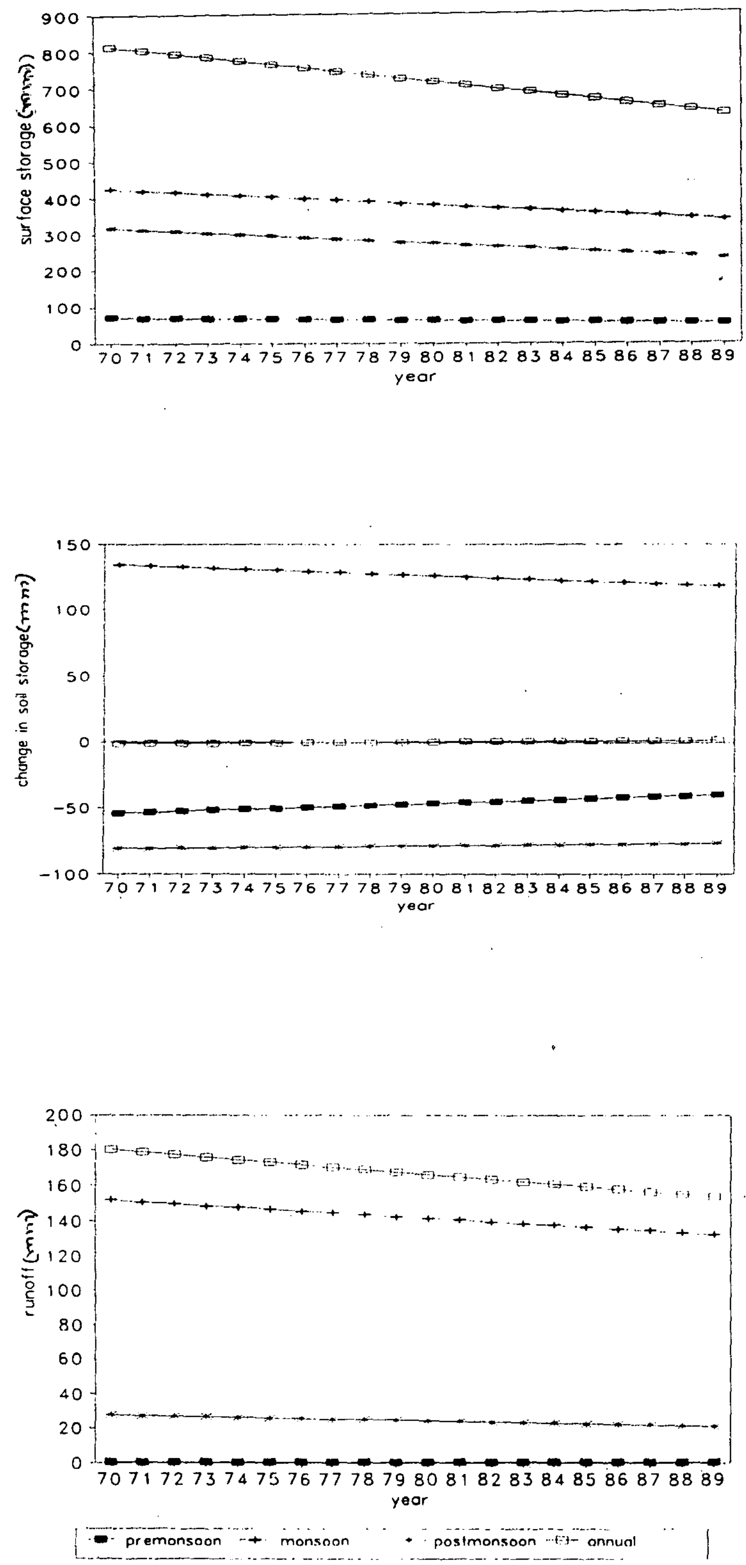


Fig 5.1 b: Linear fit in moisture parameters for the period 1970-1989

season and slight negative trend -0.3 °C in monsoon season. The decreasing trend of temperature in premonsoon season, observed in the present study, could not be explained at this stage.

Precipitation trends :

There is only a little change in precipitation in premonsoon and postmonsoon seasons. Precipitation in monsoon season shows a decreasing trend. The overall annual trend of precipitation also shows a decrease. More than 90 % of rainfall in the basin occurs in monsoon season. Rainfall in other seasons accounts for less than 10 % . The annual trend of precipitation , therefore, follows the trend of monsoon precipitation.

Trend of evaporation and soil storage :

AE, except a small decrease in premonsoon season, increases in other seasons. The increase is maximum in postmonsoon season. Annual change in AE over the past 20 years is also significant.

Soil storage is decreasing in all the four cases. This may be due to the decreasing precipitation in monsoon season. Change in soil storage gives increasing trend in pre and post monsoon season but the trend is decreasing in monsoon season. Annual changes in soil storage are, however, small. Over a period of past 20 years, annual change in soil storage is very close to zero.

Trend of runoff :

Runoff in the river in premonsoon season is almost nil. The source of water for the river is mainly rainfall. Soil storage accounts for some amount of runoff in postmonsoon season but by the premonsoon season it is exhausted. Runoff in monsoon and postmonsoon seasons give decreasing trends, and similar is the trend of average annual runoff. Trend of average annual runoff can be fairly correlated with decreasing trend of precipitation and increasing trend of evaporation.

Effect of temperature on moisture parameters :

Effect of temperature on precipitation, AE, runoff and change in soil storage was then estimated. Simple regression analysis was done for the purpose. The relations as obtained for the three seasons are given below :

Premonsoon :

$P = -0.0945589 \times T + 4.60188$

$AE = 0.0307706 \times T + 5.66927$

$R = 0.0176936 \times T - 0.489309$

$St = -0.121051 \times T - 1.19554$

Monsoon :

$P = 3.08785 \times T - 16.8371$

$AE = 2.12036 \times T - 19.9589$

$R = 0.699223 \times T - 4.86331$

$St = 0.0188915 \times T + 12.119$

Postmonsoon :

$P = 0.399838 \times T - 3.24324$

$AE = 1.11078 \times T - 11.8534$

$R = -0.961941 \times T + 24.8059$

$St = -0.722793 \times T + 8.90049$

where P is precipitation, R is runoff and St is change in soil storage.

Results from the greenhouse experiments have predicted a rise in annual mean temperature of 2.0 to 3.5 °C over the Indian subcontinent in the next hundred years (Lal, 1993). Keeping this into account hypothetical scenarios were constructed which assumed an increase in temperature of 1, 2, 3, and 4 °C. These scenarios were then applied to the above regressions to see the response of climate change of such a magnitude on the moisture parameters. Annual changes were calculated from the seasonal changes, giving due weightage to seasonal means.

Probable changes in these parameters are given in Table 5.1 . Runoff changes are given in terms of volume of water also so that effect of hypothetical climate changes on water availability can be easily visualized. Percentage changes in the parameters are also given in Table 5.2.

Table 5.1 : Changes in moisture parameters as a result of hypothetical increase in temperature

Parameters	change in T	pre monsoon	monsoon	post monsoon	annual
values in cm.					
	+1°C	-00.1	+03.1	+00.4	+03.4
	+2°C	-00.2	+06.2	+00.8	+06.8
P	+3°C	-00.3	+09.3	+01.2	+10.2
	+4°C	-00.4	+12.4	+01.6	+13.6
	+1°C	+0.03	+02.1	+01.1	+03.2
	+2°C	+0.06	+04.2	+02.2	+06.5
AE	+3°C	+0.09	+06.4	+03.3	+09.8
	+4°C	+0.12	+08.5	+04.4	+13.0
	+1°C	-0.12	+0.02	-00.7	-00.8
	+2°C	-0.24	+0.04	-01.5	-01.7
St	+3°C	-0.36	+0.06	-02.2	-02.5
	+4°C	-0.48	+0.08	-02.9	-03.3
	+1°C	+0.02	+00.7	-01.0	-0.28
	+2°C	+0.04	+01.4	-02.0	-0.56
R	+3°C	+0.06	+02.1	-03.0	-0.84
	+4°C	+0.08	+02.8	-04.0	-1.12
Changes in the volume of water (million cubic meters)					
	+1°C	+13	+460	-650	-177
	+2°C	+26	+910	-1300	-364
R	+3°C	+39	+1400	-1900	-461
	+4°C	+52	+1800	-2600	-748

Effect on precipitation :

It is obvious from Table 5.2 that precipitation, except in premonsoon season, increases with increase in temperature. In premonsoon season precipitation decreases by 5 % for 1 °C change in temperature. With successive increase in temperature precipitation proportionately decreases, the decrease being 20 % for 4 °C warming.

Table 5.2 : Percentage changes in moisture parameters as a result of hypothetical increase in temperature

Parameters	change in T	pre monsoon	monsoon	post monsoon	annual
	+1°C	-05.3	+04.6	+07.0	+04.5
	+2°C	-10.5	+09.2	+13.0	+09.0
P	+3°C	-15.8	+13.8	+20.0	+13.6
	+4°C	-21.1	+18.4	+26.0	+18.1
	+1°C	+00.5	+05.6	+08.0	+05.5
	+2°C	+01.0	+11.2	+16.0	+11.1
AE	+3°C	+01.4	+16.8	+24.0	+16.8
	+4°C	+01.8	+22.4	+32.0	+22.3
	+1°C	-02.6	almost	-08.9	
	+2°C	-05.1	no	-19.0	
St	+3°C	-07.7	change	-27.9	
	+4°C	-10.2		-36.7	
	+1°C	almost	+05.0	-40.0	-01.7
	+2°C	no	+10.0	-80.0	-03.4
R	+3°C	change	+15.0	-120.0	-05.0
	+4°C	+20.0	-160.0	-45.5	-06.7

In monsoon and postmonsoon seasons precipitation increases with increase in temperature. For 1 °C rise of temperature precipitation increases by

5 % in monsoon season whereas the increase is 7 % in postmonsoon season. The precipitation goes on increasing with successively higher temperatures. Though the increase in precipitation is around 5 % in pre and post monsoon seasons, the quantitative increase is not very significant as precipitation in these seasons is only a small fraction of the total annual rainfall. Annual precipitation, therefore, follows the trend of monsoon precipitation. For 1 °C rise in temperature, annual precipitation increases by about 5 % . In terms of depth of rainfall the increase is 3.4 cm for 1 °C warming and increases with further increase in temperature.

The studies concerning the impact assessment of greenhouse warming indicate that rainfall distribution of a region will undergo changes as a consequence of increased temperature. Monsoon trough will advance northward in a warmer atmosphere and if it happens, the monsoon rainfall over the central plains of India will increase (Lal, 1993). Using IPCC's scenario A, Lal predicted an increase in total annual precipitation of 18 cm per year. In the present study monsoon rainfall is found to increase with temperature but the magnitude of increase is small compared to that predicted by Lal.

One thing should be made clear at this point that precipitation gives a decreasing trend for monsoon and annual averages in fig 5.1 but the trend of precipitation is increasing with temperature (Tables 5.1 and 5.2) . This is because of the fact that fig 5.1 gives the trend of actual precipitation occurring, which depends not only on temperature but other factors as well. In case of Tables 5.1 and 5.2 the precipitation is assumed to be a function of temperature only. This is true in case of other parameters as well.

Effect on AE :

AE on the other hand increases in all the four cases, the increase, however, is small in premonsoon season. This is expected also for AE as increase in temperature will lead to greater evapotranspiration, provided sufficient moisture is available for the purpose. Maximum increase is observed in monsoon season. Increase in AE is significant in postmonsoon season also but in premonsoon season this is very small. Total annual increase is 3.2 cm, ie. an increase of about 5.5 % for 1 °C change in temperature and reaches upto 13 cm, ie. 22 % if temperature increases by 4 °C.

Effect on soil storage change :

Soil moisture change decreases in premonsoon and postmonsoon seasons and increases slightly in monsoon months. On an average soil storage change decreases.

Effect on runoff :

Runoff in premonsoon and monsoon seasons increases slightly but it decreases in postmonsoon season. The overall effect is a decrease in total annual runoff. Annual decrease in runoff is 2 % for 1 °C rise in temperature, ie. on 1 °C warming runoff decreases by 177 million cubic meters. In Table 5.2 it can be noticed that changes in runoff satisfy the water balance equation.

In Table 5.3, result of correlation between temperature and moisture parameters for the four cases, has been given. The coeficients of correlation are very small.

Precipitation runoff relationship :

Runoff is very much dependent on precipitation . Therefore, regression was done for this set of parameters also to see how a change of a few per cent

Table 5.3 : Correlation results between temperature and moisture parameters.

Premonsoon

LABELS	temp	ppt	AE	St	RO
temp	1.000	-0.068	0.014	-0.080	0.265
ppt	-0.068	1.000	0.657	0.030	-0.237
AE	0.014	0.657	1.000	-0.734	0.277
St	-0.080	0.030	-0.734	1.000	-0.581
RO	0.265	-0.237	0.277	-0.581	1.000

Monsoon

LABELS	temp	ppt	AE	St	RO
temp	1.000	0.162	0.376	0.006	0.057
ppt	0.162	1.000	0.671	0.669	0.949
AE	0.376	0.671	1.000	0.392	0.433
St	0.006	0.669	0.392	1.000	0.553
RO	0.057	0.949	0.433	0.553	1.000

Postmonsoon

LABELS	temp	ppt	AE	St	RO
Temp	1.000	0.137	0.389	-0.380	-0.439
ppt	0.137	1.000	0.780	0.330	0.134
AE	0.389	0.780	1.000	-0.333	0.238
St	-0.380	0.330	-0.333	1.000	-0.157
RO	-0.439	0.134	0.238	-0.157	1.000

Annual

LABELS	temp	ppt	AE	St	RO
Temp	1.000	-0.002	0.180	-0.254	-0.088
ppt	-0.002	1.000	0.759	0.259	0.939
AE	0.180	0.759	1.000	0.022	0.493
St	-0.254	0.259	0.022	1.000	0.282
RO	-0.088	0.939	0.493	0.282	1.000

in precipitation affects runoff. The relationship is given below :

Premonsoon : $R = -0.00677143 \times P + 0.0327303$

Monsoon : $R = 0.607773 \times P - 26.758$

Postmonsoon : $R = 0.104154 \times P + 1.83039$

From the Table 5.1 it can be seen that increase or decrease of precipitation for warming of 1 to 4 °C is around 5 to 20 % . Precipitation scenarios involving increase and decrease of 10 and 20 % of precipitation were developed. These values are substituted in the above precipitation-runoff relations and corresponding percentage change in runoff have been given in Table 5.4.

Table 5.4 : Effect of hypothetical changes in precipitation on runoff

Precipitation changes %	Premonsoon %	Monsoon %	Postmonsoon %	Annual %
-20	runoff	-12.2	-2.1	-10.8
-10	very	-06.1	-1.0	-05.5
+10	small	+06.1	+1.0	+05.5
+20		+12.2	+2.1	+10.8

From Table 5.4. It can be seen that runoff increases with higher precipitation and decreases with decrease in precipitation. This is very much expected for runoff. Change in runoff is the most significant in monsoon season. For 10 % increase in precipitation, increase in runoff is 6 % and for 20 % increase this increase is 13 % , the reverse is the case with decrease in precipitation.

Testing a linear model between runoff and other moisture parameters :

The water balance equation suggests that runoff is principally a function of precipitation, evapotranspiration and any change in soil storage. A linear model was fitted between the parameters with the help of multiple regression. The results of model fitting in all the four cases are given in Table 5.5 .

Coefficient of correlation is close to one for monsoon and annual runoff. There is good correlation in premonsoon season also but in postmonsoon season the relationship is not significant. The results are within 90 % confidence limits in case of premonsoon season and within more than 99 % confidence limits in case of monsoon season and annual. In postmonsoon season the model results are acceptable with 65 % confidence only.

The observed values are plotted against the predicted values in all the four cases in fig 5.2 (i) and fig. 5.2 (ii). The monsoonal and annual plots reveal a close match between the observed and predicted values but in premonsoon and postmonsoon seasons scattering is observed.

Effect of precipitation, AE and soil storage change on run of has been shown in fig. 5.3 (i) and 5.3 (ii). Of the three parameters, it is found that precipitation and AE play a major role in modifying runoff. In fact these are the parameters to be influenced more as a consequence of warming. Although percentage change in soil storage is significant in postmonsoon season and on an annual basis, quantitatively this is small in comparison to change in precipitation and AE.

It can be seen from the table 5.5 and fig. 5.3 that effect of precipitation on runoff is positive but that of AE and soil storage change is negative. Summer runoff, therefore, increases because in that season precipitation increases as temperature increases. But on an annual basis, since change in AE exceeds that of precipitation, runoff shows a decrease with increasing temperature.

Table 5.5 : Model fitting results

Premonsoon

Independent variable	coefficient	std. error	sig.level
CONSTANT	-0.011968	0.018417	0.5250
precipitation	1.794427	0.995046	0.0902
actual evapotrans.	-1.800446	0.995798	0.0894
soil storage change	-1.811976	0.996123	0.0877

R-SQ. (ADJ.) = 0.3944 SE= 0.023400

Monsoon

Independent variable	coefficient	std. error	sig.level
CONSTANT	2.215206	1.65388	0.1992
precipitation	0.856131	0.016554	0.0000
actual evapotrans.	-0.846636	0.045216	0.0000
soil storage change	-1.079874	0.118989	0.0000

R-SQ. (ADJ.) = 0.9955 SE= 0.939186

Postmonsoon

Independent variable	coefficient	std. error	sig.level
CONSTANT	-0.648106	2.922289	0.8273
precipitation	91.518316	95.017489	0.3498
actual evapotrans.	-91.37045	95.02975	0.3506
soil storage change	-91.673448	95.074365	0.3493

R-SQ. (ADJ.) = 0.0000 SE= 2.502014

Annual

Independent variable	coefficient	std. error	sig.level
CONSTANT	0.141484	0.331	0.6748
precipitation	0.977551	0.003431	0.0000
actual evapotrans.	-0.976769	0.008329	0.0000
soil storage change	-1.038062	0.054619	0.0000

R-SQ. (ADJ.) = 0.9998 SE= 0.205475

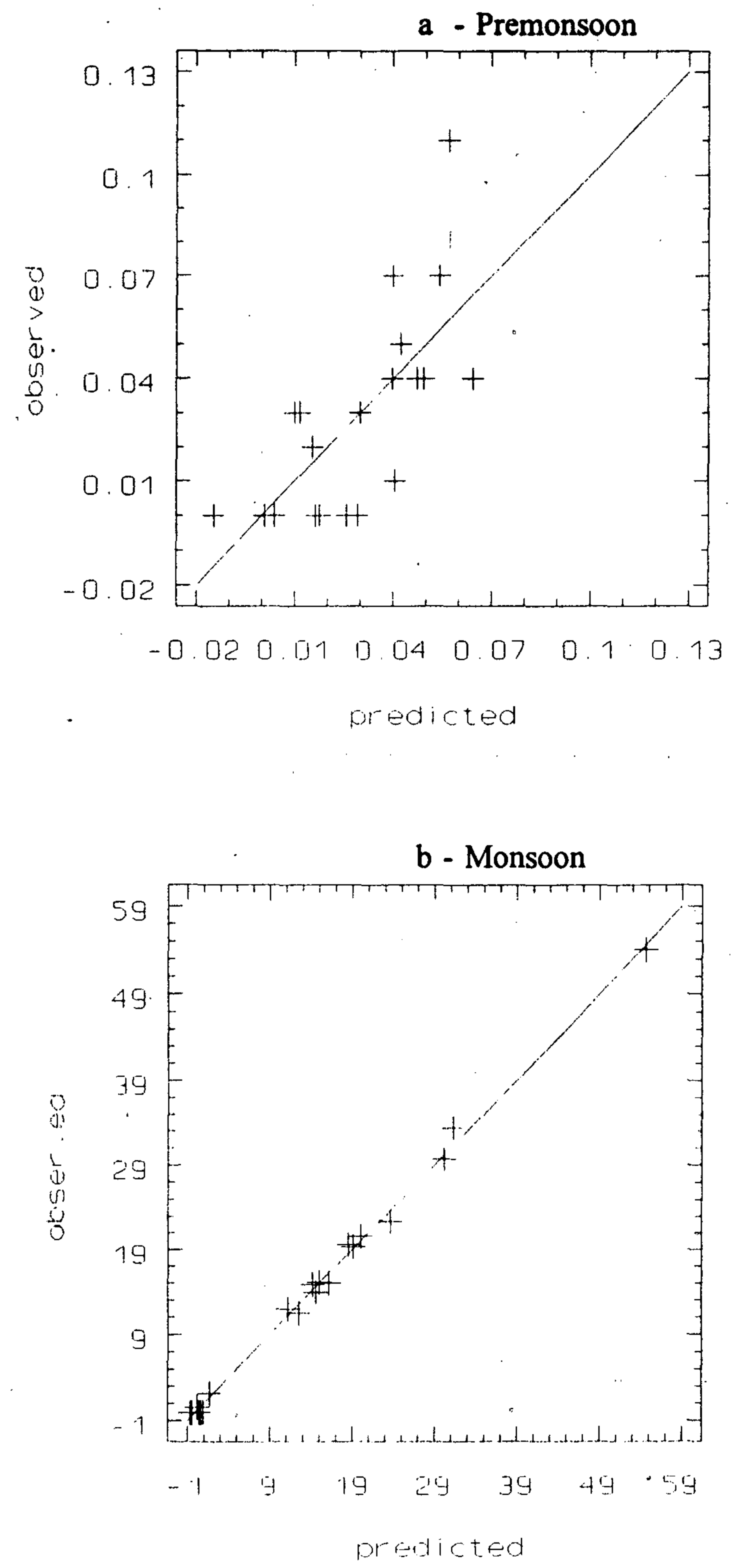
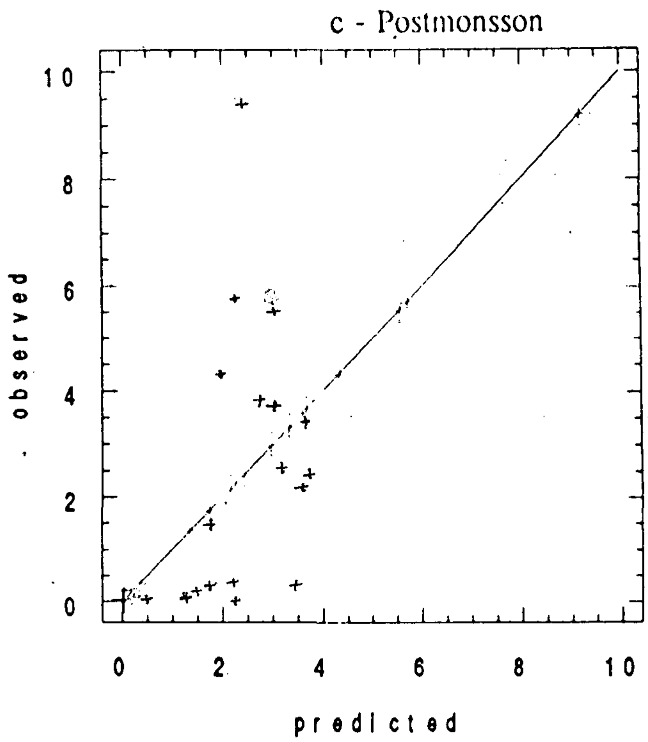


Fig 5.2 (i) : Plots of observed versus predicted value of runoff



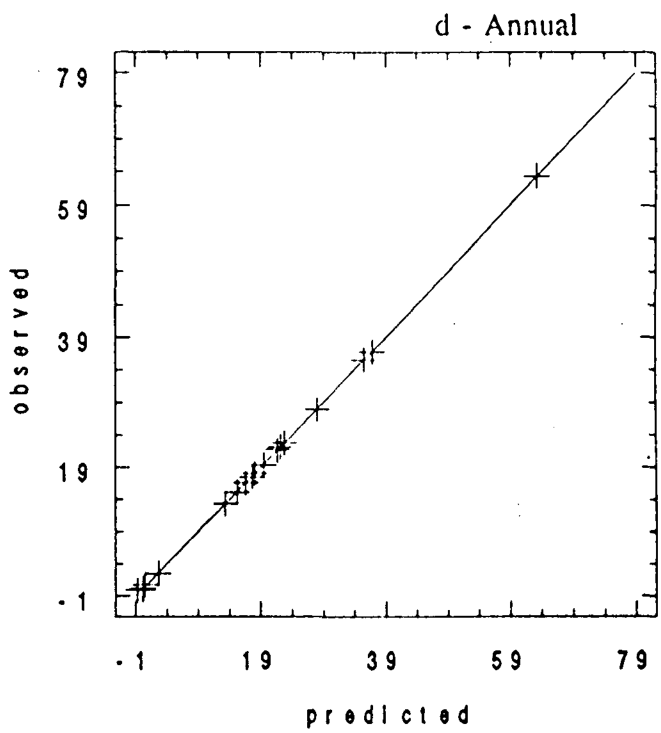
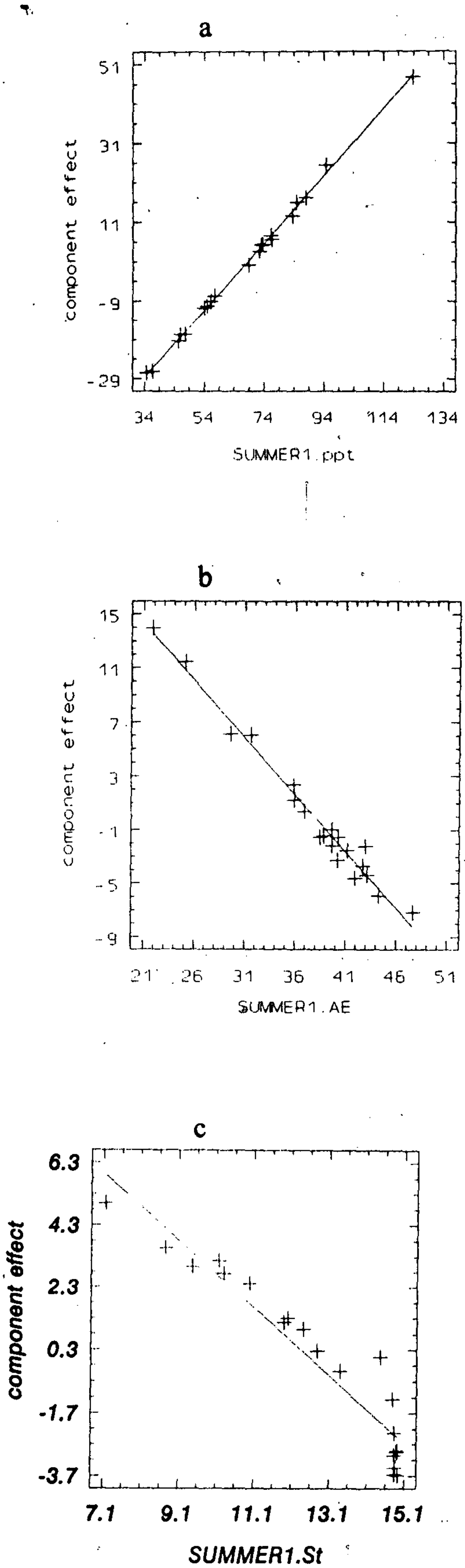


Fig 5.2 : Plots of observed versus predicted value of runoff



ppt - precipitation
St - soil storage change

Fig 5.3 : (i) Figure showing effect of individual parameters on monsoon runoff a)ppt, b)AE, c)Soil storage change

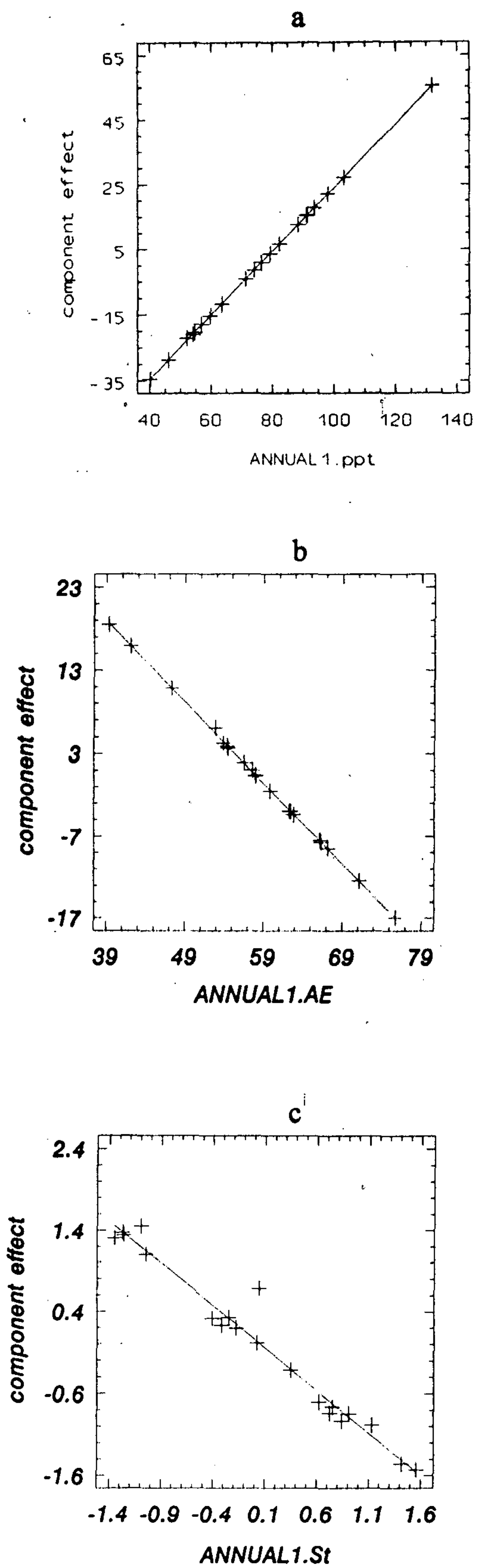


Fig 5.3 : (ii) Figure showing effect of individual parameters on annual runoff a)ppt, b)AE, c)Soil storage change

Discussion :

Though the method used is one of the widely applied tools to estimate changes in water resources, as it requires relatively small amount of data, usually surface air temperature, precipitation and annual runoff, in extrapolating regression results to future periods great caution is required. It can not be assumed that interannual pattern of meteorological parameters in the past will repeat in future also.

In the present study a linear model has been fitted between the parameters. An obvious consequence of this can be seen in the linear increase in moisture parameters for successively increasing temperatures. The data was found to be too much scattered about the line of regression, values of correlation coefficients are also small. The study suffers from one more handicap, the number of observations is only 20 , too small a figure for significant trend analysis. Again the increase in temperature of 1 to 4 °C are expected in not less than 100 years according to temperature trends in this study. Extrapolation of regressions for such a long period may not be perfect. The results of the study, therefore, should be handled carefully.

CONCLUSION

The study in brief can be summarised as follows. In the Tapti river basin an increasing trend of temperature, and actual evapotranspiration and a decreasing trend of precipitation, runoff and soil storage over a period of past 20 years was observed. It was found that under a warmer climate, precipitation and actual evapotranspiration (AE) show increase. Runoff, however, decreases as a result of warming.

The results so far obtained can be explained easily with simple hydrological principles. The relationship between temperature and precipitation, however, needs more attention. The studies carried out to find the reltionship of temperature and precipitation have demonstrated that effect of temperature on precipitation is different in different regions. The relationship may be different in different seasons as well. Precipitation is expected to increase in low latitudes and during winter in high latitudes. Mid-latitudes, are to suffer reduction in summer precipitation.

In the present study, prediction of runoff and other moisture parameters, in a warmer climate, is based on regression of these parameters with temperature. The line of regression seems not to be the true representative of dataset. The results, therefore, should be limited upto the examination of the interactions between the parameters ie. nature of relation can be assessed but the strength of relationship is week. For a reliable prediction the model necessitates some modification.

This study was limited to the examination of linear model only for prediction of runoff. Nonlinear models should be tested for runoff generation. These should be made more comprehensive by including reliable and detailed (in space as well as time) estimates of future climatic conditions. The complexity of topography, soil characteristics, natural and artificial storage should also be taken into consideration to make the model more realistic.

Since 1970 extensive study of changes in annual and seasonal runoff has been started. The issue attracts attention more because runoff meets the water demand of most regions. Watersheds located in arid and semiarid regions are more sensitive.

The hydrologic consequences of anthropogenic global warming are not limited to changes in river runoff and water balance values only. Other consequences are changes in total water amount and levels, erosion in riverbeds and modifications of turbidity and sediment load. Quality of water in many water bodies could also deteriorate. Decreasing river runoff and lake levels decrease the possibility of dissolving pollutants and flushing process.

Intensive assessments of water resource sensitivities are necessary in developing countries, especially those located in arid and semiarid regions.

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