Impact of Groundwater Irrigation on Dry Season Flow of the Tangan River

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CERTIFICATION OF THE PROJECT

The project report titled "**Impact of Groundwater Irrigation on Dry Season Flow of the Tangan River**" submitted by Mousumi Datta. Roll No: D10062804F, Session: October, 2006 has been accepted as satisfactory in partial fulfillment of the requirement for Post Graduate Diploma in Water Resources Development on 01 July, 2008.

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It is hereby declared that this report or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

In Bangladesh groundwater irrigation is a common practice for agricultural production Increased use of groundwater irrigation for agricultural uses may have resulted in declines of dry season streamflow and baseflow. In this study, an attempt was made to investigate the relation of the Tangan River dry season flow and baseflow with the abstraction of groundwater in its catchment through the systematic use of statistical and baseflow separation techniques. Data analyzed include streamflow, baseflow, and groundwater levels. The baseflow separation was done using the software BFLOW.

Boro season (January to early May) was considered for the study since groundwater is the only source of irrigation during these four months. Average decadal (10- day) streamflow and baseflow were calculated for these four months over a period from 1973 to 1993. Time series of average decadal srtreamflow and baseflow showed a declining trend of river flow. The study estimated the percentage of average streamflow and baseflow reduction in the Tangan River during these four months period over the study time of 1973 to 1993 and these were found to be 41 % and 35 % respectively. Trend line fitted to the lowest groundwater table was also found to be downward and this indicates the lowering of groundwater table through the time period of 1973 to 1993. An increased amount of groundwater was withdrawn from the study area over the study time, which was estimated from drawdown and specific yield data. A correlation coefficient of -0.66 between the streamflow and groundwater abstraction was obtained for the period from 1973 to 1993. For baseflow and groundwater abstraction, the correlation coefficient was found to be -0.67. Furthermore, for baseflow, the correlation coefficient increases to -0.91 if data from 1978 are considered due to their better reliability. Groundwater abstraction correlates well with baseflow (-0.91) than streamflow (-0.66). With 1 unit increase of groundwater abstraction, baseflow of the river would decrease by about 0.2 unit. The statistical analysis indicates that the primary factor causing the streamflow and baseflow declines is lowered groundwater level caused by increased abstraction mainly from dry season irrigation.

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ABBREVIATIONS AND ACRONYMS

β	Filter parameter
BADC	Bangladesh Agricultural Development Corporation
b_t	Baseflow
BWDB	Bangladesh Water Development Board
DTW	Deep Tubewell
GWT	Groundwater table
Ha	Hectare
HTW	Hand Tubewell
IWM	Institute of Water Modelling
K_h	Horizontal Hydraulic Conductivity
K_v	Vertical Hydraulic Conductivity
LLP	Low Lift Pump
Mm	Millimeter
Mm^3	Million Cubic Meter
NMIC	National Minor Irrigation Census
NWRD	National Water Resources Database
PWD	Public Works Datum
Q	Original streamflow
q_t	Filtered surface runoff
SW 285	Thakurgaon Discharge Station
SW 287	Kodalkatigaon Discharge Station
USA	United States of America
WARPO	Water Resources Planning Organization

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Streamflow of a river consists of three components: surface runoff, interflow and baseflow. Through most of the dry season (November - May) of the year, the streamflow is composed primarily of baseflow. During the wet season (June - October), discharge is made up of its three components. Therefore, baseflow is the major contributor to streamflow, not only in periods of low flow or without rain but also during floods. Baseflow is an important component of a streamflow hydrograph, which comes from groundwater and/or shallow subsurface storages. Dry season streamflow is generally regarded as being a result of groundwater discharging into the stream, while the direct runoff is considered to be the result from overland or near surface flow. Detailed knowledge of groundwater contribution to stream, i.e. baseflow, is important in many water management areas: water supply, waste water dilution, navigation, hydropower generation and aquifer characterization. Also, baseflow can directly be related to aquifer recharge (Birtles, 1978; Wittenberg and Sivapalan, 1999; Szilagyi et al., 2003), which is crucial in ascertaining safe yields of water development schemes, such as irrigation planning in the Great Plains (Sophocleous, 2000).

In a stream-aquifer system, the stream may receive discharge from groundwater when the water table in the aquifer is higher than the water level of the stream. If there is good hydraulic connection between an unconfined aquifer and a surface water body, pumping well located near a river can diverts groundwater flow, which under natural conditions would have discharged into the river as baseflow. As a result, the baseflow to the river might be reduced. As pumping continues, a reverse hydraulic gradient around the river may be formed and the river begins to discharge water to the aquifer. This induced river infiltration further reduces streamflow. The reduced baseflow and induced river infiltration may lead to total streamflow depletion and there may be a change in or loss of wildlife habitat or a decline in the fishery.

Bangladesh is a highly populated country. Population of the country has been increasing day by day. Agricultural production has to be increased to meet the growing food demand of the countrys population. Agricultural productivity holds the key to the country's overall economic growth and welfare to its people. Irrigation is the lifeline of agriculture. Bangladesh has fertile agricultural land and abundant water in the wet season but limited water at the time of need in the dry season. In Bangladesh, minor irrigation plays a positive role to improve agricultural production during the dry season. Minor irrigation was introduced in Bangladesh in early sixties using low lift pumps. The emphasis soon changed to groundwater abstraction initially through deep tubewells (DTWs) followed by introduction of shallow tubewells (STWs) (BADC, 2006). Agricultural productivity has increased through the expansion of groundwater irrigated agriculture. In the study area, groundwater has been used to meet the domestic demand as well. But groundwater use for agriculture is greater than that for the household purpose. So, groundwater irrigation has become a topic of interest in this study. In the study area, the flows of the Tangan River is lowering over the years and during the dry season it reaches to its lowest level at which instream requirement cannot be maintained. This will be harmful for the ecosystem. Local people then cannot use river water for domestic and other purposes and they have no other way than to depend on groundwater. Local people of the study area use hand tubewells (HTWs) for their drinking purpose, and for irrigation they depend on DTWs under the Barind Multipurpose Development Authority and also on STWs under their private ownership. As a result, a huge amount of groundwater is abstracted every year and the continued increase in abstraction might have put pressures on groundwater table.

At present, the main source of irrigation water in Bangladesh is groundwater covering about 75% of the total irrigated area (BADC, 2006). Recently groundwater based irrigation system is experiencing difficulties in different parts of the country as shallow aquifer level is getting out of reach due to fast depletion of groundwater table. Intensification of irrigation with pumped groundwater is considered to be a reason for the depletion of groundwater table. Increasing groundwater withdrawal may reduce the baseflow to the river. Consequently, the flow available for the environment could decline.

Thus, the reduction in baseflow, and hence the streamflow, might have adverse impact on many water related projects and aquatic vegetation and species In this study, an attempt has been made to evaluate the effect of groundwater irrigation on dry season streamflow and baseflow of the Tangan River.

1.2 Objectives of the Study

The present study has been carried out to find out the effect of groundwater abstraction on streamflow and baseflow of the Tangan River as a result of increased irrigation. The possible outcome of the study would be helpful in planning water sector projects and for agricultural water management of the study area as well as of the country. The specific objectives of this study are:

1. To analyze the trend in observed streamflow data and separate the baseflow component of the streamflow hydrograph using digital filter technique.
2. To analyze the trend in observed groundwater level data.
3. To establish a relationship of dry season streamflow and baseflow with groundwater irrigation.

1.3 Organization of the Report

The report has been arranged in six chapters. Introductory aspects like background of the study, objectives of the study and how the report is organized are discussed in this chapter.

Chapter two reviews the available literature related to the study. Literature regarding the streamflow hydrograph, baseflow separation, river aquifer interaction, groundwater development, safe yield criteria and groundwater table are reviewed here.

Chapter three includes methodology and data collection. In this chapter data collection, data processing for carrying out the analysis and the method which is followed in the study are discussed.

Chapter four gives a general description of the study area. It describes the location, upazillas covered, population, climate, soil, cropping pattern, river system and drainage network, surface water irrigation project and groundwater irrigation in the study area.

Chapter five describes the detailed analysis and results of the study. Dry season streamflow, baseflow and groundwater level data are analyzed in this chapter.

Finally, some conclusions of the study and recommendations for further study are made in chapter six.

CHAPTER TWO

LITERATURE REVIEW

2.1 Streamflow Hydrograph

A hydrograph is a graph showing discharge versus time. Discharge hydrographs of rivers carry the cumulated information on the various hydrological processes occur in catchments and the influences imposed on them. Water that reaches the stream comes from three sources, namely from surface runoff (overland flow), interflow, and baseflow (groundwater flow). It follows that a streamflow hydrograph may be made up of three components, i.e. surface runoff, interflow, and baseflow. In addition, the term direct runoff refers to the sum of surface runoff and interflow. In this case, direct runoff and baseflow are the two components of a streamflow hydrograph. The proportion of stream water that is derived from groundwater inflow varies across physiographic and climatic settings.

Williams and Pinder (1990) have shown that groundwater makes up more than 90% of the streamflow in portions of the Atlantic Coastal Plain. Part of the precipitation on the basin infiltrates through the soil zone to the water table and becomes groundwater. Some of this groundwater is subsequently discharged to the streams as baseflow and some is lost to the atmosphere by evapotranspiration.

The amount of groundwater that contributes to streams can be estimated by analyzing streamflow hydrographs to determine the groundwater component, which is termed as baseflow. Several different methods of analyzing hydrographs have been proposed by hydrologists to estimate the baseflow component of streamflow. A streamflow hydrograph is generally a graphical, tabular, or mathematical representation of the flow discharges of a river, stream or canal that pass through a given cross section as a function of time At the very beginning in a streamflow hydrograph, the flow is about constant or decreases with time, then it increases reaching a maximum value, and thereafter the flow decreases or recedes through time. The increasing part of a flood hydrograph is called rising limb; the part around the maximum flow is called the crest, and that of decreasing flows after the flood peak is called the falling or recession limb.

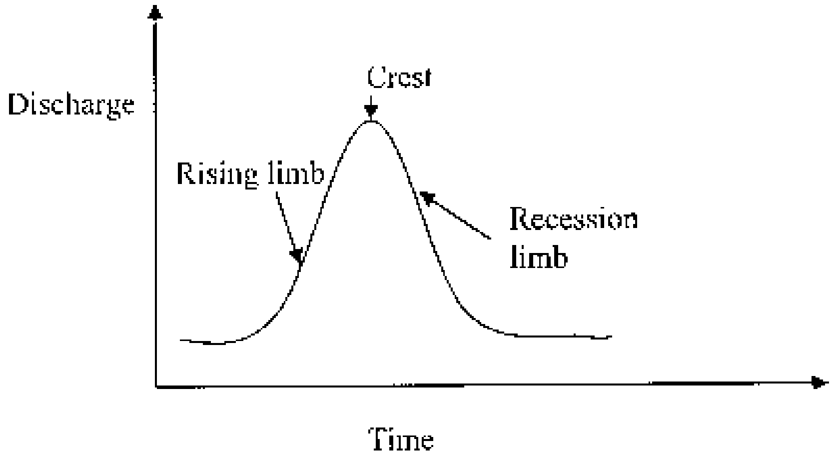

Fig. 2.1: A typical streamflow hydrograph

2.2 Baseflow Separation

Hall (1968) and Tallaksen (1995) stated that baseflow separation from streamflow hydrographs had long been a topic of interest in hydrology since the baseflow recession curve itself contains valuable information about the aquifer properties. Baseflow separation from quick storm response is required for numerous widely used hydrological models (e.g. HEC-1 flood hydrograph package by the US Army Corps of Engineers, unit hydrograph techniques) and other water resource applications (Vogel and Kroll, 1996).

The first step in hydrograph analysis entails separation of streamflow into the two major components: surface runoff and baseflow. Pinder and Jones (1968) cited that the exact separation of each component is often arbitrary and based on either the use of standard methodologies or in a few instances, the use of chemical or isotopic tracers and mass balance approaches.

Baseflow separation techniques use the time-series record of stream flow to derive the baseflow signature. The common separation methods are either graphical which tend to focus on defining the points where baseflow intersects the rising and falling limbs of the quickflow response, or involve filtering where data processing of the entire stream hydrograph derives a baseflow hydrograph.

Barnes (1939) suggested that the three individual components of streamflow, direct runoff, interflow and baseflow, may be distinguished by plotting the logarithms of the flows against time.

White and Sloto (1990) stated that manual separation of the streamflow hydrogaraph into surface flow and groundwater flow is difficult and inexact; often results derived from such manual methods cannot be replicated among investigators. Recently several programs or methodologies have been written to automate this process (Nathan and McMahon. 1990; White and Sloto, 1990; Rutledge, 1993). White and Sloto (1990) programmed three techniques developed by Pettyjohn and Henning (1979) to separate the groundwater/ surface water components of streamflow hydrographs.

Nathan and McMahon (1990) analyzed two baseflow separation techniques for use in prediction of low flow characteristics. The first was a simple smoothing and separation technique developed by the Institute of Hydrology (1980), and the second was a recursive digital filter technique which could be easily executed with a computer. The two methods compared well having a coefficient of determination of 0.94 and a slope 1.04. The recursive digital filter was found to be a fast and objective method of continuous baseflow separation by Nathan and McMahon (1990). .

Digital filter generates higher baseflows under flashy peaks, which perhaps corresponds to actual conditions more closely than that obtained using the smoothed minima approach. However, while the baseflow hydrograph generated by the digital filter appears to be more realistic than the Institute of Hydrology (1980) technique, the baseflow recession curve does not follow the exponential decay function associated with storage depletion.

2.3 River - Aquifer Interaction

In a stream-aquifer system, the stream which receives discharge from groundwater are called gaining stream. Figure 2.2 is a schematic diagram showing a stream-aquifer system where the stream gains water from the aquifer through baseflow.

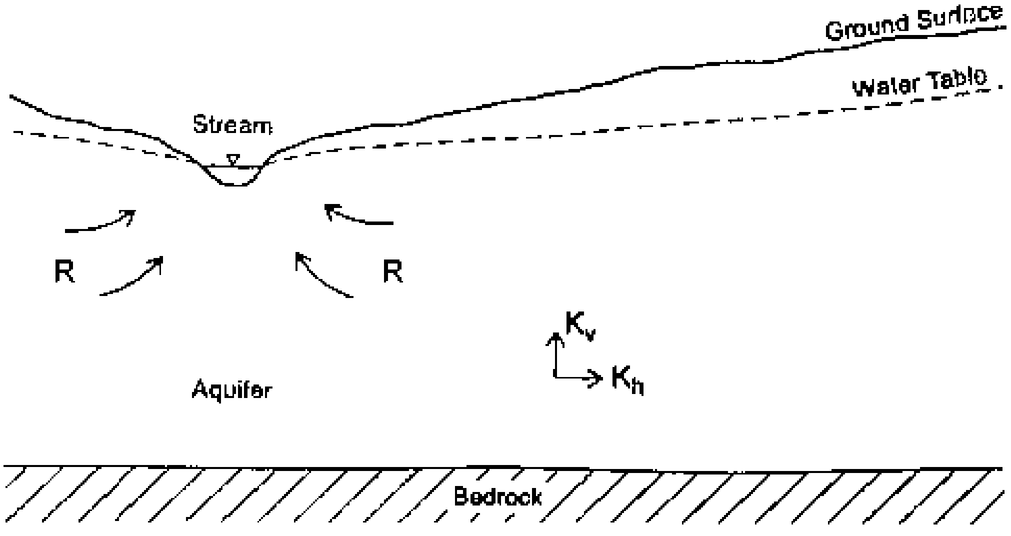

Fig. 2.2 Schematic drawing showing the hydraulic relationship between an aquifer and a stream, where baseflow (R) discharges to the stream, K_v and K_h are vertical and horizontal hydraulic conductivity of the aquifer.

For gaining streams, the amount of groundwater discharge is directly proportional to the hydraulic gradient toward the stream and to the hydraulic conductivity of the surrounding aquifers. For a fully penetrating stream, groundwater flow to the stream is dominantly horizontal and the horizontal hydraulic conductivity (K_h) plays an important role. For a stream-aquifer system where the stream partially penetrates the aquifer, three dimensional conditions exist in the vicinity of the streambed (Conrad and Beljin, 1996). Under this circumstance, the vertical hydraulic conductivity (K_v) has a significant role in controlling the groundwater discharge rate. A pumping well near a stream can intercept baseflow and thus reduce the groundwater discharge rate to the stream (Figure 2.3).

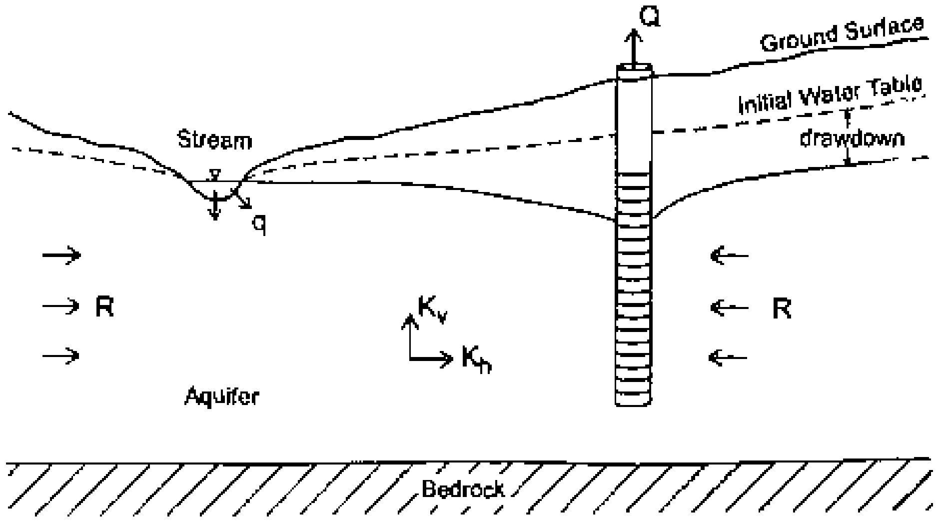

Fig. 2.3 Schematic drawing showing a pumping well intercepts baseflow and induces stream infiltration (q), K_v and K_h are vertical and horizontal hydraulic conductivity of the aquifer.

Two processes can cause a gaining stream to temporarily recharge the aquifer. First, when stream stages (elevation of water level in the stream) are higher (for example during flooding) than the water table in the aquifer, the stream discharges water to the aquifer. Second, after a continuation of pumping, a reverse gradient established below a segment of the stream leads to streambed infiltration (Figure 2.3). The stream infiltration rate may be different in various parts of the channel segment.

Chen and Yin (1999) have demonstrated that irrigation wells located at a certain distance from a gaining stream will not reverse hydraulic gradient below the stream and thus do not induce stream infiltration. However, the pumping depletes streamflow entirely from the reduced baseflow.

2.4 Groundwater Development

Groundwater development concept to protect crops from natural droughts was first initiated in Thakurgaon area in Northwest Bangladesh between 1961 and 1966 with the sinking of 380 DTWs by Bangladesh Water Development Board (BADC, 2003). Availability of good aquifer and limited scope of surface water development indicated the suitability of groundwater development to meet the irrigation as well as domestic and industrial demands of the area.

When groundwater is pumped by a well or set of wells, the groundwater level, either the water table or potentiometric level, will decline near the well as groundwater is removed from aquifer storage. This decline (typically referred to as "drawdown") is usually small when a domestic well is pumped; however, this decline may be quite large in areas where a single or multiple high-capacity wells (e.g., municipal, irrigation and industrial wells) pump large quantities of groundwater (Patterson and Zaporozec, 1986). Drawdown is the greatest at the well withdrawing water and is smaller away from the well, creating a "cone of depression" around the pumping well. In general, the greater the pumping rate, the larger the cone of depression as water is pulled from greater distances from the well.

Groundwater quantity problems arises when wells are spaced too closely together (which can lead to interference between wells) or the aquifer is over pumped or both. In these cases, excessive drawdown occurs because of constraints on the aquifer due to the ability of the aquifer to transmit water or boundaries which inhibit groundwater movement.

The practical implications of groundwater withdrawal that occurs due to well interference or pumping at too high a rate include: increased pumping costs because the pump has to lift water a greater height, lowered well yield, dewatering or mining of an aquifer until it no longer meets water supply needs, drying up of nearby shallow wells (e.g., domestic wells), and recharge of surface water to groundwater. Groundwater withdrawals may also decrease the amount of groundwater discharged as baseflow to streams. Baseflow may make up the entire streamflow at times when runoff is not occurring. Excessive groundwater withdrawals may also reduce groundwater levels to the point that surface water recharges groundwater rather than the other way around. Such streams are called losing streams. A reduction in baseflow could also impact on the habitat and change plant and/or animal communities, either because of a reduction or elimination of the amount of water available or a change in the water chemistry.

2.5 Safe Yield Criteria

The safe yield of a groundwater basin can be defined as the amount of water that can be withdrawn under specific operating condition without causing any undesirable results. DTWs and STWs are being used for abstracting irrigation water. DTWs are used to meet the drinking and industrial water demands in the municipal areas. As STWs operate under suction mode, these become completely inoperable condition when depth to groundwater table goes below suction limit, i.e., 7 m from ground surface (IWM, 2005). Wetlands, ponds and small streams also dry out when depth of groundwater table goes below 7 m. Considering these facts, 6 m depth to groundwater table from ground surface has been considered as safe yield limit to ensure the drinking and irrigation water supply through STWs and HTWs respectively with full operational efficiency (IWM, 2005). The groundwater resource of 7 m depth has also been estimated considering for the preservation of wetlands, ponds, dug wells and in-stream flow during dry period.

Recharge means the replenishment of groundwater storage that is depleted by withdrawal of groundwater with the tubewells and by natural process. Potential recharge is the mean annual volume of surface water that could reach an infinite groundwater reservoir and be stored there, limited only by the rate at which the soil or subsurface clay allows the water to infiltrate and percolate. The upazilla wise potential recharge data of the study area was available from the National Water Resources Database (NWRD) of Water Resources Planning Organization (WARPO) are shown in Table 2.1. It is seen from the table that potential recharge for the entire study area under the recharge conditions of low, medium and high are about 310 mm, 390 mm and 470 mm respectively.

Table 2.1: Upazilla wise potential recharge for the study area

District	Upazilla	Area (km^2)	Potential Recharge (mm)			Area*Potential recharge (Mm^3)		
			Low	Medium	High	Low	Medium	High
Thakurgaon	Thakurgaon Sadar	645	330	413	495	212850	266385	319275
	Pirganj	394	300	375	450	118200	147750	177300
Dinajpur	Birol	357	240	300	360	85680	107100	128520
	Bochaganj	225	240	300	360	54000	67500	81000
	Kaharole	207	300	375	450	62100	77625	93150
Panchagarh	Boda	429	390	488	585	167310	209352	250965
Total		2257	-	-	-	700140	875712	1050210
Average potential recharge of the study area (mm)						310	388	465

Source of data: National Water Resources Database of WARPO

The specific yield is the volume of water per unit volume of aquifer that can be extracted by pumping. The specific yield for the Tangan River watershed is about 7% (MPO, 1987). For the upazillas of Atwari, Boda, Pirganj, Thakurgaon Sadar, Biral, Bochaganj and Kaharole, the yields are 13, 11, 7, 10, 6, 6 and 9 % respectively (IWM, 2005).

2.6 Groundwater Table

Generally, groundwater levels vary seasonally. Groundwater levels in shallow aquifers tend to fluctuate at greater frequency and extent than do groundwater levels in deeper and confined aquifers because recharge reaches the shallow aquifers more quickly. In wet season, groundwater levels rise rapidly due to recharge from rain and flooding. In summer, groundwater levels gradually decline because of uptake of infiltrating water by plants, decreased rainfall, increased evaporation, groundwater abstraction for different uses, and groundwater discharge as baseflow to streams. The number of serviceable DTWs not operated due to groundwater lowering in each of the Boda and Thakurgaon sadar upazillas was one (BADC, 2003).

CHAPTER THREE

DATA COLLECTION AND METHODOLOGY

3.1 Data Collection

The present study used observed streamflow and groundwater level data of Bangladesh Water Development Board (BWDB) for analysis. One field visit was made to collect information on Tangan river flow, performance of the barrage located on the river and the present condition of groundwater irrigation.

Streamflow and groundwater level data were collected from BWDB. Daily discharge data of two discharge stations of Tangan river at Thakurgaon (SW 285) with latitude of $26^{0}02'40''$ and longitude of $88^{0}27'36''$ and Kodalkatigaon (SW 287) with the same of $25^{0}41'24''$ and $88^{0}25'48''$ respectively have been used (see Figure 4.2 in Chapter Four). Kodalkatigaon station is about 58 km downstream to the Thakurgaon station. Groundwater level data from eight observation wells (Figure 4.2) were used in the present study

3.1.1 Streamflow Data

Daily streamflow data of Thakurgaon and Kodalkatigaon stations for twenty one years from 1973 to 1993 were available. The data of Kodalkatigaon were used in this study. Mean daily discharge of these two stations could have been estimated from the observed water level data of 1994 to 2006 using rating curve equations. However, due to unavailability of rating curve equations, data after 1993 could not finally be used in the study Prior to analyzing the data it was necessary to fill in the missing data of the test station (Kodalkatigaon). Correlation of discharge data between Thakurgaon and Kodalkatigaon stations was determined. Thus any missing data of Kodalkatigaon is filled with using this correlation. The daily discharge data of Thakurgaon station has a good correlation of 0.84 with its downstream discharge station Kodalkatigaon. After filling the missing data, baseflow component of streamflow hydrograph was separated using automated digital filter technique as discussed later.

3.1.2 Groundwater Level Data

To find out the relationship of dry season streamflow with groundwater abstraction, groundwater level data of available observation wells from 1973 to 1993 have been analyzed. Groundwater table in m PWD of available observation wells have been estimated by deducting both parapet height and groundwater depth below the land surface from the reduced level of the well top. Average drawdown depth of observation wells over the catchment area has been estimated from the groundwater table data. Groundwater abstraction of the catchment area over the period has been calculated by multiplying the drawdown depth with both catchment area and specific yield value. Details of the groundwater level data used in the study are listed in the Table 3.1.

Table 3.1: Details of the groundwater level data collected

Well Id	Name of district	Longitude	Latitude	Sources of data	Length of record
THA008	Thakurgaon	$88^0 23' 15''$	$25^0 55' 45''$	BWDB	1973-1993
THA010	Thakurgaon	$88^0 24' 00''$	$25^0 57' 36''$	BWDB	1980 -1993
THA029	Thakurgaon	$88^0 27' 00''$	$25^0 59' 45''$	BWDB	1978-1993
DIN502	Dinajpur	$88^0 32' 00''$	$25^0 42' 45''$	BWDB	1985-1993
DJN503	Dinajpur	$88^0 29' 00''$	$25^0 53' 00''$	BWDB	1985-1993
DIN010	Dinajpur	$88^0 27' 25''$	$25^0 41' 45''$	BWDB	1973-1993
DIN011	Dinajpur	$88^0 30' 15''$	$25^0 51' 50''$	BWDB	1973-1993
DIN026	Dinajpur	$88^0 30' 15''$	$25^0 51' 50''$	BWDB	1976-1993

3.1.3 Data Collection through Field Visit

To collect necessary information, one field visit of two days duration was made to the study area in the first decade of April, 2008 when the Boro season was going on. Local people were interviewed and necessary information were collected through their opinion and visual observation.

3.2 Methodology

3.2.1 Bseflow Separation Technique

Baseflow separation is used to partition the streamflow hydrograph into its two components:

1. Direct runoff component
2. Baseflow component

The common separation methods are either graphical or involve filtering of streamflow data.

3.2.1.1 Graphical separation methods

Graphical methods are commonly used to plot the baseflow component of a flood hydrograph event, including the point where the baseflow intersects the falling limb (Figure 3.1). Streamflow, subsequent to this point, is assumed to be composed of entirely baseflow, until the start of the hydrographic response to the next significant rainfall event. The point (D) along the falling limb where quickflow has ceased and all of the streamflow is baseflow estimated by using an empirical relationship:

$N = 0.827A^{0.2}$

where N is the number of days between the storm crest and the end of quickflow, and A is the area of the catchment in square kilometres (Linsley et al, 1975). The value of the exponential constant (0.2) can vary depending on catchment characteristics such as slope, vegetation and geology. The notations used in Figure 3.1 are: A= point where the rising limb of the hydrograph begins, G = crest, F = inflection point, AB = line parallel to the x-axis, Q_t = discharge and t = time.

The graphical methods to partitioning baseflow vary in complexity and include:

A) Method I

In this method, the base flow is defined by a line parallel to the X- axis and passing through the point A, i.e. AB.

B) Method II

In this method, the baseflow curve existing prior to the commencement of the surface runoff is extended till it intersects the ordinate drawn at the peak (point C in Figure 3.1).

This point is joined to point D by a straight line. Segments AC and CD demarcate the baseflow and surface runoff.

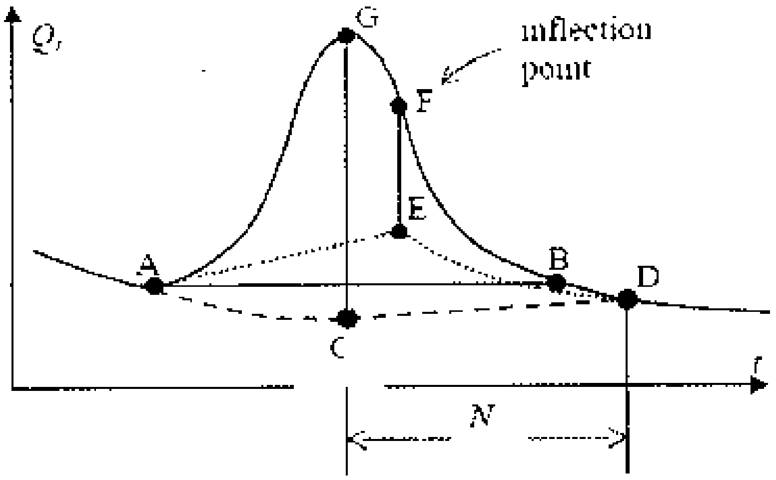

Fig. 3.1 Graphical baseflow separation techniques

C) Method III

In this method the baseflow recession curve after the depletion of the flood water is extended backwards till it intersects the ordinate at the point of inflection (line DE in Figure 3.1). Points A and E are joined by an arbitrary smoothed curve. In this method, the base flow is defined by the line AED.

3.2.1.2 Filtering separation methods

The baseflow component of the streamflow time series can also be separated using data processing or filtering procedures. These methods tend not to have any hydrological basis but aim to generate an objective, repeatable and easily automated index that can be related to the baseflow response of a catchment (Nathan and McMahon, 1990).

Examples of continuous hydrographic separation techniques based on processing or filtering the data record include:

1. The smoothed minima technique which uses the minima of 5-day nonoverlapping periods derived from the hydrograph (Institute of Hydrology, 1980; FREND, 1989). The baseflow hydrograph is generated by connecting a subset of points selected from this minima series. The HYSEP hydrograph separation program uses a variant of this technique called the local-minimum method (Sloto and Crouse, 1996).
2. Recursive digital filters, which are routine tools in signal analysis and processing, are used to remove the high-frequency quickflow signal from streamflow, and thus to derive the low-requency baseflow signal (Nathan and McMahon, 1990).

As discussed above, there are a number of methods available to separate baseflow from total streamflow. The baseflow separation method used in this study is the digital filter technique of Nathan and McMahon (1990). This method is described below.

3.2.1.3 Digital filter technique

This baseflow separation procedure with digital filter technique is based upon a recursive digital filter commonly used in signal analysis and processing (Lyne and Hollick, 1979). The equation of the filter is given by:

$$q_t = \beta * \; q_{t-1} + \frac{(1+\beta)}{2}(Q_t - Q_{t-1}) \qquad (1)$$

where q_t is the filtered surface runoff (quick response) at the time step t (one day), Q is the original streamflow, and β is the filter parameter. The value of 0.925 for β was determined by Nathan and McMahon (1990) and Arnold et al. (1995) to give realistic results comparing with the graphical separation techniques. Baseflow, b_t is, calculated with the equation

$$b_t = Q_t - q_t \qquad (2)$$

The filter is passed over the streamflow data three times (forward, backward, then forward again). The parameter β affects the degree of attenuation, and the number of passes determines the degree of smoothing; the reverse pass is done to nullify any phase distortion of the data due to the forward pass of the filter. In general, each pass will result in less baseflow as a percentage of total flow. This option gives the user some added flexibility to adjust the separation more accurately for each site condition.

Arnold et al. (1995) compared the digital filter results with results from manual separation techniques and PART model for 11 watersheds in Pennsylvania, Maryland, Georgia, and Virginia in USA. Annual baseflow from one pass of the filter was on an average within 11 percent (plus or minus) of baseflow estimated by manual techniques and the PART model. A recent study by Mau and Winter (1997) found that this filter method agreed reasonably well with graphical (manual) partitioning if the appropriate filter parameter is used

The justification for use of this technique rests merely on the fact that filtering out high frequency signals is intuitively analogous to the separation of low frequency baseflow from the higher frequencies of quick flow. Furthermore, the technique does provide an objective and repeatable estimate of an index of baseflow that is easily automated. The output of the filter was constrained so that the separated slow flow or baseflow was not negative or greater than the original streamflow.

3.2.2 Statistical Analysis

3.2.2.1 Correlation

To see the relation of the Tangan River dry season flow and baseflow with the groundwater abstraction in its watershed, correlation analyses were carried out using Microsoft Excel. Correlation is concerned with describing the direction (positive or negative) and strength of the relationship between two variables. If X and Y denote the two variables under consideration, a scatter diagram shows the location of points (X, Y) on a rectangular coordinate system. If all points in this scatter diagram seem to lie near a line, as in (a) and (b) of Figure 3.2, the correlation is called linear. If Y tends to increase as X increases, as in (a), the correlation is called positive or direct correlation. If Y tends

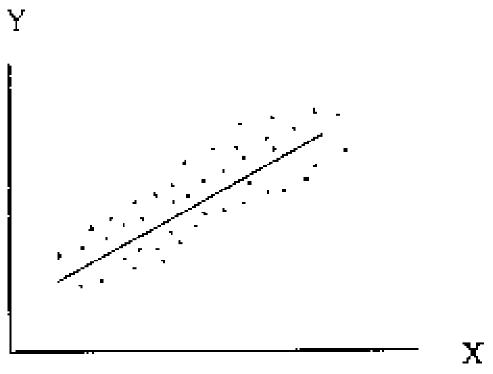

Fig. 3.2(a) Positive Linear Correlation

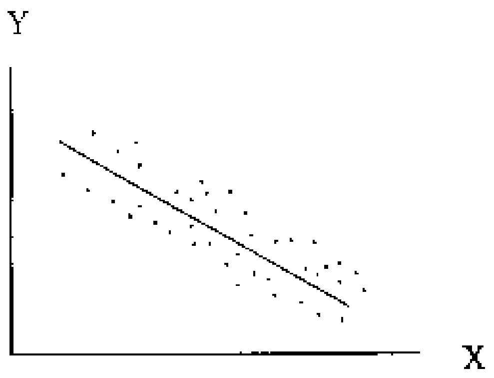

Fig. 3.2(b) Negative Linear Correlation

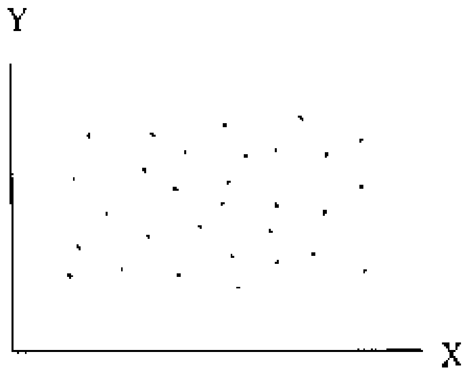

Fig. 3.2(c) No correlation

to decrease as X increases, as in (b), the correlation is called negative or inverse correlation. The direction and strength of the relationship can be expressed by means of a correlation coefficient "r", which is mathematically defined as:

$$r = \frac{S_{xy}}{S_x S_y} = \frac{SCP}{\sqrt{(SSX)(SSY)}}$$

where the sum of cross products of deviations is given by:

$$SCP = \sum \left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right) = \sum X_i Y_i - \frac{\left(\sum X_i\right)\left(\sum Y_i\right)}{n}$$

The sum of squared deviations for X

$$SSX = \sum \left(X_i - \overline{X}\right)^2 = \sum X_i^2 - \frac{\left(\sum X_i\right)^2}{n}$$

The sum of squared deviations for Y

$$SSY = \sum \left(Y_i - \overline{Y}\right)^2 = \sum Y_i^2 - \frac{\left(\sum Y_i\right)^2}{n}$$

A correlation coefficient varies from -1 to +1 with -1 indicating a perfect negative relationship (one increase while other decrease), 0 indicating no relationship and +1 indicating positive relationship. The size of the correlation indicates the strength of the relationship.

3.2.2.2 Regression

Regression is primarily concerned with using the relationship for the purpose of predicting one variable from knowledge of the other. The value of a variable Y corresponding to a given value of a variable X can be estimated from a least square curve which fits the sample data. The resulting curve is called a regression curve of Y on X, since Y is estimated from X If the independent variable X is time, the data shows the values of Y at various times. Data arranged according to the time are called time series. The regression line or curve of Y on X in this case is often called a trend line or trend curve. In this study, trend line was developed on the time series data. The simple linear regression equation is given as:

$$\hat{Y} = b_0 + b_1 X$$

where X= given data (year in this study); b_0 = intercept of regression line; and b_1 = slope of the regression line. The slope of the regression line is given by:

$$b_1 = \frac{SCP}{SSX}$$

where $SCP = \sum\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right) = \sum X_i Y_i - \frac{\left(\sum X_i\right)\left(\sum Y_i\right)}{n}$; and

$$SSX = \sum\left(X_i - \overline{X}\right)^2 = \sum X_i^2 - \frac{\left(\sum X_i\right)^2}{n}$$

The intercept of regression line is given by:

$$b_0 = \overline{Y} - b_1 \overline{X}$$

CHAPTER FOUR

DESCRIPTION OF THE STUDY AREA

4.1 Location and Upazillas Cover

The geographical area of this study is located in the North-West region of the country and consists of seven upazillas, Atwari and Boda upazillas in Panchagarh district; Pirganj and Thakurgaon sadar in Thakurgaon district; and Biral, Bochagonj and Kaharole in Dinajpur district. The area lies between the latitude of about $25^0 32'$ N to $26^0 22'$ N and longitude of about $88^0 21'$ E to $88^0 34'$ E. The geographic location of the study area is shown in Figure 4.1. The upazilla wise population of the study area is presented in Table 4.1.

Table 4.1: Upazilla wise population of the study area

District	Upazilla	Population
Panchagarh	Atwari	57149
	Boda	12943
Thakurgaon	Thakurgaon Sadar	293761
	Pirganj	104038
Dinajpur	Birol	166092
	Bochagonj	115070
	Kaharole	56863

Source: Zaman, 2004

4.2 Climate

Like other areas of Bangladesh, the study area has a tropical monsoon climate. Average annual rainfall in the area ranges from 1800 mm to 3000 mm. About 92 % of the annual rainfall occurs during the five months monsoon season between June to October. Occasional rainfall occurs in the study area in the dry season from November to May.

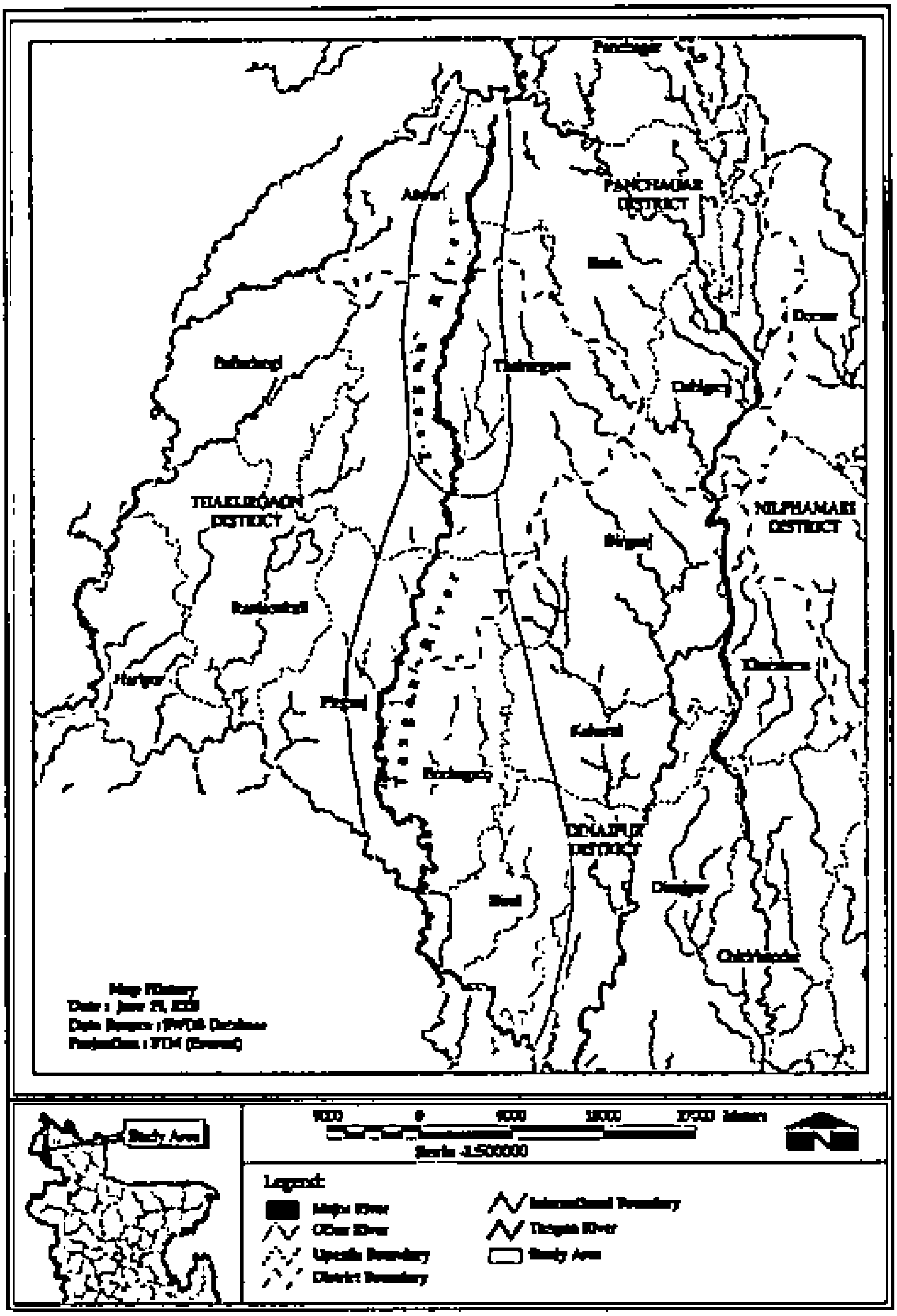

Figure 4.1: Geographic Location of the Study Area

4.3 Soil and Cropping Pattern

The study area is highly fertile for producing a wide range of agricultural crops. The soils of the area support more than one agricultural crop. The major crop of the study area is rice. Transplanted Aman (Kharif II) and Boro (Rabi) rice are two important crops grown in the area. In the study area, the cultivable land is about 1,68,422 ha and about 1,23,617 ha of these are under irrigation (BADC, 2006). Cropping intensity of the cultivated land is 201.26%. The cropping pattern followed in the study area is presented in the Table 4.2. The area is under the agro-ecological zone of Old Himalayan Piedmont plain which consists of mainly non- calcareous soils. The soil texture of the area is sandy loam.

Table 4.2: Cropping pattern in the study area

Crops	Cropping pattern
Single Cropping	Boro-Fallow-Fallow
	Brinjal-Fallow-Fallow
	Zinger-Fallow-Fallow
Double Cropping	Boro-Fallow-Transplanted Aman
	Wheat- Fallow-Transplanted Aman
	Maize-Fallow-Transplanted Aman
	Watermelon-Fallow-Transplanted Aman
	Vegetable-Fallow-Transplanted Aman
	Brinjal-Fallow-Transplanted Aman
	Onion-Fallow-Transplanted Aman
Triple Cropping	Wheat-Jute- Transplanted Aman
	Wheat-Seedbed-Transplanted Aman
	Potato-Jute-Transplanted Aman
	Potato-Maize-Transplanted Aman

4.4 River System and Drainage Area

The study area is drained by the Tangan River. The catchment area of the river is about 600 km^2 The river originates near Atwari in Panchagarh district and the outfall of it is at Bochagonj in Dinajpur district. The catchment area of the Tangan River is shown in the Figure 4.2. Considering the surface water sources, it is found that Tangan is a perennial

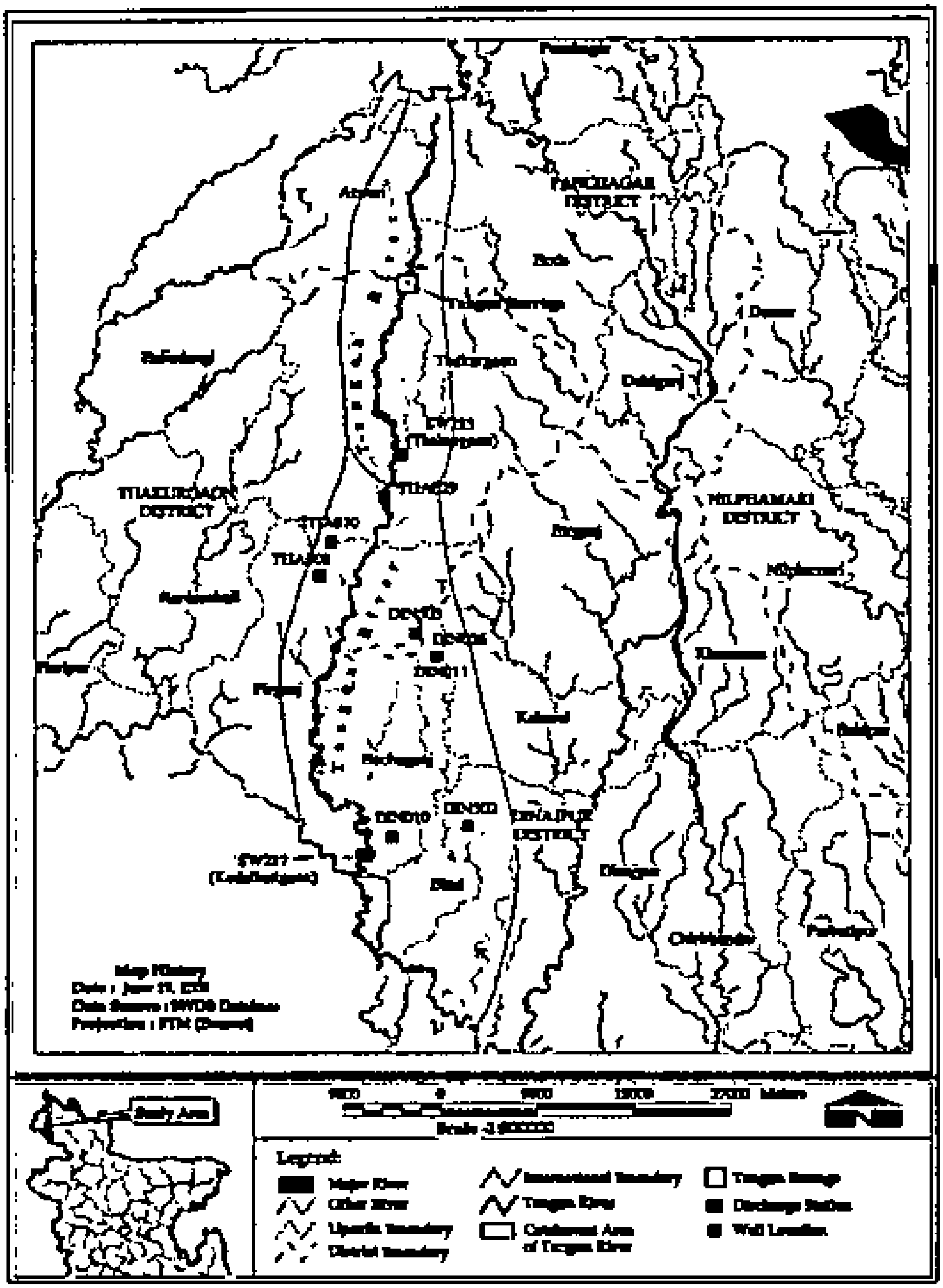

Figure 4.2: Catchment Area of Tangon River with the Location of Observation Well, Discharge Station and Tangon Barrage

river system The minimum flow of this river is 4 m^3/s occurring during the months of March and April at Thakurgaon station while the maximum flow is 172 m^3/s occurring during the month of August.

4.5 Existing Surface Water Irrigation Project

In the study area, there is a limited water resource during the dry season but abundant water during the monsoon season. Considering the available surface water resources in the rainy season, a barrage had been constructed to utilize the Tangan River flow for supplemental irrigation purpose. The barrage, known as Tangan barrage (Fig. 4.2), is located on the Tangan River at the upstream of the two discharge stations at Ramadia village under Thakurgaon Sadar Upazilla of Thakurgaon District. As a result of this barrage, only 2500 ha of land can be irrigated at present out of the targeted command area of 4450 ha because the highest reservoir level of 64 m PWD could not be achieved due to the submersion of 300 homesteads at the upstream side in Atwari Upazilla. According to the project planning, major construction works including the barrage were completed in 1990. However, due to the complicacy of land acquisition, all works of the project were completely ended in 1993 and started to supply irrigation from the next year.

4.6 Irrigation with Different Equipents

In the study area, STWS, DTWs and LLPs are used for irrigation STWS and DTWs are groundwater irrigation equipments. Present dry season irrigation practice is mostly dependent on groundwater source, major portion of which comes through STWs. The number of STWs has increased from 22,307 in 1996 to 43,384 in 2006. Figures 4.3 and 4.4 show the number of STWs and DTWs for three time periods in each of the seven upazillas of the study area.

In 2006, about 1,00,048 ha was irrigated with STWs, which is 81% of the total irrigated area. About 22,881 ha was irrigated with DTWs which is about 18% of the total irrigated area (BADC, 2006). Upazilla wise irrigated area with different irrigation equipments is presented in Table 4.3. Dry season groundwater irrigation has increased by 16% from 1996 to 2006. It is seen from the table that the total irrigated area was about 1,06,134 ha in 1996. The area increased to about 1,23,617 ha in 2006. The rate of increase in irrigated area is about 1.5% per year

Table 4.3: Upazilla wise irrigated area (ha) with different irrigation equipments (STW, DTW and LLP) in three different years

Upazilla	**1996**			**2003**			**2006**		
	STW	**DTW**	**LLP**	**STW**	**DTW**	**LLP**	**STW**	**DTW**	**LLP**
Atwari	2858	345	0	3475.2	80	0	5430	715	0
Boda	4118	559	0	7434.1	306	0	8696	941	314
Thakurgaon Sadar	11479	36674	22	17497.4	2186.58	0	28613	13483	0
Pirganj	12207	1603	2	16063.9	778.22	0	25171	2239	0
Birol	18480	1335	123	19833.7	2436.26	0	8296	2160	24
Bochaganj	7195	919	114	10373.5	727.63	132.7	10420	883	350
Kaharole	7301	797	3	6811.5	982.17	7.34	13422	2460	0
Total irrigated area	63638	42232	264	81489	7496	140	100048	22881	688
Total irrigated area with all modes	106134			89126			123617		

Source of data: NMIC, 1998; BADC, 2003; BADC, 2006

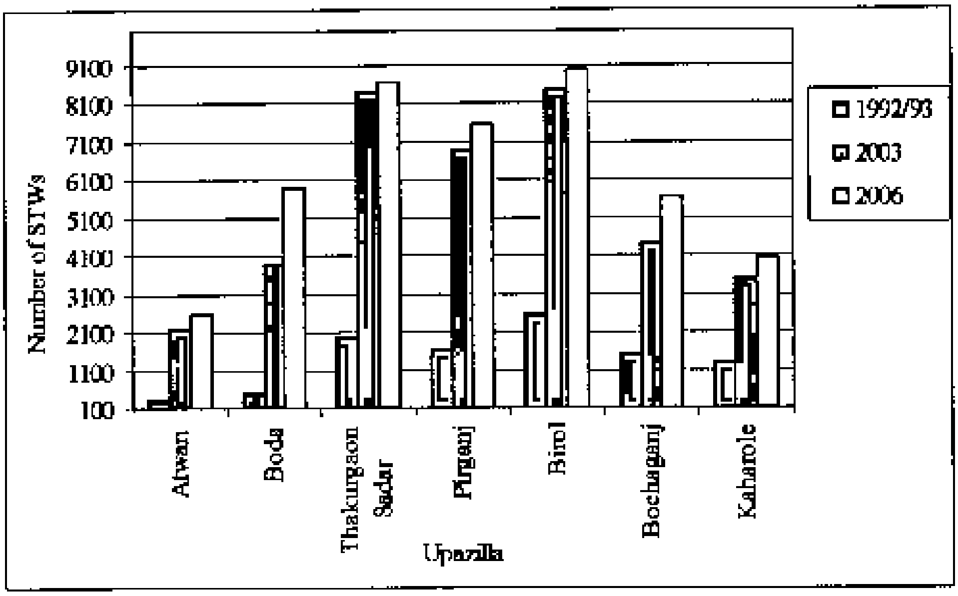

Fig.4.3 Number of shallow tubewells (STWs) in different upazillas of the study area

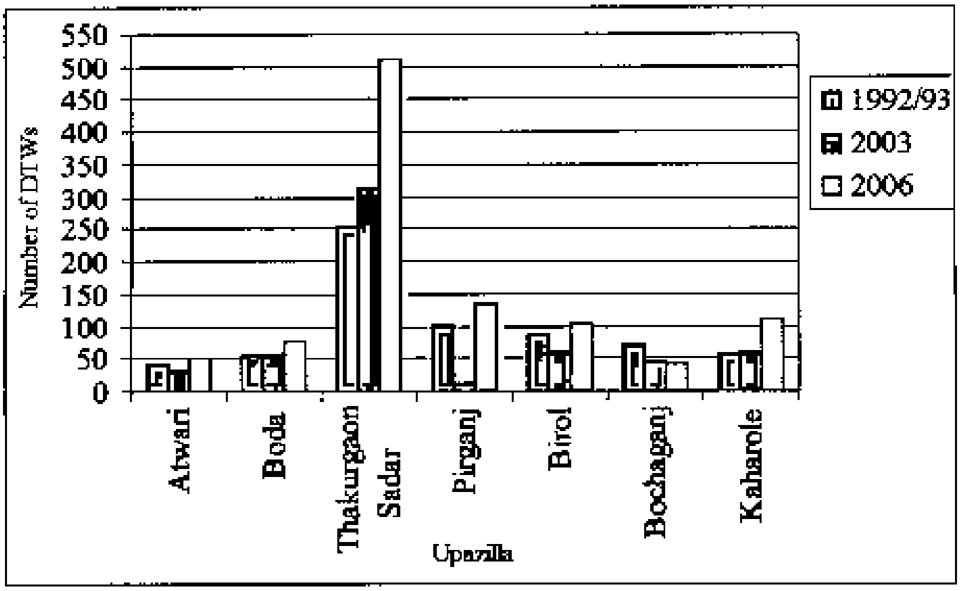

Fig. 4.4 Number of deep tubewells (DTWs) in different upazilas of the study area

CHAPTER FIVE
RESULTS AND DISCUSSION

5.1 Time Series of Decadal Streamflow and Baseflow

Daily streamflow data of the Tangan River over the years from 1973 to 1993 have been used for carrying out this study November to May, these seven months are the dry season in our country and the river flow during this period is termed as dry season flow. Out of these seven months, four to five months starting from January to early May have been considered for detailed analysis since extensive irrigation is required during this period In the study area, cropping season starts from January and ends in early May for Boro rice cultivation. Average decadal dry season flow of the river for the month of January to early May has been estimated with the daily discharge data over the period. Table 5.1 shows the average decadal streamflow for Boro season from 1973 to 1993.

Table 5.1: Average decadal streamflow (m^3/s) in Boro season

Decade / Year	Jan1	Jan2	Jan3	Feb1	Feb2	Feb3	Mar1	Mar2	Mar3	Apr1	Apr2	Apr3	May1
1973	13.10	12.96	12 91	12.70	12.70	12.70	12.70	12.51	12.51	4.13	3.45	2.56	3.08
1974	8.09	7.63	7.44	6.99	5.11	4.63	4.36	3.56	2.42	5.33	5 62	4.67	7.20
1975	6.31	5.40	5.36	8.22	12.53	12.68	11.65	10.59	9.58	2.26	2.26	4 70	7.13
1976	8.41	8.09	7 69	7.36	7.64	7.14	6.65	6 31	5.74	4.78	4.46	4.35	4.17
1977													
1978	10.72	8.15	4.05	1.36	10.75	11 28	10.61	9.44	8 28	5.02	5.36	6.83	6.47
1979	7.64	7.27	6.92	6.56	6.39	5.89	5.52	5.06	5.03	4.53	4.43	4.6	4.59
1980	7.71	7.05	6.30	5.87	5.81	5.88	6.07	6.13	5.38	4.77	4.30	5.21	5.96
1981	7.51	7.18	6.42	5.70	5.35	5 27	5.05	4.96	10 13	4.97	4.44	4.99	4.16
1982	6 99	6.83	6.31	5.81	5.44	5.21	5.03	4.75	3.84	3.75	4.05	4.18	3.83
1983	7.12	6.44	6.17	5.70	5.24	4.87	4.46	4 22	5.03	5.60	6.32	5.35	5 48
1984	8.17	6.62	6 12	6.08	6.14	6.24	6 58	7.01	6.90	4.77	4.43	4.53	5.44
1985			11.74	7.69	7 45	6.64	5.77	4.79	3.98	3.88	3.98		
1986	7.44	6.43	5.97	5 77	5.55	5.54	5.67						
1987													
1988													
1989	7.98	7.14	6.34	5.85	5.38	5.09	4.21	3.35	2 56	2.11	2.16	2.12	2.15
1990					7 37	7.04	6.02	4 51	3.79	3.77	3.94	3 99	
1991	10.01	8 53	6.93	5.83	5.20	4.15	3 56	3.34	2.88	2.62	2.22	1.98	1.91
1992	5.72	4.90	4.52	5.00	5.37	5.07	4.60	3.84	3.18	2.16	1.26	1.11	1.83
1993	5.95	10.33	10.71	8.87	7.88	7.07	6.11	5.30	5.05	3.85	3.01	4.20	3 99

Figures 5.1 to 5.13 show the time series of average decadal streamflow starting from the 1st decade of January to the 1st decade of May. To see the trend during this period of record, a linear regression line has been superimposed on each decadal time series. Decreasing trend is observed (Figures 5.1 to 5.13) in each decadal dataset of streamflow from 1973 to 1993.

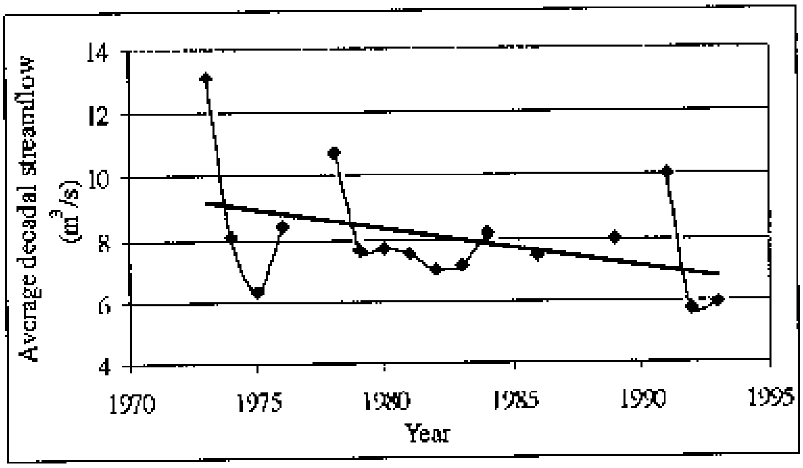

Fig. 5.1 Time series plot of streamflow of the Tangan River for the first decade of January

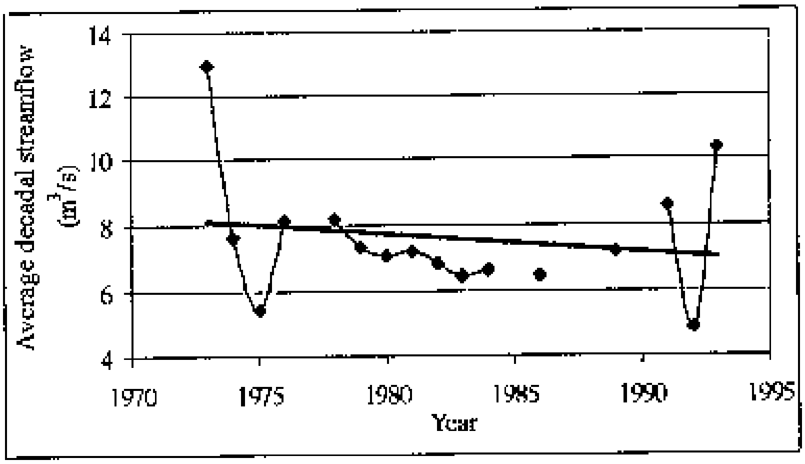

Fig 5.2 Time series plot of streamflow of the Tangan River for the second decade of January

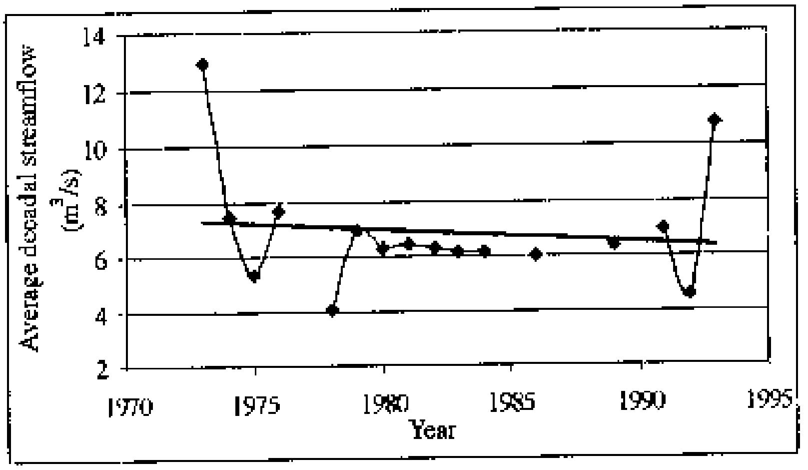

Fig. 5.3 Time series plot of streamflow of the Tangan River for the third decade of January

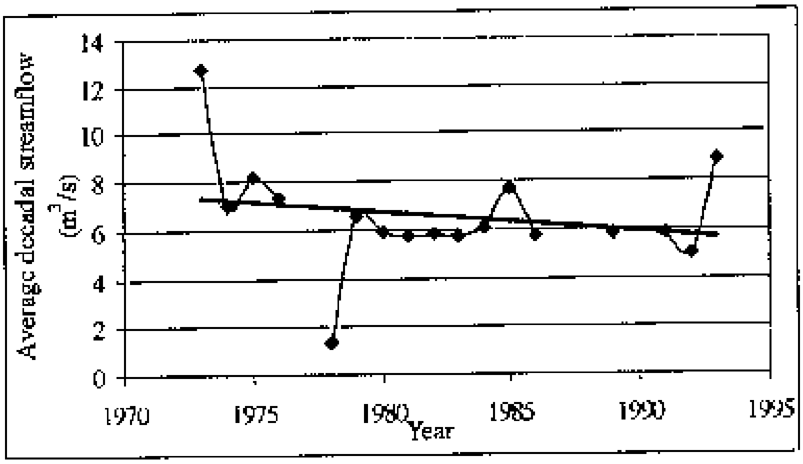

Fig. 5.4 Time series plot of streamflow of the Tangan River for the first decade of February

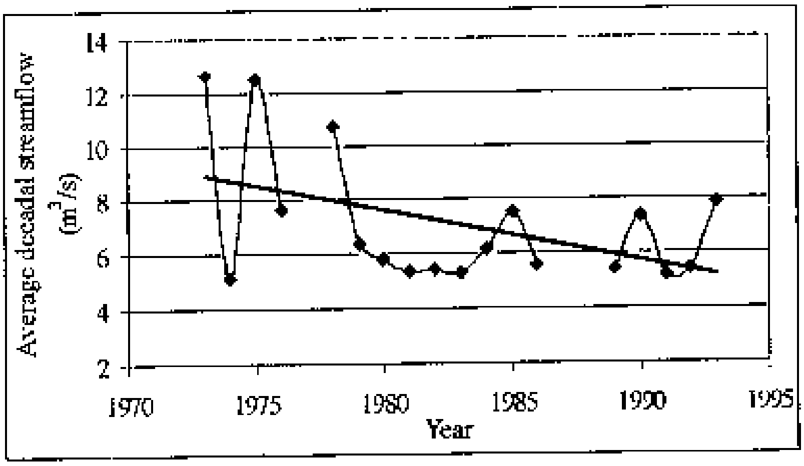

Fig. 5.5 Time series plot of streamflow of the Tangan River for the second decade of February

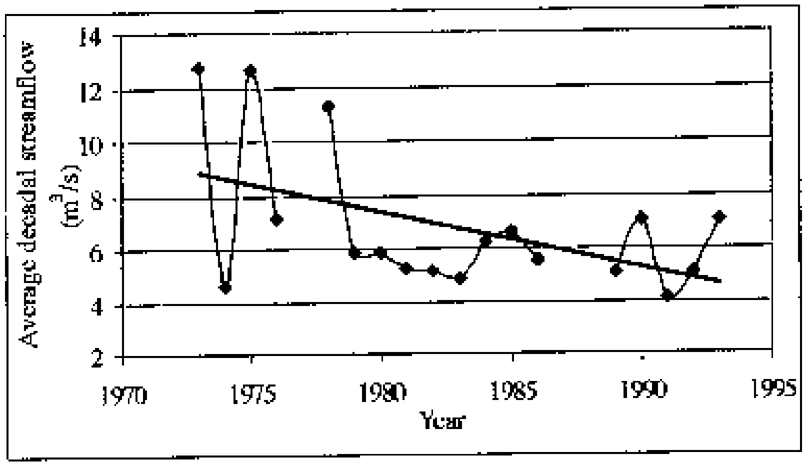

Fig 5.6 Time series plot of streamflow of the Tangan River for the third decade of February

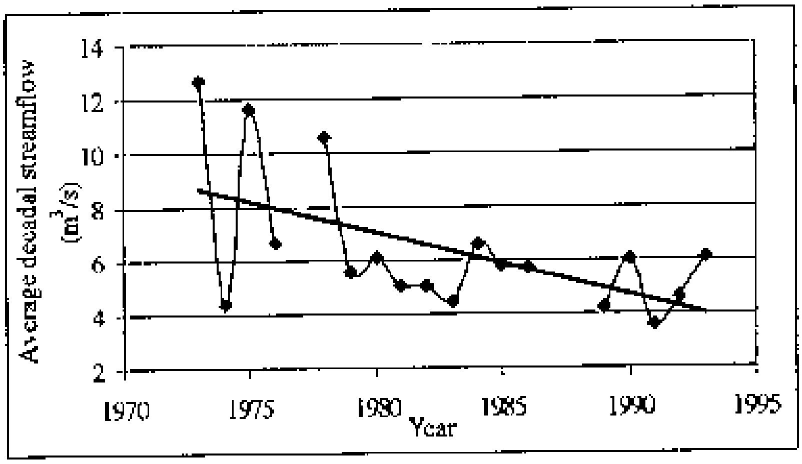

Fig. 5.7 Time series plot of streamflow of the Tangan River for the first decade of March

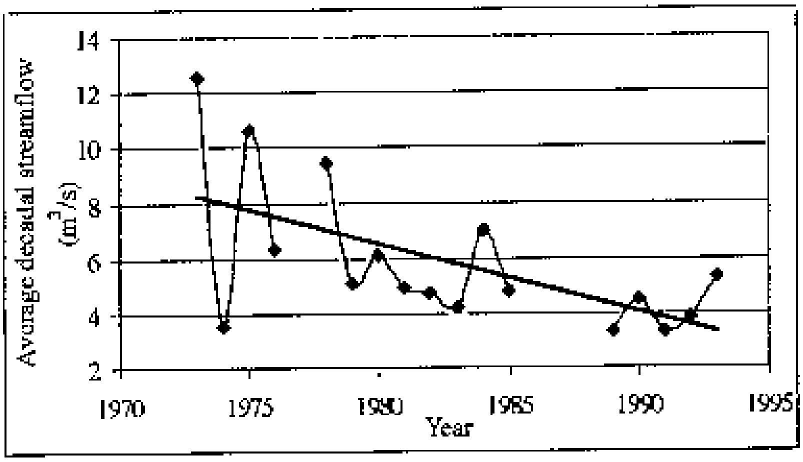

Fig. 5.8 Time series plot of streamflow of the Tangan River for the second decade of March

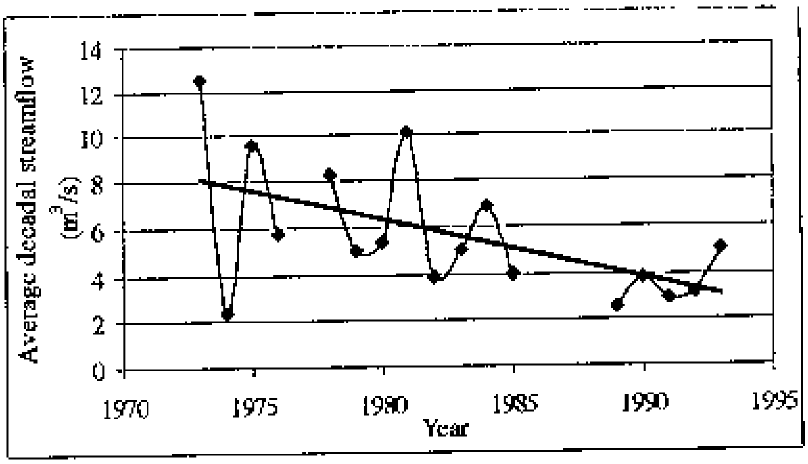

Fig. 5.9 Time series plot of streamflow of the Tangan River for the third decade of March

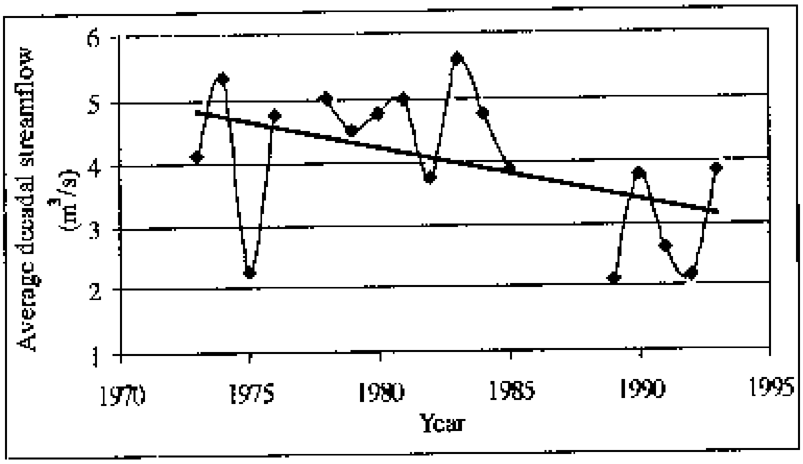

Fig 5 10 Time series plot of streamflow of the Tangan River for the first decade of April

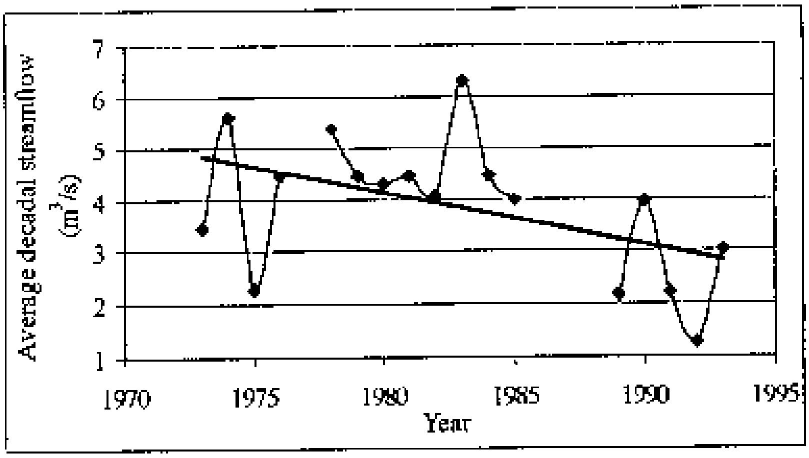

Fig. 5.11 Time series plot of streamflow of the Tangan River for the second decade of April

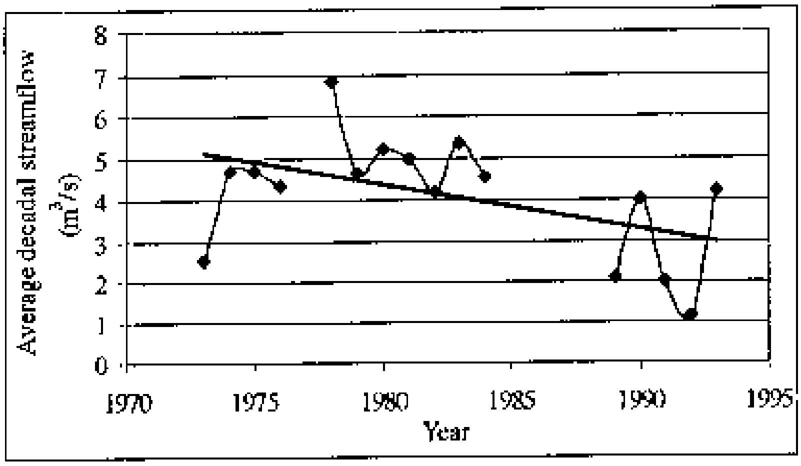

Fig. 5.12 Time series plot of streamflow of the Tangan River for the third decade of April

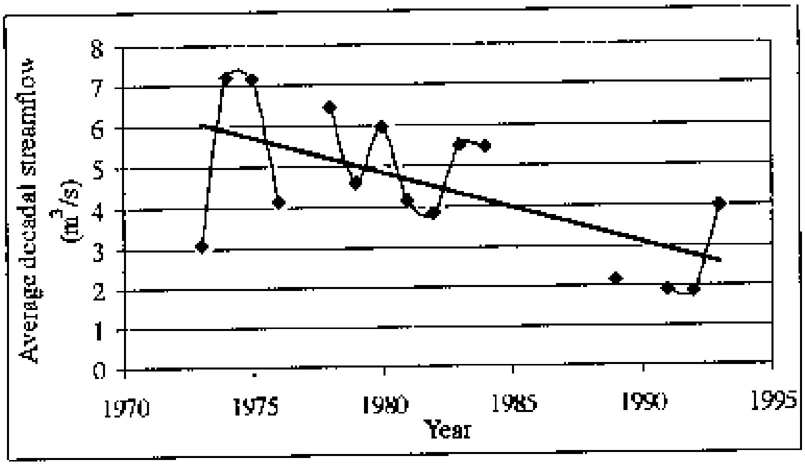

Fig. 5.13 Time series plot of streamflow of the Tangan River for the first decade of May

During the Boro season, streamflow of the river is mainly composed of baseflow. Decreasing trend of streamflow during the months from the 1st decade of January to the 1st decade of May might be the result of decreasing baseflow. For the Tangan River daily baseflow has been estimated from the daily discharge data using the software BFLOW. Table 5.2 presents the average decadal baseflow for Boro season from 1973 to 1993.

Table 5.2: Average decadal base flow (m^3/s) for Boro season

Decade Year	Jan1	Jan2	Jan3	Feb1	Feb2	Feb3	Mar1	Mar2	Mar3	Apr1	Apr2	Apr3	May1
1973	6.97	8.60	10.28	11.41	11.94	11.99	11.36	9.89	6.54	3.32	2.66	2.27	2.33
1974	7.30	6.98	6.43	5.35	4.43	3.94	3.43	2.58	2.09	2.21	3.08	3.76	4.21
1975	5.47	4.99	4.88	5.16	6.31	8.06	9.00	7.67	4.63	2.26	2.26	2.30	3.17
1976	8.00	7.68	7.36	7.19	6.95	6.52	6.08	5.59	4.93	4.44	4.27	4.14	4.06
1977													
1978	7.22	4.48	1.79	0.94	1.55	3.89	6.17	7.15	5.95	4.71	4.60	4.84	4.61
1979	7.15	6.84	6.47	6.14	5.79	5.38	5.07	4.78	4.61	4.42	4.38	4.32	4.09
1980	6.92	6.34	5.92	5.71	5.61	5.64	5.64	5.33	4.73	4.26	4.07	4.19	4.51
1981	6.91	6.39	5.76	5.34	5.15	4.99	4.79	4.58	4.44	4.46	4.31	4.22	3.93
1982	6.53	6.22	5.77	5.36	5.04	4.76	4.45	3.94	3.42	3.30	3.35	3.54	3.66
1983	6.44	5.99	5.61	5.14	4.77	4.45	4.22	4.11	4.18	4.47	4.85	4.92	4.75
1984	6.86	6.18	6.06	6.02	6.02	6.06	6.12	5.97	5.06	4.47	4.30	4.27	4.38
1985			7.88	7.02	6.34	5.53	4.79	4.14	3.85	3.81	3.83	4.67	7.65
1986	6.53	5.98	5.73	5.56	5.46	5.46	5.49	6.31					
1987													
1988													
1989	7.00	6.28	5.70	5.14	4.60	3.98	3.28	2.63	2.17	2.02	2.04	2.06	2.07
1990					1.28	3.05	4.00	3.88	3.63	3.57	3.64	3.72	3.85
1991	8.22	6.89	5.74	4.91	4.14	3.50	3.17	2.84	2.52	2.23	1.98	1.87	1.85
1992	4.97	4.57	4.48	4.52	4.61	4.29	3.68	2.93	2.20	1.42	1.10	1.03	1.06
1993	4.78	5.32	6.83	7.46	6.72	5.93	5.20	4.61	3.91	3.01	2.73	2.87	3.18

Figures 5.14 to 5.26 show the time series of average decadal baseflow from the month of January to early May. Trend line has been superimposed on the average decadal baseflow data.

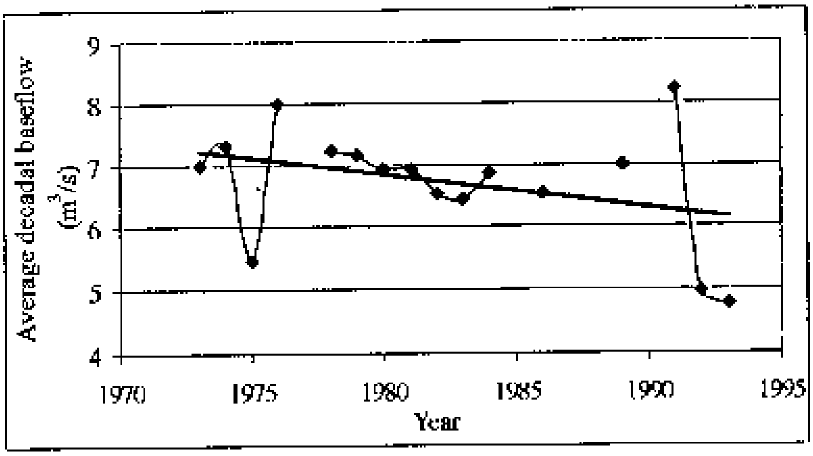

Fig. 5.14 Time series plot of baseflow of the Tangan River for the first decade of January

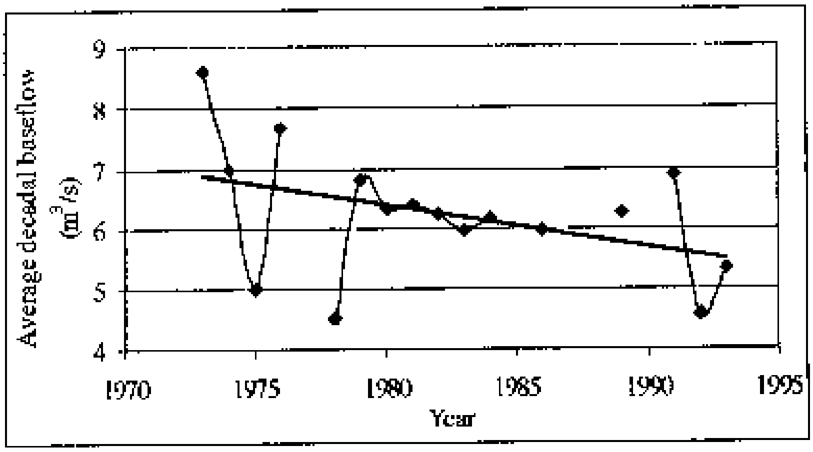

Fig. 5.15 Time series plot of baseflow of the Tangan River for the second decade of January

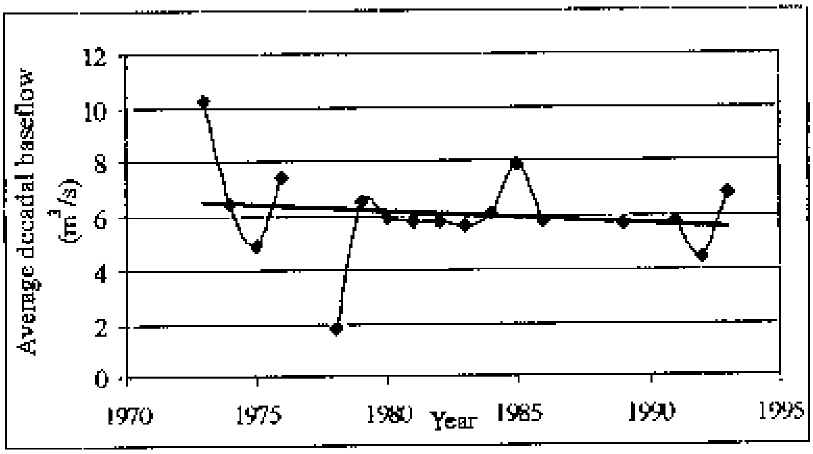

Fig. 5 16 Time series plot of baseflow of the Tangan River for the third decade of January

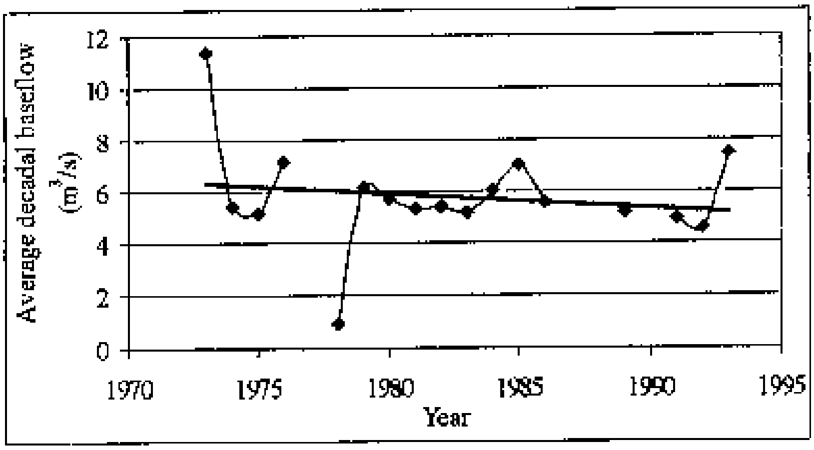

Fig. 5.17 Time series plot of baseflow of the Tangan River for the first decade of February

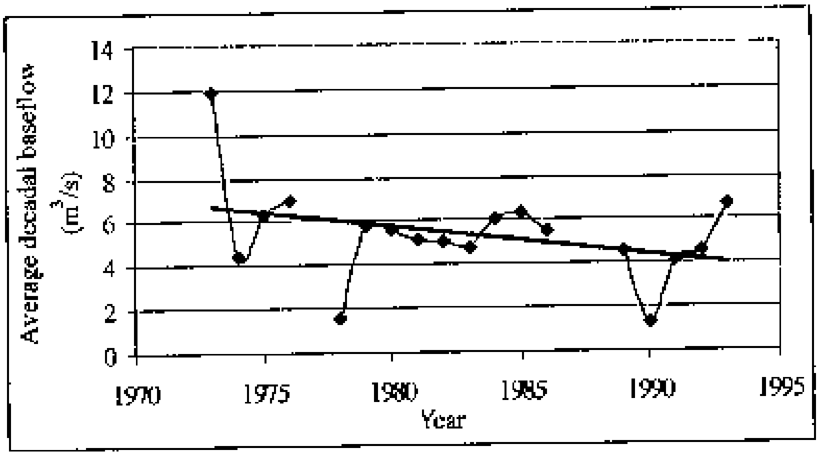

Fig. 5.18 Time series plot of baseflow of the Tangan River for the second decade of February

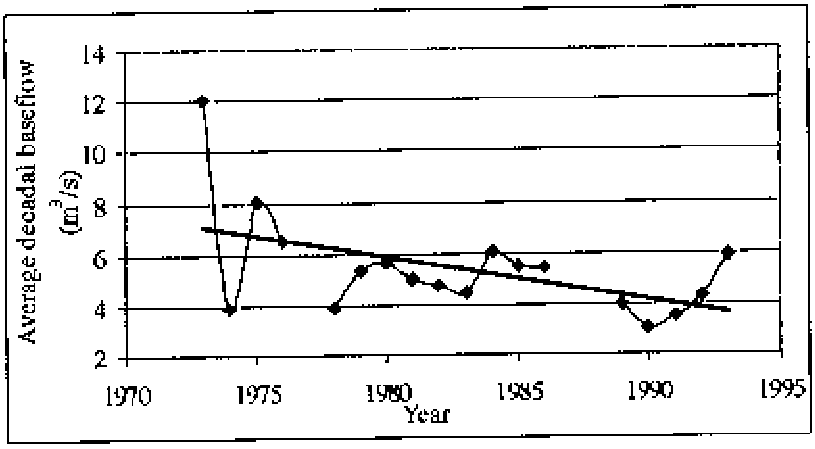

Fig. 5.19 Time series plot of baseflow of the Tangan River for the third decade of February

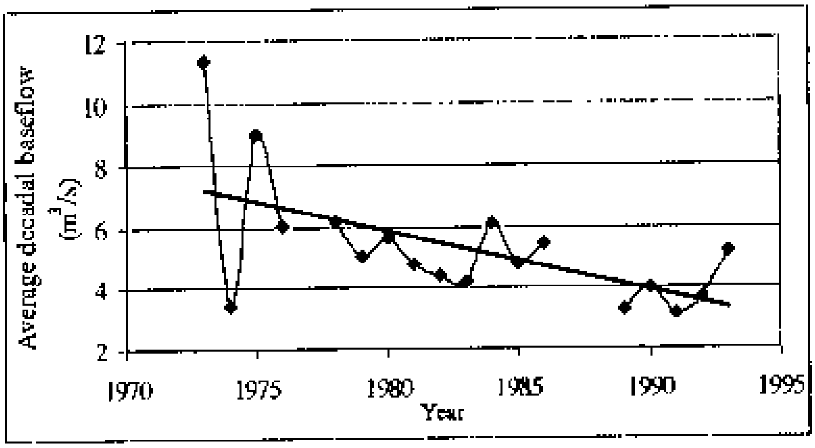

Fig 5.20 Time series plot of baseflow of the Tangan River for the first decade of March

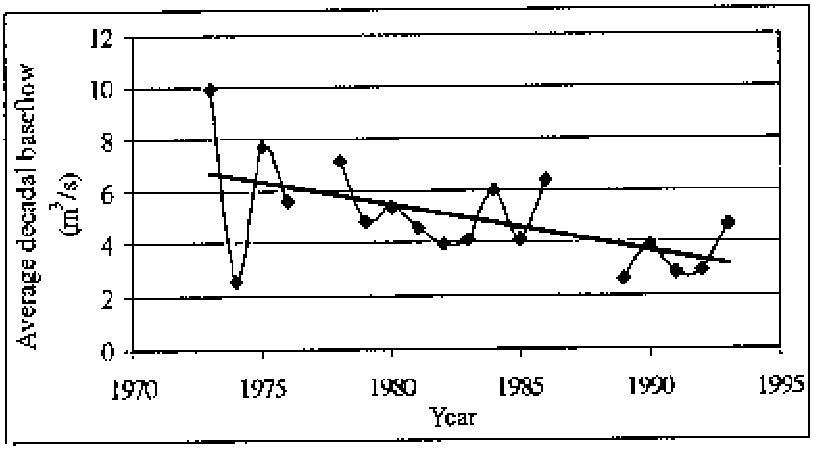

Fig. 5.21 Time series plot of baseflow of the Tangan River for the second decade of March

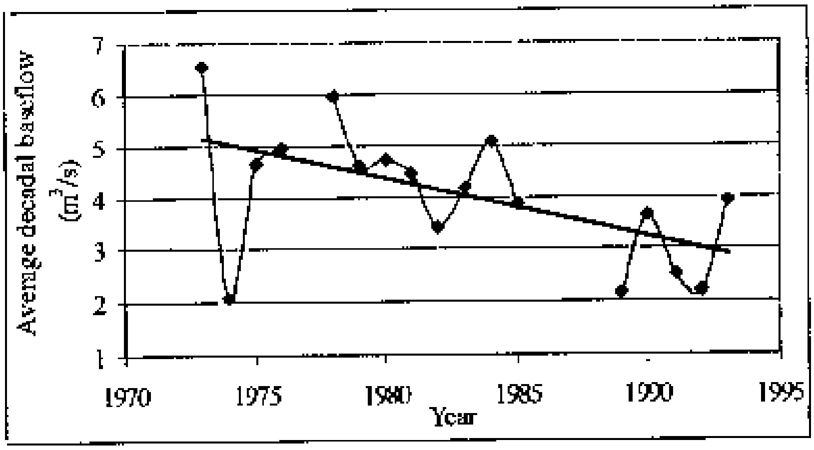

Fig. 5.22 Time series plot of baseflow of the Tangan River for the third decade of March

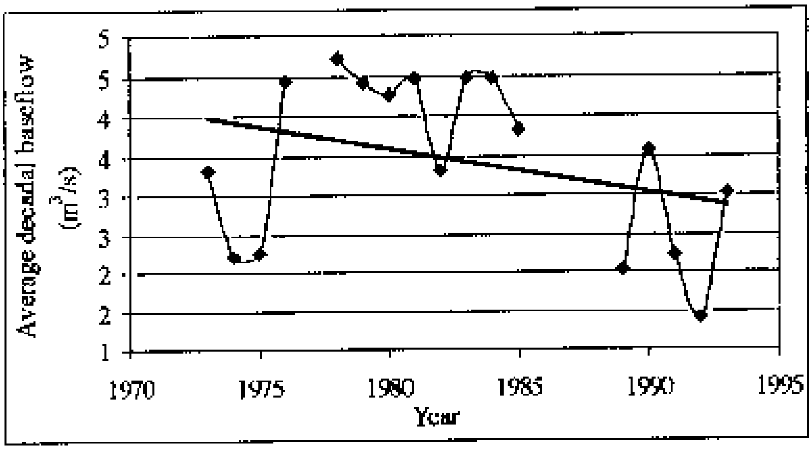

Fig. 5.23 Time series plot of baseflow of the Tangan River for the first decade of April

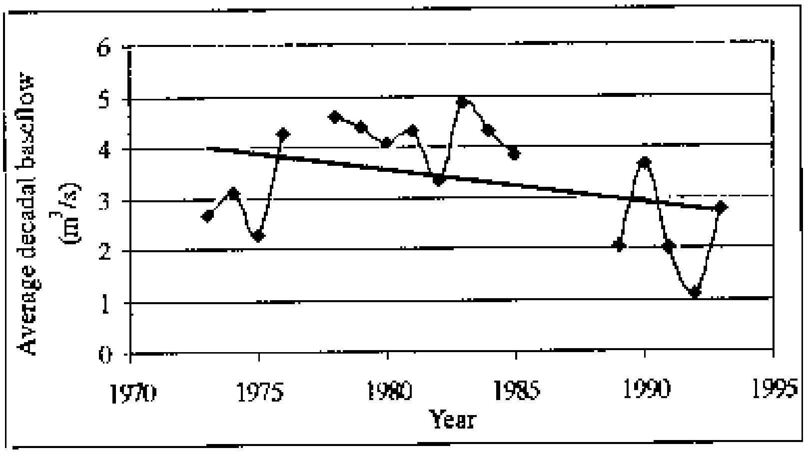

Fig. 5.24 Time series plot of baseflow of the Tangan River for the second decade of April

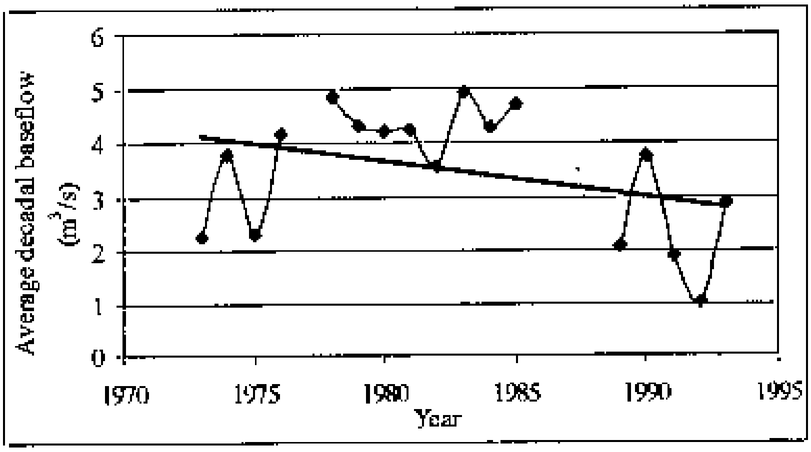

Fig. 5.25 Time series plot of baseflow of the Tangan River for the third decade of April

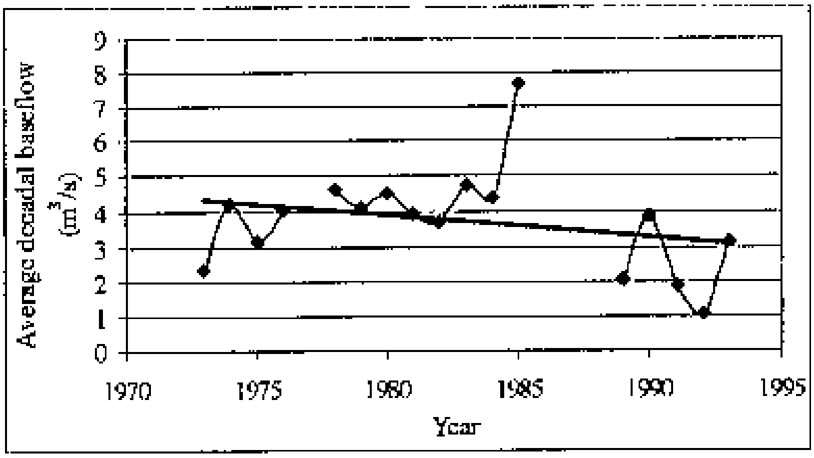

Fig. 5.26 Time series plot of baseflow of the Tangan River for the first decade of May

Figures 5.14 to 5.26 show declining trends of baseflow for the Boro season of 1973 to 1993 in the month of January, February, March, April and the first decade of May when irrigation activities reach a maximum Data after the year 1993 could not be used due to their unavailability. Furthermore, the Tangan barrage started its operation in 1994 and it might have an impact on river flow of the later years Declining trend in baseflow indicates the decreasing rate of groundwater flow towards the river over the period. Increasing use of groundwater for irrigation can reduce this baseflow. Table 5.3 shows the seasonal average streamflow and baseflow of Boro season (January to early May) over the period from 1973 to 1993.

Table 5.3: Boro season average (1st decade of January to the 1st decade May) streamflow (m^3/s) and baseflow (m^3/s) over the period from 1973 to1993

Year	Streamflow	Baseflow
1973	9.85	7.60
1974	5.62	4.30
1975	7.51	5.04
1976	6.37	5.94
1977		
1978	7.48	4.45
1979	5 73	5.34
1980	5.88	5.29
1981	5.90	5.02
1982	5.08	4.56
1983	5.55	4.92
1984	6.09	5.52
1985		
1986		
1987		
1988		
1989	4.33	3.77
1990		
1991	4 56	3.85
1992	3.73	3.14
1993	6.34	4.80

Graphical presentation of seasonal streamflow and baseflow have been shown in Figures 5 27 and 5.28, respectively. It is seen from these figures that both streamflow and baseflow have decreased over the period 1973-1993. Average streamflow and baseflow decline over the period from 1973 to 1993 in the Boro season estimated from the regression line were 41% and 35% respectively.

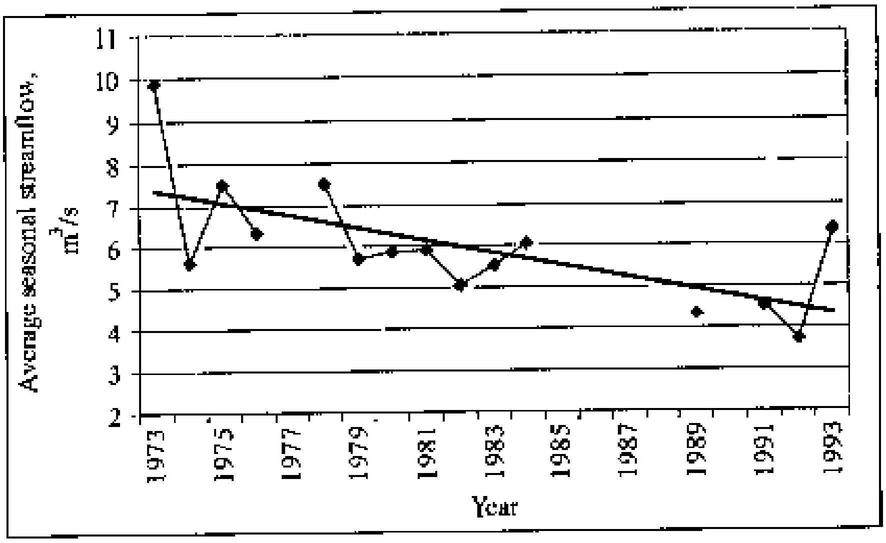

Fig 5 27 Average seasonal (1st decade of January to the 1st decade May) streamflow

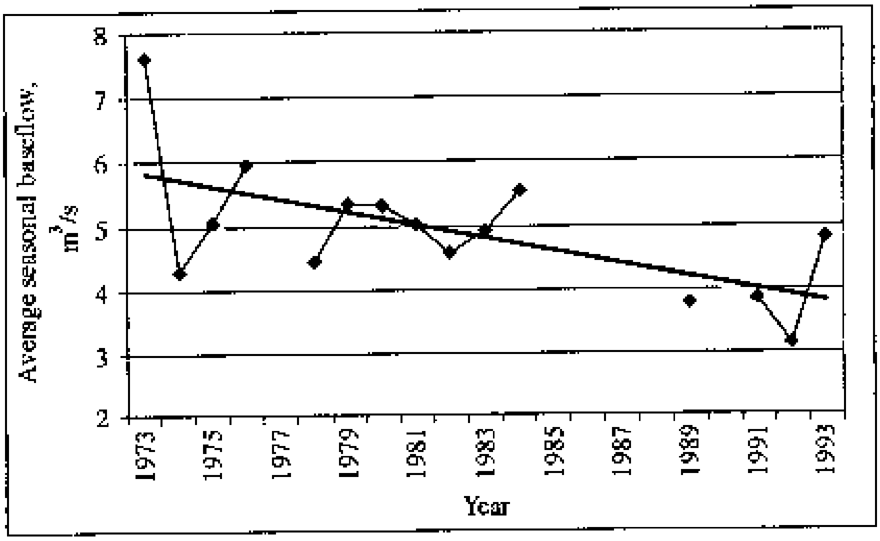

Fig. 5.28 Average seasonal (1st decade of January to the 1st decade May) baseflow

5.2 Trend in Lowest Groundwater Table

To investigate the relationship of streamflow and baseflow with groundwater irrigation, groundwater level data of eight observation wells in the catchment area have been analyzed. The position of the lowest groundwater table with the corresponding date of

Table 5.4: The position of the Lowest Groundwater Table (m PWD) with the dates of the occurance at selected observation wells located in the catchment area over the period 1973-1993

Well Id / Year	THA008	THA010	THA029	DIN010	DIN011	DIN026	DIN502	DIN503
1973	41.7 7 May			34 30 April	28.5 9 April			
1974	44.4 18March			34.7 22 April	29.58 18March			
1975	42.46 28 April			35.38 14 April	29.16 17March			
1976	42.32 31 May			34.96 31 May	27.6 26 April	32.3 19 April		
1977	43.02 16 May			34.6 30 May	28.66 2 May	33.08 9 May		
1978	43.54 22 May		44.17 15 May	35.91 1 May	29.78 8 May	32.72 22 May		
1979	41.86 4 June		43.47 4 June	35.06 4 June	27.9 28 May	31.56 11June		
1980	39.8 7 April	34.54 5 May	43.99 5 May	36.76 5June	29.02 14 April	32.52 12 May		
1981		34.24 6 April	43.91 11 May	35 11June	29.02 11 May	31.5 11 May		
1982		34.04 10 May	43.35 24 May	36.01 24June	28.14 10 May	31.3 10 May		
1983	43.18 25 April	33.54 14March	43.69 2 May	34.84 9 May	27.14 25 April	32.74 30 May		
1984	44.06 16 April	34.96 30 April	43.19 11 June		28.02 30 April	37.94 28 May		
1985		32.34 13 May	43.61 29 April	34.98 10June	27.64 6 May	33.7 29 April	30.94 15 April	33.7 22 April
1986	42.6 14 April	32.72 2 June	44.05 21 April	36.48 16June	27.5 28 April	34.8 28 April	32.24 21 April	34.28 21 April
1987		32.82 25 May			28 20 April		32.74 13 April	34.42 20 April
1988		31.34 21 March	44.11 30 May	34.46 6 June	27.4 11 April		31.28 18 April	33.92 11 April
1989	40.3 1 May	31.28 15 May	43.13 15 May	36.16 22 May	25.94 17 April	30.6 8 May	29.08 1 May	33.04 24 April
1990	40.9 21 May	31.72 7 May	43.81 23 April	34.5 9 April	27.5 23 April	21.38 12March	30.78 26March	33.74 30 April
1991	40.5 29 April	30.48 13 May	43.01 20 May		26.54 6 May	30.44 13 May	29.78 22 April	32.48 13 May
1992	39 4 May	29.5 18 May	42.83 25May		26.3 11 May	31.54 1 June	25.88 4 May	31.76 27 April
1993	41.1 14 June	30.68 17 May	42.62 3 May	33.5 19 April	27.8 12 April	33.48 19 April	30.18 12 April	33.64 10 May

occurrence at eight observation wells from 1973 to 1993 over the catchment area have been presented in the Table 5.4. These data are shown graphically in Figures 5.29 to 5.36.

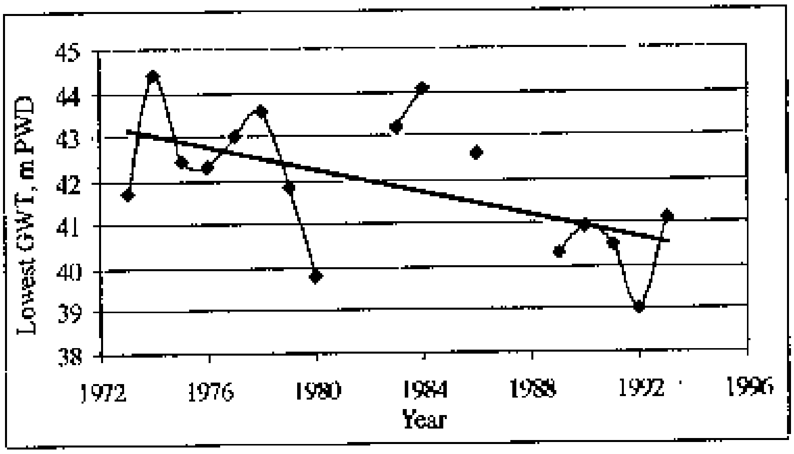

Fig. 5 29 The variation of the lowest groundwater table (GWT) of the observation well THA008

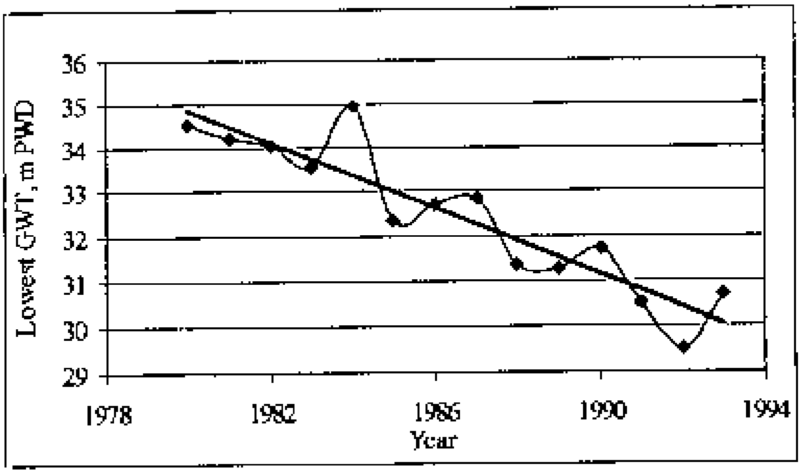

Fig. 5.30 The variation of the lowest groundwater table (GWT) of the observation well THA010

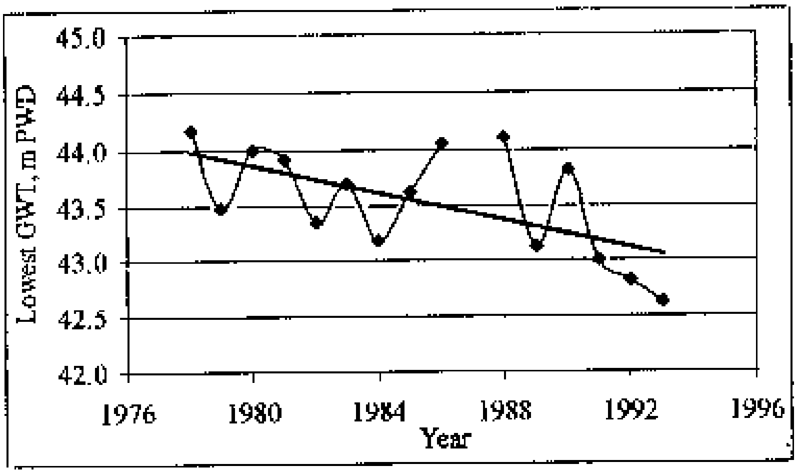

Fig. 5.31 The variation of the lowest groundwater table (GWT) of the observation well THA029

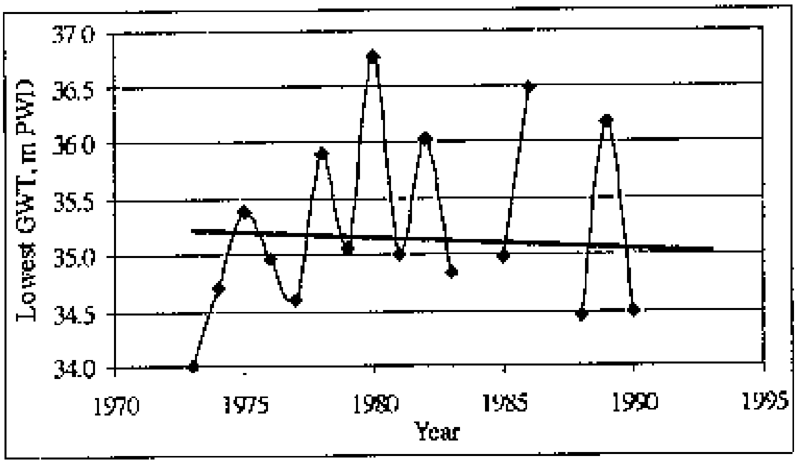

Fig. 5.32 The variation of the lowest groundwater table (GWT) of the observation well DIN010

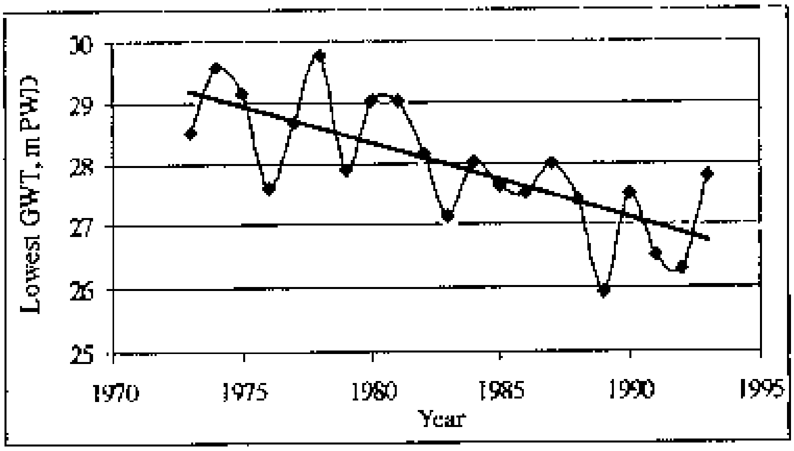

Fig. 5.33 The variation of the lowest groundwater table (GWT) of the observation well DIN011

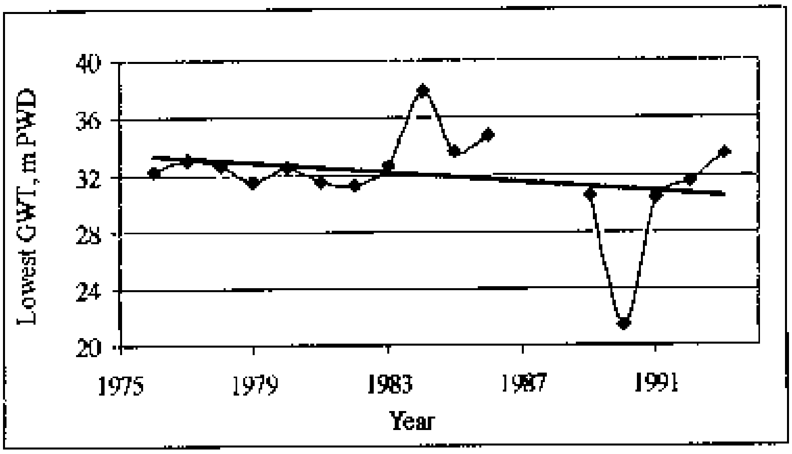

Fig. 5.34 The variation of the lowest groundwater table (GWT) of the observation well DIN026

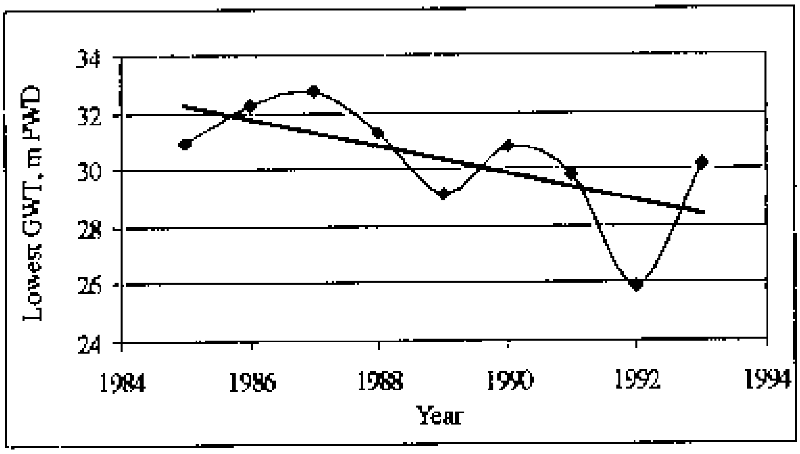

Fig. 5 35 The variation of the lowest groundwater table (GWT) of the observation well DIN502

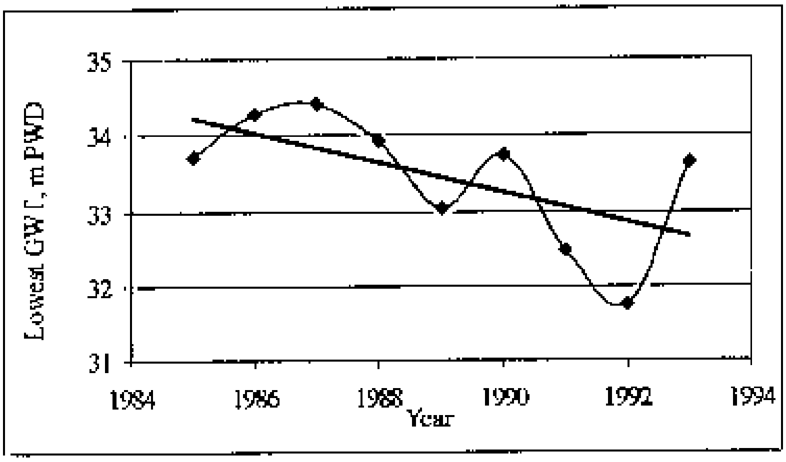

Fig. 5.36 The variation of the lowest groundwater table (GWT) of the observation well DIN503

Figures 5.29 to 5.36 show that the trend of lowest groundwater table over the period is downward, which means that minimum level of groundwater table has been decreasing year by year. This also signifies that fluctuation of groundwater table has increased throughout the period. The cumulative frequency distribution of the time of occurrence of annual minimum gruundwater level since 1973 to 1993 is shown in Figure 5.37. It is seen from the figure that the lowest level occurs by the end of April or early May in about 50% of the wells.

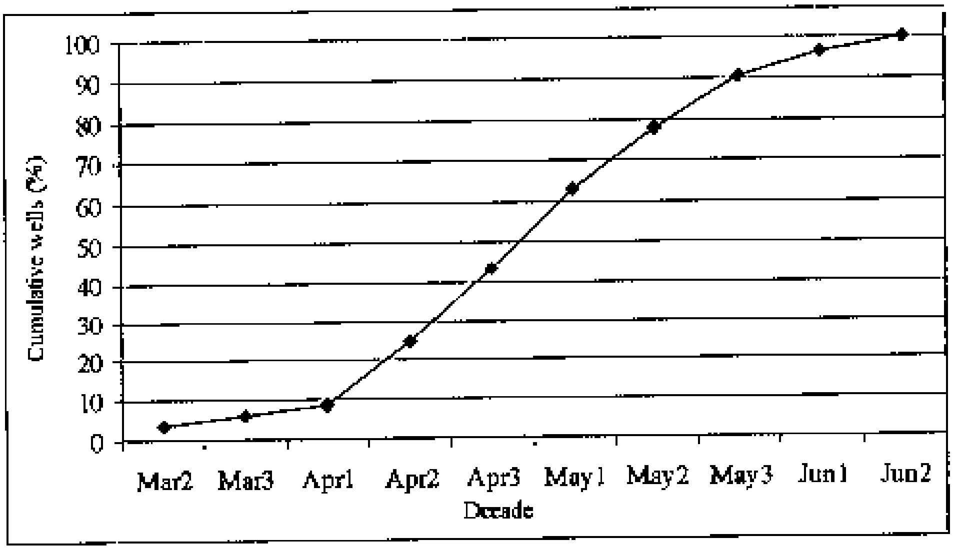

Fig. 5 37 Cumulative frequency distribution of the time of occurrence of annual minimum groundwater level since 1973 to 1993

5.3 Trend in Drawdown of the Observation Well

Year wise drawdown of each well was estimated from the water table data from the start of Boro season (1st January) to the occurrence of the lowest water table for the respective year. The estimated drawdown is presented in the Table 5.5. Figures 5.38 to 5.45 show the trends in drawdown of the observation wells.

Table 5.5: Drawdown (m) of selected observation wells located in the catchment area over different years

Well Id / Year	THA008	THA010	THA029	DIN010	DIN011	DIN026	DIN502	DIN503
1973	3.76			1.32	2.14			
1974	1.52			2.34	1.26			
1975	3.42			1.66	1.32			
1976	3.56			1.68	3.44	6.88		
1977	2.5			2.8	2.02	5.64		
1978	3		2	1.8	2.18	6.92		
1979	3.2		1.76	1.68	2.74	3.66		
1980	6.74	1.94	1.62	1.36	2.28	6.82		
1981		1.42	1.24	1.14	1.92	7.28		
1982		1.34	1.88	0.34	2.6	7.42		
1983	1.96	2.52	1.72	3.14	3.86	6.14		
1984	2.04	1.2	2.6		3.34	1.52		
1985		1.42	1.86	2.44	3.5	5.46	4.66	2.46
1986	5.84	1.36	1.22	2.38	3.9	4.96	3.66	2.72
1987		1.06			3.2		3.16	2.36
1988		2.56	1.42	3.36	3.66		4.52	2.62
1989	3.3	2.48	1.8	1.46	4.82	7.88	6.20	2.96
1990	3	2.2	1.88	1.8	3.84	5.54	4.76	2.88
1991	3.2	3	2.04		4.68	7.94	5.90	4.28
1992	3.5	4.02	2.3		4.54	7.36	9.50	4.4
1993	3.8	2.48	2.94	2.9	3.4	5.1	5.20	2.86

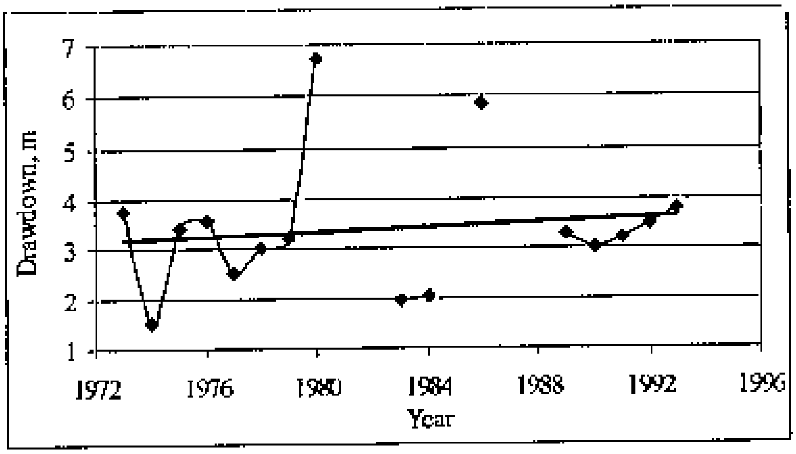

Fig. 5.38 The variation of the drawdown of the observation well THA008

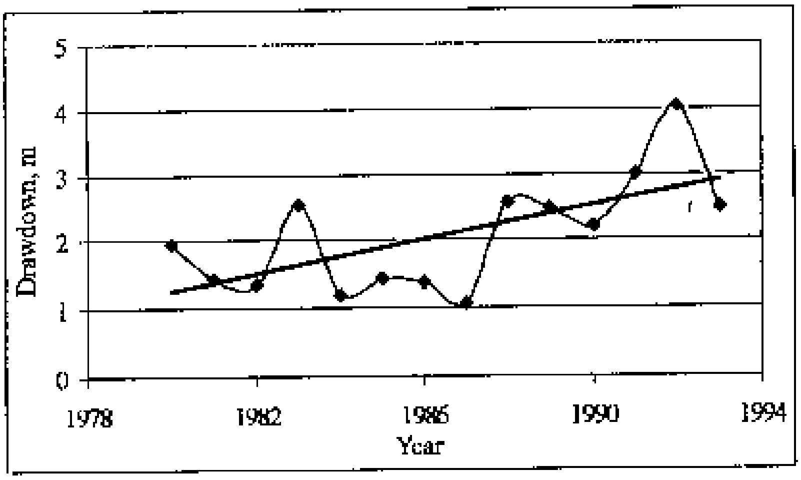

Fig. 5.39 The variation of the drawdown of the observation well THA010

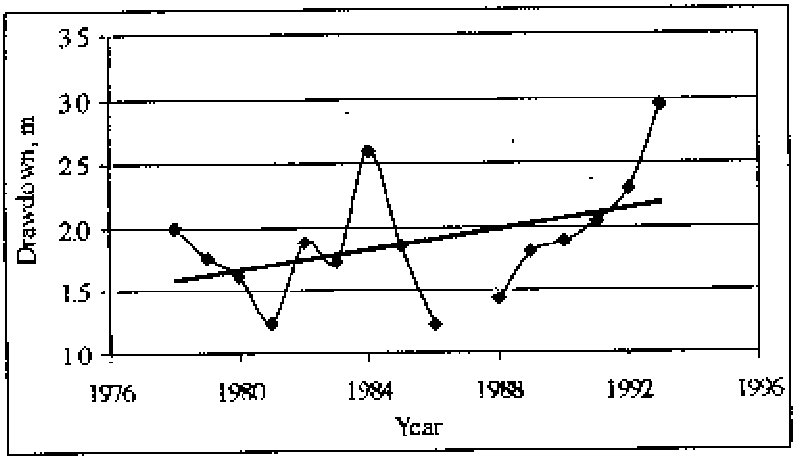

Fig. 5.40 The variation of the drawdown of the observation well THA029

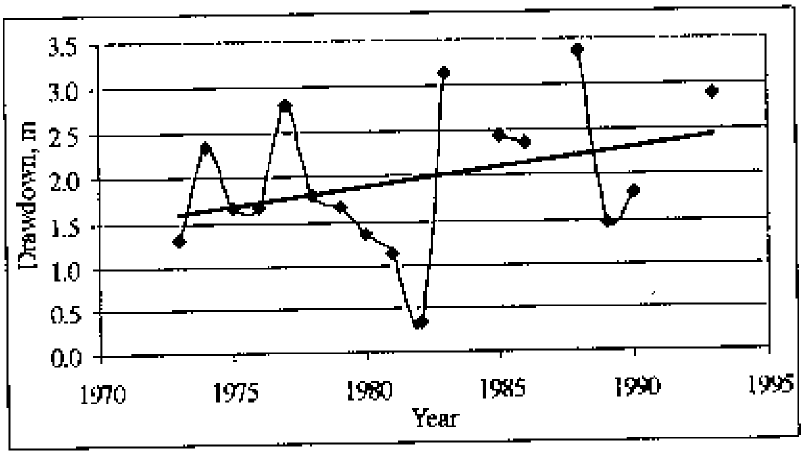

Fig. 5.41 The variation of the drawdown of the observation well DIN010

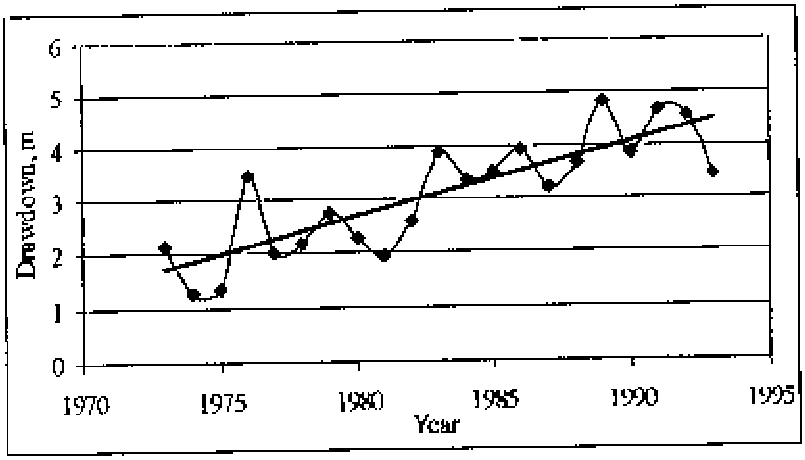

Fig. 5.42 The variation of the drawdown of the observation well DIN011

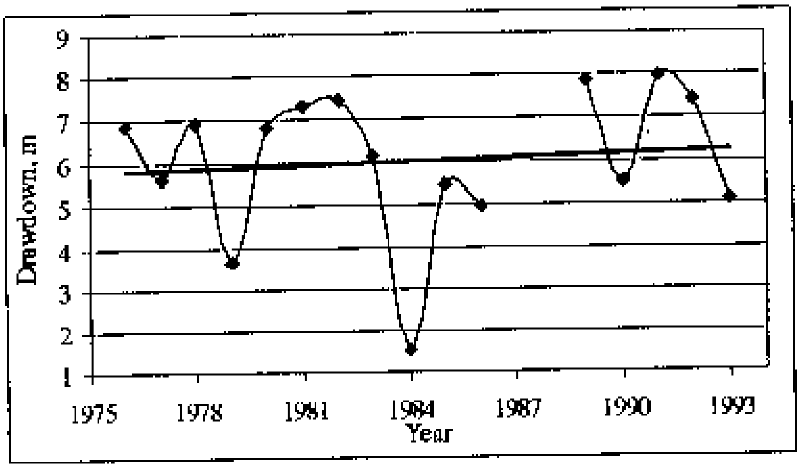

Fig. 5.43 The variation of the drawdown of the observation well DIN026

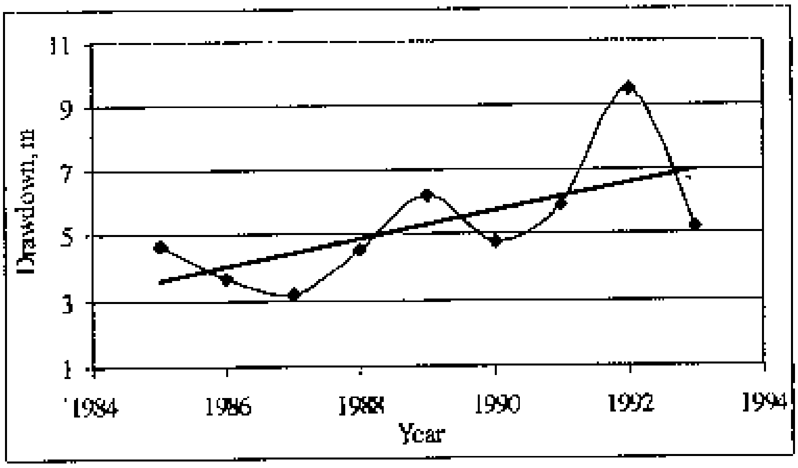

Fig. 5.44 The variation of the drawdown of the observation well DIN502

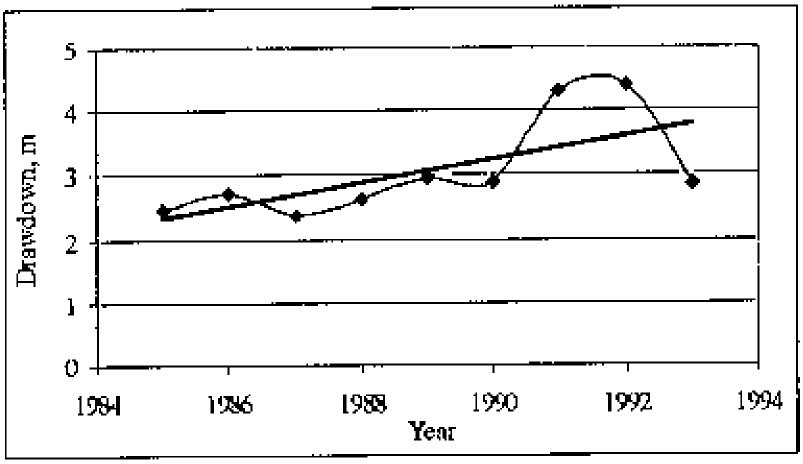

Fig. 5.45 The variation of the drawdown of the observation well DIN503

It is seen from the Figures 5.38 to 5.45 that groundwater withdrawals have increased in the study area over time. This drawdown might have an effect on the quantity of groundwater available for baseflow to the Tangan River Groundwater abstraction plus baseflow estimated from the average drawdown, specific yield and catchment area over the period is presented in Table 5.6.

Table 5.6: Estimation of groundwater abstraction plus baseflow

Year	Average Drawdown of the area (m)	Specific Yield	Catchment area (km^2)	Groundwater abstraction plus baseflow (Mm^3)
1973	2.41	7%	600	101.08
1974	1.71			71.68
1975	2.13			89.60
1976	3.89			163.38
1977	3.65			136.08
1978	3.18			133.56
1979	2.61			109.54
1980	3.46			145.32
1981	2.60			109.20
1982	2.72			114.07
1983	3.22			135.38
1984	2.14			89.88
1985	3.11			130.80
1986	3.26			136.71
1987	2.45			102.69
1988	3.02			126.98
1989	3.86			162.23
1990	3.24			135.98
1991	4.43			186.24
1992	5.09			213.72
1993	3.59			150.57

5.4 Relation of Boro Season Streamflow and Baseflow with Groundwater Irrigation

Groundwater abstraction was estimated by subtracting baseflow from combined abstraction and baseflow data of Table 5 6. Total streamflow, baseflow and groundwater abstraction from January to 1st decade of May over the time period (1973-1993) have been presented in the Table 5.7 Groundwater abstraction is shown in both volumetric and depth units. It is seen from the table that the highest amount of groundwater use was 297 mm in 1992. However, this is less than the potential recharge of 310 mm in the area. Thus, it appears that there was no permanent mining in the groundwater table during the

Table 5.7: Seasonal streamflow, baseflow and groundwater abstraction for the Boro season over the years 1973-1993

Year	Total streamflow (Mm^3)	Total baseflow (Mm^3)	Groundwater abstraction plus baseflow (Mm^3)	Groundwater abstraction(Mm^3)	Groundwater abstraction (mm)
1973	110.61	85.40	101.08	15.68	26.13
1974	63.15	48.26	71.68	23.42	39.04
1975	84.34	56.60	89.60	33.00	55.00
1976	72.08	67.22	163.38	96.16	160.27
1977					
1978	84.06	50.02	133.56	83.54	139.23
1979	64.34	60.02	109.54	49.52	82.53
1980	66.55	59.93	145.32	85.39	142.32
1981	66.29	56.41	109.20	52.79	87.98
1982	57.01	51.23	114.07	62.84	104.74
1983	62.31	55.27	135.38	80.11	133.52
1984	68.88	62.44	89.88	27.44	45.73
1985					
1986					
1987					
1988					
1989	48.64	42.30	162.23	119.92	199.87
1990					
1991	51.23	43.20	186.24	143.04	238.41
1992	42.18	35.50	213.72	178.22	297.03
1993	71.26	53.95	150.57	96.62	161.03

study period. Figure 5.46 shows the trend of groundwater abstraction in volumetric unit and Figure 5.47 shows the trend in depth unit. Both figures reveal that consumption of groundwater in the study area is gradually increasing. To investigate the relationship of Boro season streamflow and baseflow with groundwater irrigation, the correlations among these variables have been estimated. Figures 5.48 to 5.50 show the relationship of streamflow and baseflow with groundwater abstraction

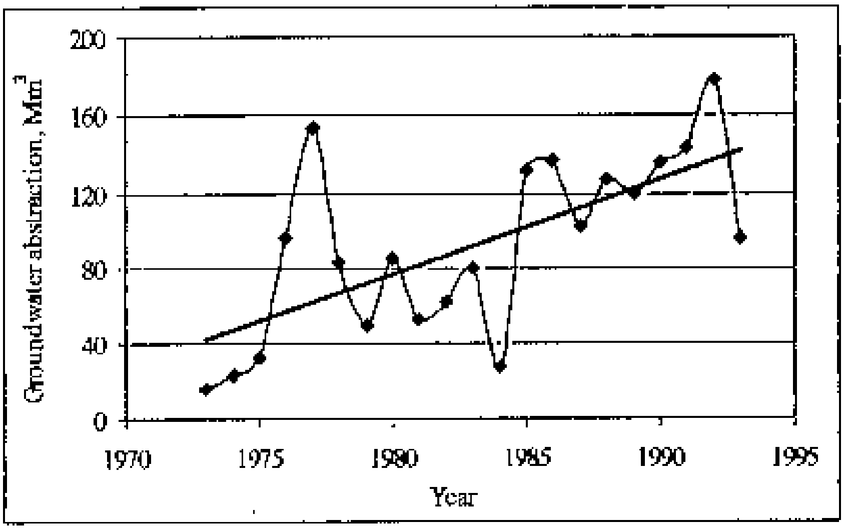

Fig. 5.46 Time series of groundwater abstraction in volumetric unit during the Boro season over the period of 1973 to 1993

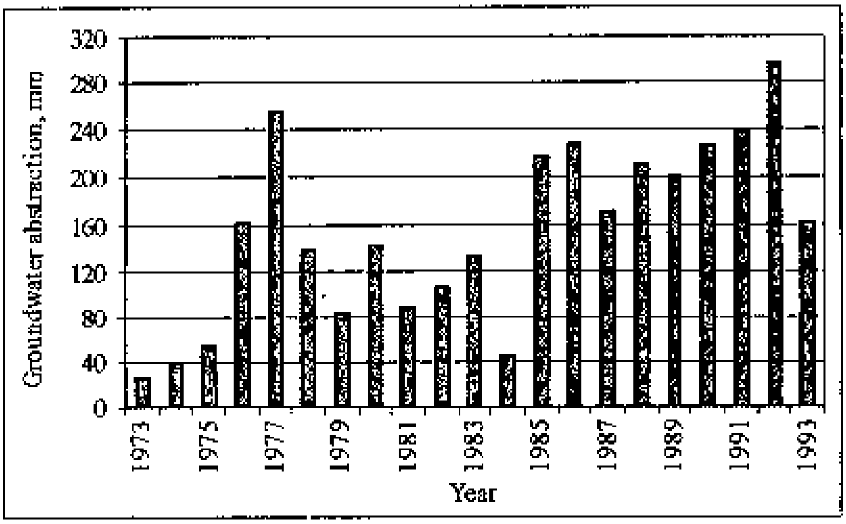

Fig 5.47 Time series of groundwater abstraction in depth unit during the Boro season over the period of 1973 to.1993

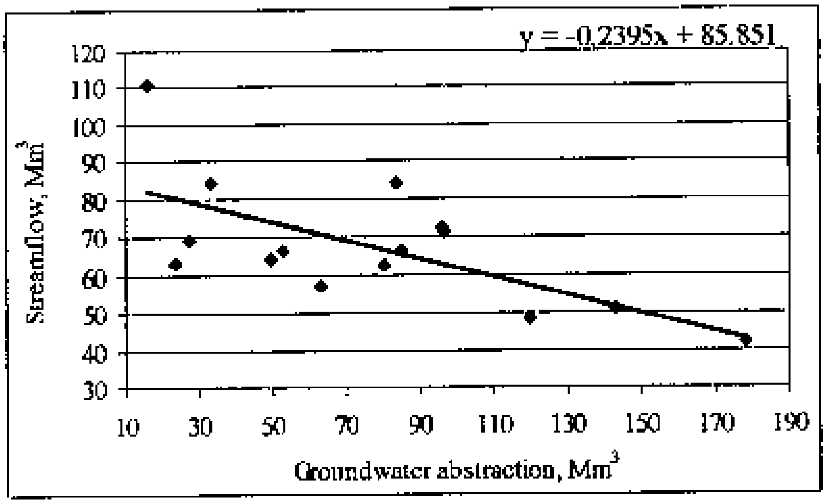

Fig. 5.48 Scatter plot of streamflow and groundwater abstraction over the period of 1973 to 1993

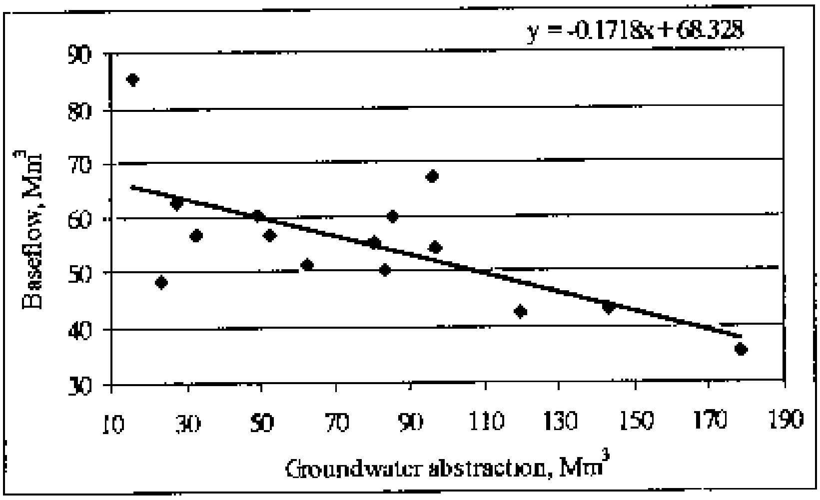

Fig. 5.49 Scatter plot of baseflow and groundwater abstraction over the period of 1973 to 1993

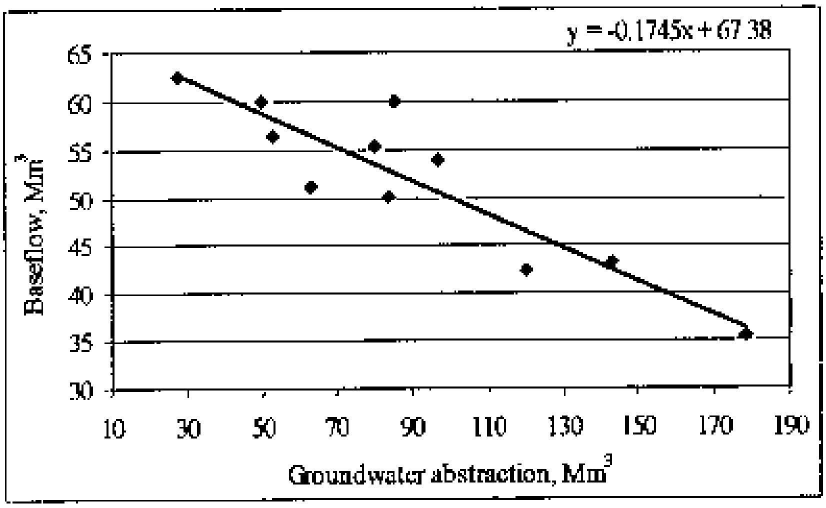

Fig. 5.50 Scatter plot of baseflow and groundwater abstraction over the period of 1978 to 1993

A correlation coefficient of -0.66 between Boro season streamflow and groundwater abstraction and a correlation of -0.67 between Boro season baseflow and groundwater abstraction have been found. In the case of baseflow, the correlation coefficient increases to -0.91 if the data from 1978 are considered. It is to be noted that the groundwater abstraction before 1978 is not very reliable as we had data for only three wells. The analysis indicates that both streamflow and baseflow have been declining since 1973. Groundwater abstraction correlates well with baseflow and this indicates that flow declines are related to groundwater development. With 1 unit increase of groundwater abstraction, baseflow of the river would decrease by about 0.17 unit.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this study, an attempt has been made to investigate the impact of groundwater irrigation on dry season flow and baseflow of the Tangan River. Statistical analysis (correlation and regression) was done to find out the relation of streamflow and baseflow declines with groundwater abstraction. The following conclusions are drawn based on the findings of this study:

- Baseflow of the streamflow hydrograph was separated from the daily streamflow data of the river over the period from 1973 to 1993 using a software BFLOW which implements a digital filter technique.
- Time series of average decadal streamflow and baseflow for four to five months (January to early May) indicate that Tangan river flow has reduced over the period from 1973 to 1993. The reduction is 41% for streamflow and 35% for baseflow.
- Lowest groundwater level was found to occur by the end of April or early May in about 50% of the wells.
- Groundwater abstraction was estimated from the average drawdown data over the years 1973 to 1993 and specific yield data of the study area.
- Decreasing trend of lowest groundwater table and increasing trend of drawdown indicate that groundwater table has declined in the study area over the period from 1973 to 1993 in response to the increase in groundwater abstraction. With 1 unit increase of groundwater abstraction, baseflow of the river has decreased by about 0.2 unit.
- A correlation coefficient of -0.66 was obtained between the streamflow and groundwater abstraction over the period from 1973 to 1993 while the correlation coefficient of -0.67 was found between baseflow and groundwater abstraction. The coefficient for baseflow and groundwater abstraction increases to -0.91 if data for the post 1977 period is considered due to their better reliability.

6.2 Recommendations

The following recommendations are made for further study:

- This study only identifies if there is any impact of groundwater irrigation on baseflow and streamflow of the Tangan River. It has not evaluated / investigated the adverse impacts of the streamflow and baseflow reduction on river ecosystem, navigation, morphology and socio-economic condition of the local people. This can be an interesting topic for further research. The study also does not answer the mechanism of reducing groundwater abstraction.
- Groundwater level data of only eight observation wells were analyzed due to budget constraints. It did not consider the distance of the wells from the river bank. The study could be more reliable if rainfall analysis was also done. Streamflow data after 1993 could not be used because of the absence of reliable data and a number of missing data were also present in the streamflow data. The study could give a more real picture with the presence of these data. A more detailed study is recommended considering the additional groundwater observation wells, their distance from the river bank and including the rainfall analysis.

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