

This discussion paper is/has been under review for the journal Hydrology and Earth System Sciences (HESS). Please refer to the corresponding final paper in HESS if available.

# Relating trends in streamflow to anthropogenic influences: a case study of Himayat Sagar catchment, India

R. Nune, B. A. George, P. Teluguntla, and A. W. Western

Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia

Received: 25 June 2012 – Accepted: 2 August 2012 – Published: 9 August 2012

Correspondence to: R. Nune (rajeshnune@gmail.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

9295

## Abstract

Catchment development has been identified as potentially causing major changes in streamflow in India. This paper tests for trends in rainfall and streamflow in Himayat Sagar catchment and shows major declines in streamflow without significant changes in precipitation. It then relates the streamflow trends to anthropogenic influences in Himayat Sagar catchment. A simple rainfall-runoff regression model was used to quantify the change in magnitude of rainfall-runoff relationship over the study period. Then, the anthropogenic changes in the catchment including land use, watershed development, groundwater abstractions and storages, and evapotranspiration were quantified. The changes in the components of the water balance were then compared. Streamflows were found to decline at a rate of  $3.6 \text{ mm yr}^{-1}$ . The main land use change was found to be a conversion from rainfed to irrigated agriculture, fed by groundwater extractions. Irrigated area increased from 8% to 23% of the cropping area during the monsoon (Kharif) season (June–November) and from 8% to 16% of cropping area during the dry (Rabi) season (December–March). Various estimates of changes in evapotranspiration/irrigation water use were made. Well inventories suggest groundwater extractions increase of  $7.2 \text{ mm yr}^{-1}$ , typical irrigation practices suggests applied water increased by  $10.8 \text{ mm yr}^{-1}$ , while estimates of evapotranspirations using AVHRR images showed an increasing rate of  $4.1 \text{ mm yr}^{-1}$ . Surface water storage capacity for various small watershed development structures increased 2mm over 7 yr. Taken together, the streamflow trends and groundwater information suggest the most plausible estimates of evapotranspiration changes comes from the AVHRR imagery.

## 1 Introduction

Many regions of the world face water shortages that are increasing and may become severe in the future (Rockstrom et al., 2009). A range of studies have discussed water shortages in regions and river basins including the Indus, Ganges and Krishna basins

9296

in south Asia (Bouwer et al., 2006; Sharma et al., 2010) , southern and eastern European countries (Stahl et al., 2010) , many regions in England (Charlton and Arnell, 2011) and in Australia (Chiew and McMahon, 2002) , among others. These studies emphasised the necessity of understanding different drivers that impact water resources for addressing future water shortages.

The drivers that could affect water availability, in particular streamflow and groundwater include climate change, water resource development and water use at a variety of scales, and a wide range of anthropogenic changes in catchment characteristics. Specific examples include construction of water retention structures (Beavis et al., 1997; Ramireddygari et al., 2000; Schreider et al., 2002) , increased and/or changing agricultural land use (Masih et al., 2011) and increased groundwater extraction and artificial water storages for groundwater recharge (Ramireddygari et al., 2000; Alemayehu et al., 2007). In some cases, these variations may change evapotranspiration and the surface energy balance, thereby also affecting the local climate (Cassardo and Jones, 2011). While development activities may provide benefits in agricultural production, they can also have adverse effects on streamflow and groundwater availability that may lead to both human and ecological impacts downstream (Schreider et al., 2002). In rapidly developing catchments, there are often a number of changes occurring simultaneously with significant potential to impact on the hydrology.

The most visible sign of hydrologic change in a catchment is from the trend of streamflow, which indicates that changes have occurred within the catchment but, in itself, does not provide information on the relative contributions of multiple drivers of change. Such information is critical for developing evidence based policies to manage such changes into the future. A number of studies have tried to explain observed trends in streamflow with respect to changes in climate, catchment characteristics and anthropogenic activities. For e.g. Adnan and Atkinson (2011) observed that the trend in streamflows of the Kelantan catchment, Malaysia resulted from changes in precipitation and land use in the catchment. Rientjes et al. (2011) evaluated the streamflow trend in the upper Gilgel Abay catchment and found it to be associated with rainfall

9297

distribution and land use changes. In Tunisia, Chulli et al. (2011) , found that the decrease in surface runoff in the upper Merguellil catchment is due to consequences of human activities. Similarly Van Kirk and Naman (2008), analysed climatic and non-climatic (irrigation withdrawals) drivers and their affects on base flow trends. Most of the studies have discussed streamflow trends with respect to changes in land use or climate variability or both within a catchment; whereas only a few studies have related streamflows to all the changes within the catchment.

This study aims to understand a variety of changes in the Himayat Sagar catchment (HSC), India where there has been a number of changes at small scales including increased hydrological structures and groundwater extractions that are challenging to scale up. Since 1987, in drought prone areas of India, small scale water resource developments under various watershed development programmes were introduced by the Government of India, including the Drought Prone Area Programme (DPAP) and Integrated Wasteland Development Programme (IWDP). From 1994–1995, these programmes have intensified after the launch of detailed new guidelines on organizational aspects, finance, training and stakeholder participation (Kalpataru Research Foundation, 2001; Hanumantha Rao, 2006). In many arid and semi-arid regions of India, these programmes aimed to improve socio economic conditions through increased agricultural production in rain fed areas, and to control land degradation by conserving rainwater for use during dry periods. The study area (HSC) is located in a semi-arid region. This region is historically among the poorest areas in India and it has previously been severely affected by droughts (World Bank, 2005). Therefore, Water Development Structures (WDS, Fig. 1) such as percolation tanks, mini-percolation tanks, check dams, sunken pits, and farm pits, have been developed in the study area (HSC).

While these structures are beneficial to upstream users, they affect the downstream flows. A case-study on percolation efficiency of artificial tanks found that only 35 % of stored water recharges the groundwater (Sylvain et al., 2008). Another study on small water storage structures reported that these structures can lose 50 % of their total volume every year to evaporation due to their high surface area to volume ratio

9298



and Sewerage Board (HMWSSB); Land use statistics from the Directorate of Economics and Statistics (DES); Groundwater levels (pre-monsoon (end of May) and post-monsoon (end of November)) of 10 observation wells from the Central Groundwater Board (CGWB); and the time series of WDSs sanctioned in Rangareddy district from the District Water Management Agency (DWMA), Rangareddy district.

### 3.1 Rainfall

The 12 rainfall stations and their locations are shown in Fig. 2, and their detailed properties are given in Table 1. The elevation of rainfall stations ranges from 535 m to 720 m above sea level. Among these stations, six had longer records covering 1980–2004, while the other six had shorter records covering 1990–2004.

### 3.2 Reservoir data

Monthly streamflow into HS reservoir has been estimated using water storage levels (1980 to 2004), storage-area-capacity tables, surplus discharges (1980–2004) and water supply withdrawals (1980 to 2004). Evaporation losses are estimated using monthly evaporation depths estimated by HMWSSB and were assumed to be constant for all the years during the study period.

### 3.3 Land use information

The mandal (sub-district area, 1985–1987, 1991–1994 and 1999–2004) and district (1985–2004) wise land use information of the study area was collected from DES. Data gaps (1988 and 1990) found in the mandal level were filled with the corresponding percentage changes observed in the district level information. Area irrigated during the Kharif (monsoon, June–November) and Rabi (dry, December–March) seasons in the catchment were obtained from the mandal wise information under area irrigated by the groundwater sources. The difference between the net sown area and the irrigated area was considered as rain fed area.

9301

### 3.4 Groundwater levels

The locations and other details of the observation wells are given in Fig. 2 and Table 2, respectively. The surface elevations of observation wells above mean sea level range from 570 m to 680 m. The district wise groundwater production wells inventory information (1980–2004) was obtained from the Minor Irrigation Census, (MIC, Ministry of Water Resources), India. The number of groundwater wells within the catchment was obtained from the district level information and the percent of area covered by each district.

### 3.5 Groundwater extractions survey

The groundwater extraction survey has been taken place based on groundwater status in the catchment. The groundwater status is defined using four categories based on the ratio of groundwater usage to rainfall recharge. The categories are Over-Exploited (> 100%), Critical (90–100%), Semi-Critical (75–90%) and Safe (< 75%). The groundwater status has been evaluated in every watershed by CGWB for every two years. The groundwater status (2004–2005) was taken as the average status for all villages within the watershed (Fig. 3). The information needed to estimate the groundwater extractions including typical pumping hours and flow rates, the number of wells per hectare used during the cropping seasons, were collected through field survey in representative villages of every category.

### 3.6 Watershed development structures

The information of watershed development structures (1995–2005, Table 3) was extracted from the data collected at DWMA, Rangareddy district based on the village locations covered within the catchment. The function of these structures is either silt control (sunken pits, feeder channels and gully control structures) or groundwater recharge (check dams, percolation tanks, mini-percolation tanks and farm pits). Although the silt

9302









(Table 10). The Surface water storage capacity of tanks and WDS has increased from  $26.4 \text{ mm yr}^{-1}$  (1995) to  $28.4 \text{ mm yr}^{-1}$  (2004).

The above all changes indicate that evapotranspiration from the catchment must be have increased significantly. The ET estimates obtained using AVHRR remote sensing images show a continuous increasing trend of  $4.1 \pm 2.6 \text{ mm yr}^{-1}$  from 1984 to 2001 (Teluguntla et al., 2011) (Fig. 8). This increase in ET is mainly due to increase in Leaf Area Index (as indicated by NDVI) which is directly linked to irrigation as there are no other significant changes in land use in the study area.

## 6 Discussion

The trend tests results showed no significant changes within the rainfall; however, significant declining trend was observed in streamflows during the study period. The difference between 5-yr average annual streamflows of 1980–1984 and 2000–2004 shows a decrease of 73 mm from  $105 \text{ mm yr}^{-1}$  to  $32 \text{ mm yr}^{-1}$ . The streamflow simulated by the regression model also show that median streamflows reduced by 61 mm from 1980 ( $80 \text{ mm yr}^{-1}$ ) to 2004 ( $19 \text{ mm yr}^{-1}$ ). Overall, the rate of change of observed and model simulated streamflows is  $-3.6 \pm 3.5 \text{ mm yr}^{-1}$  and  $-3.5 \pm 3.0 \text{ mm yr}^{-1}$  respectively. Given the lack of trend in rainfall, the trend observed in the streamflows is likely to be due to internal changes within the catchment, not due to changes in rainfall.

Our analysis of catchment characteristics shows changes in land use, particularly within cropping areas; changes in groundwater extraction; and changes in the number of hydrological structures in the catchment. The major change in land use was in the irrigated area, which increased in both Kharif (from 8% to 23%) and Rabi (from 8% to 16%) cropping seasons. Most of this irrigation demand was met from groundwater and is reflected in the groundwater storage which is decreasing at a rate of  $6.1 \text{ mm yr}^{-1}$ . Groundwater irrigation was originally practised as supplemental irrigation to satisfy the deficits from rainfall but later become the main water resource for irrigation because of its availability at low cost.

9311

It is also likely that irrigation practice has changed in the past two decades in the catchment. During field survey, it is observed that the farmers are irrigating the crops without considering the crop water demand. This is mainly because of the availability of free electricity to utilise groundwater. The statistical data on the evolution of the total number of wells in use also demonstrates this. The mix of irrigated crops has also changed with dry crops favoured over wet crops in the wet season, and wet crops favoured over dry crops in the dry season now.

The change in irrigated area has affected groundwater level and storage in the catchment. We examined 11 observation wells for the period from 1998 to 2004. It was observed that the groundwater levels decreased at a rate of  $0.30 \pm 0.29 \text{ m yr}^{-1}$ , which is  $6.1 \pm 5.9 \text{ mm yr}^{-1}$  of decrease in groundwater storage. A study carried out in the Musi catchment during the period 1998–2004 concluded that the water table is declining at a rate of  $0.18 \text{ m yr}^{-1}$  (Sylvain et al., 2007).

Estimates of groundwater extractions based on inventory of wells and land use statistics show increased rates of  $7.2 \pm 1.6 \text{ mm yr}^{-1}$  and  $10.8 \pm 6.7 \text{ mm yr}^{-1}$ , respectively. There is some evidence (Fig. 7) of increasing rates of groundwater decline over the period 1998–2004, although it is likely that inter-annual variability influences these patterns, so it is hard to draw firm conclusions. There is also some uncertainty in the specific yield values used in this analysis which needs some verification in the future. Large changes in groundwater levels are not observed in spite of increased pumping, which may be because overall recharge might has increased due to increased recharge from irrigation and WDSs and also due to reducing base flows in streams.

Given that annual groundwater extraction rates have increase by around  $40 \text{ mm yr}^{-1}$  to  $75 \text{ mm yr}^{-1}$  over 1998–2004 and that groundwater storages are only declining by an average of  $6 \text{ mm yr}^{-1}$  over this period, it is likely that there was both a decline in base flow and an increase in recharge in the catchment over this period. The WDS information collected suggest only a limited increase in recharge. The WDS data (1995–2005) show that the runoff capture increased at the rate of  $0.24 \pm 0.10 \text{ mm fillings}^{-1} \text{ yr}^{-1}$ , or  $2.0 \pm 0.85 \text{ mm 8 fillings}^{-1} \text{ yr}^{-1}$  (i.e., assumed that the

9312





- Chulli, B., Favreau, G., Jebnoun, N., and Bédir, M.: Impact of changing climate in the kairouan hydrological basin (central tunisia), *J. Environ. Sci. Eng.*, 5, 682–688, 2011.
- Dewandel, B., Gandolfi, J. M., de Condappa, D., and Ahmed, S.: An efficient methodology for estimating irrigation return flow coefficients of irrigated crops at watershed and seasonal scale, *Hydrol. Process.*, 22, 1700–1712, doi:10.1002/hyp.6738, 2008.
- George, B., Malano, M. H., and Davidson, B.: Integrated water allocation-economic modelling at a catchment scale, MODSIM-2007, Christchurch, 2007.
- Gurunadha Rao, V. V. S., Suryanarayana, G., Prakash, B. A., Mahesh Kumar, K., and Ramesh, M.: Ecological study of osmansagar and himayatsagar lakes in greater hyderabad, andhra pradesh, india, 12th World Lake Conference, Taal 2007 Jaipur, India, 2007.
- Hanumantha Rao, T.: Innivation participation technologies for water harvesting structures & catchment management in semi arid tropics of india, 2nd International Conference on Hydrology and Watershed Management, Hyderabad, 2006.
- Kalpataru Research Foundation, K.: Watershed development, Kalpataru Research Foundation, Report No. 139, 2001.
- Maréchal, J. C., Dewandel, B., Ahmed, S., Galeazzi, L., and Zaidi, F. K.: Combined estimation of specific yield and natural recharge in a semi-arid groundwater basin with irrigated agriculture, *J. Hydrol.*, 329, 281–293, doi:10.1016/j.jhydrol.2006.02.022, 2006.
- Masih, I., Maskey, S., Uhlenbrook, S., and Smakhtin, V.: Impact of upstream changes in rain-fed agriculture on downstream flow in a semi-arid basin, *Agr. Water Manage.*, 100, 36–45, doi:10.1016/j.agwat.2011.08.013, 2011.
- Ramireddygar, S. R., Sophocleous, M. A., Koelliker, J. K., Perkins, S. P., and Govindaraju, R. S.: Development and application of a comprehensive simulation model to evaluate impacts of watershed structures and irrigation water use on streamflow and groundwater: The case of wet walnut creek watershed, kansas, USA, *J. Hydrol.*, 236, 223–246, 2000.
- Rientjes, T. H. M., Haile, A. T., Kebede, E., Mannaerts, C. M. M., Habib, E., and Steenhuis, T. S.: Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin – Ethiopia, *Hydrol. Earth Syst. Sci.*, 15, 1979–1989, doi:10.5194/hess-15-1979-2011, 2011.
- Rockstrom, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S., and Gerten, D.: Future water availability for global food production: The potential of green water for increasing resilience to global change, *Water Resour. Res.*, 45, W00A12, doi:10.1029/2007WR006767, 2009.

9317

- Sakthivadivel, R., Fernando, N., and Brewer, D. J.: Rehabilitation planning for small tanks in cascades: A methodology based on rapid assessment, International Water Management Institute, Colombo, 1997.
- Schreider, S. Y., Jakeman, A. J., Letcher, R. A., Nathan, R. J., Neal, B. P., and Beavis, S. G.: Detecting changes in streamflow response to changes in non-climatic catchment conditions: Farm dam development in the murray-darling basin, australia, *J. Hydrol.*, 262, 84–98, 2002.
- Sharma, B., Amarsinghe, U., Xueliang, C., de Condappa, D., Shah, T., Mukherji, A., Bharati, L., Ambili, G., Qureshi, A., Pant, D., Xenarios, S., Singh, R., and Smakhtin, V.: The indus and the ganges: River basins under extreme pressure, *Water Int.*, 35, 493–521, doi:10.1080/02508060.2010.512996, 2010.
- Stahl, K., Hisdal, H., Hannaford, J., Tallaksen, L. M., van Lanen, H. A. J., Sauquet, E., Demuth, S., Fendekova, M., and Jódar, J.: Streamflow trends in Europe: evidence from a dataset of near-natural catchments, *Hydrol. Earth Syst. Sci.*, 14, 2367–2382, doi:10.5194/hess-14-2367-2010, 2010.
- Sylvain, M., George, B., Gaur, A., and Nune, R.: Groundwater modelling for sustainable resource management in the musci catchment, India, MODSIM-2007, Christchurch, 1429–1435, 2007.
- Sylvain, M., Jérôme, P., Cédric, M., Mohamed, W., Subash, C., and Benoit, D.: Percolation efficiency of an artificial tank in semi-arid hard rock aquifer context, South India, International Water Resources Association, 13th World Water Congress, 2008.
- Teluguntla, P., Ryu, D., George, B. A., and Walker, J.: Impact of spatial scale on remotely sensed evapotranspiration estimates from heterogeneous land surfaces, 19th International Congress on Modelling and Simulation, Perth, 2011.
- Van Kirk, R. W. and Naman, S. W.: Relative effects of climate and water use on base-flow trends in the lower klamath basin, *J. Am. Water Resour. As.*, 44, 1035–1052, doi:10.1111/j.1752-1688.2008.00212.x, 2008.
- World Bank: Drought in andhra pradesh: Long term impacts and adaptation strategies, South Asia Environment and Social Development Department, 2005.

9318





**Table 5.** Results of trend test on rainfall and streamflows.

Test	1980–2004		1990–2004		
	Z-statistic	p-value	Z-statistic	p-value	
Rainfall	Mann-Kendall	0.16	0.87	0.21	0.83
	Spearman's rho	0.25	0.80	0.16	0.87
Streamflows	Mann-Kendall	-2.07	0.03		
	Spearman's rho	-2.07	0.03		

9323

**Table 6.** Change in magnitude of streamflows at different time steps.

Percentile	Rainfall (mm)	Streamflow (mm)			
		1980	1990	2000	2004
25th	596	36	25	13	9
50th	693	80	56	30	19
75th	844	149	105	56	36

9324

**Table 7.** Average variations in net sown area at different time periods.

Year	Average rainfed area (% of NSA) (Kharif season)	Average irrigated area (% of NSA) (Kharif season)	Average irrigated area (% of NSA) (Rabi season)
1985–1990	93	7	8
1991–1996	87	13	9
1997–2001	81	19	13
2001–2004	77	23	17

9325

**Table 8.** Groundwater extraction survey particulars during field survey.

GW_Status	No. of samples	Average number of pumping days (Rabi Season)	Average number of pumping hours per day	Number of Wells used	Number of Wells used (Kharif Season) (Rabi Season)
Safe	10	115	7	All	70 %
Semi-Critical	15	120	7	All	50 %
Critical	15	120	7	All	50 %
Over-Exploited	15	120	7	All	40 %

9326

**Table 9.** Data comparison between DWMA and Google Earth for 25 villages, where GW\_S is the Groundwater status, S\_CD & S\_FP are Google Earth survey check dams, and farm pits, R\_CD & R\_FP are records available on check dams and farm pits with DWMA, Irrig. Area and T\_Cul Area are Irrigated area and Total cultivable area in the village.

S No.	Village Name	Soils	GW_S	S_CD	S_FP	R_CD	R_FP	Village area (ha)	Irrig. area (ha)	T_Cul area (ha)
1	Ammapalle	C	Cri	0	50	NA	NA	313	81	178
2	Devarampalle	C	Cri	7	43	NA	NA	381	52	297
3	Komerabanda	C	Cri	2	41	NA	NA	231	0	142
4	Ganisimiyaguda	C	Cri	4	31	1	NA	287	12	54
5	Farooqnagar	C	Cri	3	50	NA	NA	NA	NA	NA
6	Golkonda Kurd	GC	Cri	0	40	NA	NA	195	82	165
7	Gandiguda	GC	Cri	0	28	1	NA	280	43	69
8	Nagaram	GC	Cri	0	45	3	NA	577	103	103
9	Sriramnagar	L	Cri	14	41	NA	NA	940	280	871
10	Chegur	R	Cri	30	64	NA	NA	3136	298	2923
11	Ibrahimpalle	C	OE	18	42	11	NA	384	27	241
12	Kothur	C	OE	11	105	NA	NA	1962	221	803
13	Chevella	C	OE	30	75	15	NA	1205	59	456
14	Akhanpalle	C	OE	5	45	0	NA	556	67	397
15	Shubanpur	L	OE	6	50	0	NA	645	78	618
16	Yabajiguda	C	Safe	5	40	5	NA	335	19	267
17	Peddamanthal	C	Safe	19	51	18	NA	1318	49	950
18	Niz-Medipalle	C	Safe	6	37	11	NA	718	33	400
19	Anantharam	GC	Safe	16	55	12	NA	733	17	223
20	Khandlapalle	GC	Safe	11	66	9	NA	688	29	288
21	Bangaliguda	C	S-Cri	0	37	NA	NA	43	22	31
22	Kothwalguda	C	S-Cri	3	30	2	NA	1109	167	234
23	Narkhuda	C	S-Cri	10	74	10	NA	1063	180	180
24	Nagireddyguda	C	S-Cri	0	65	NA	NA	455	245	375
25	Sajjanpalli	GL	S-Cri	24	52	NA	NA	205	124	169

9327

**Table 10.** Details of water surface area by tanks existed in HS catchment.

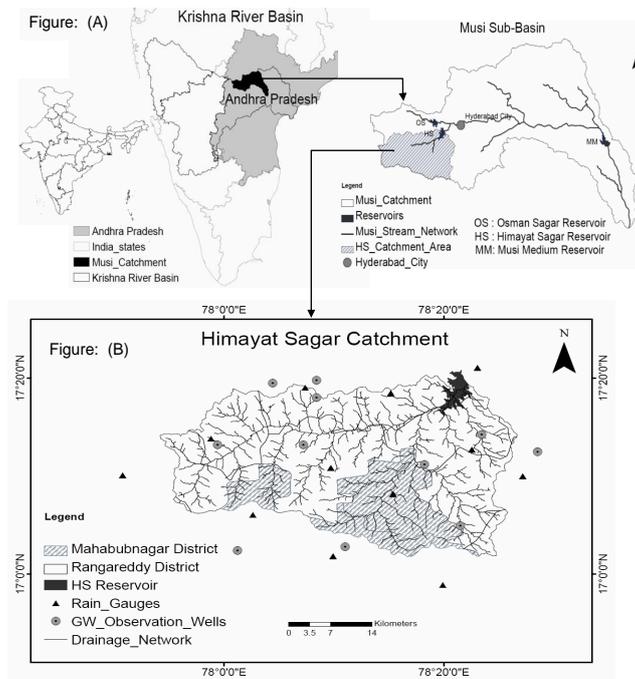
Year	Date of image	Rainfall during the month (mm)	Annual rainfall (mm)	Surface area of tanks (ha)
1981	14 October	79.20	854	1409
1989	21 November	0.00	760	680
2000	26 October 2012	41.10	774	1486

9328



**Fig. 1.** Pictures of tank and Watershed Development Structures in HSC.

9329



**Fig. 2.** (A) location of Himayat Sagar Catchment (HSC) in Musi Sub-basin of Krishna river basin. (B) districts covered by HSC, drainage network, locations of HS reservoir, rain gauge stations and ground water observation wells.

9330

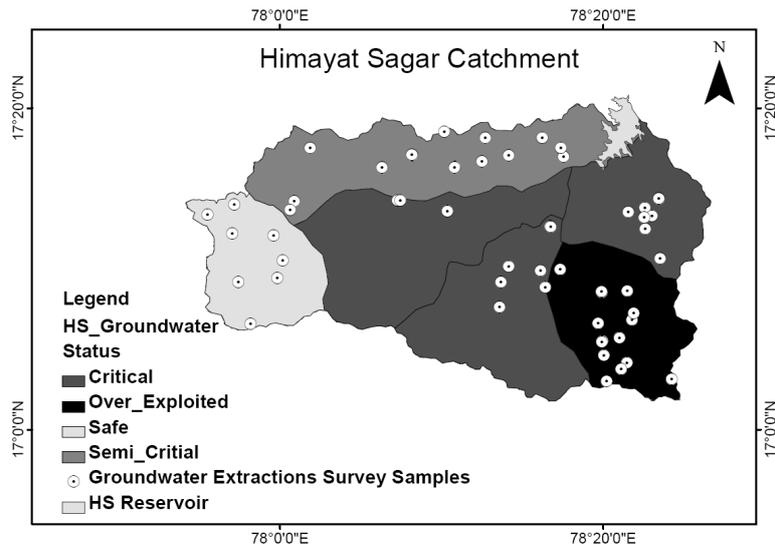


Fig. 3. Location map of groundwater extraction survey samples.

9331

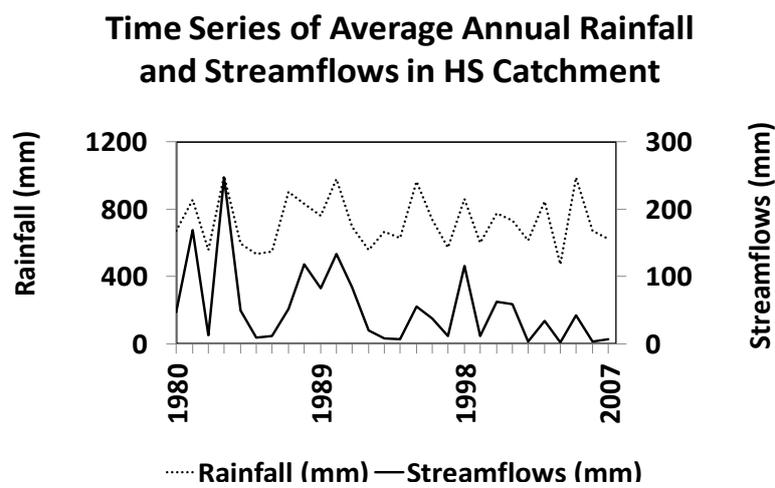
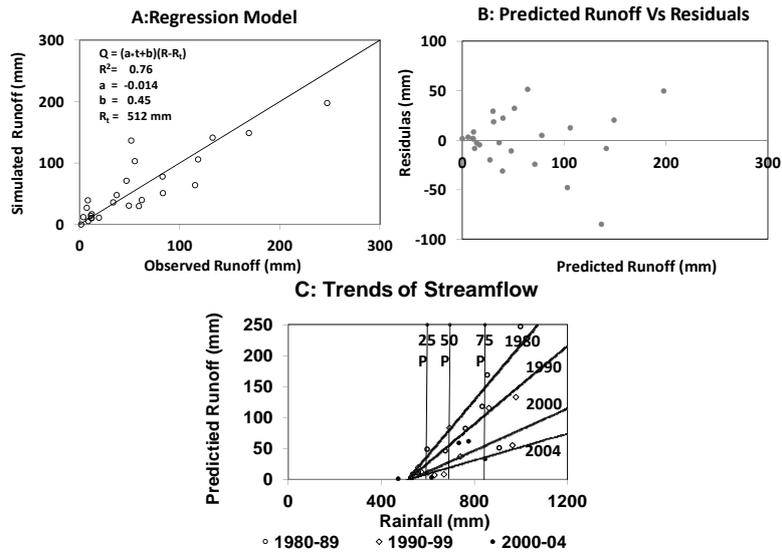


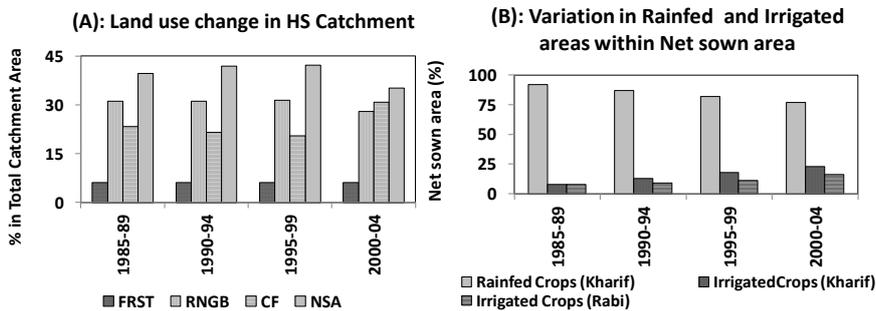
Fig. 4. Times series of average annual rainfall and streamflows of HS catchment.

9332



**Fig. 5.** (A) linear regression model of rainfall-runoff, (B) plot shows the residuals against predicted values, (C) change in magnitude of streamflows at different time trends and rainfall percentiles.

9333



**Fig. 6.** (A) over all land use details of major classes such as Forest (FRST), Range lands (RNGB) Current Fallow lands (CF), Net sown area (NSA), and in HS catchment for last two decades, (B) the change in rainfed and irrigated crops within Net sown area of the catchment from 1985–2004.

9334

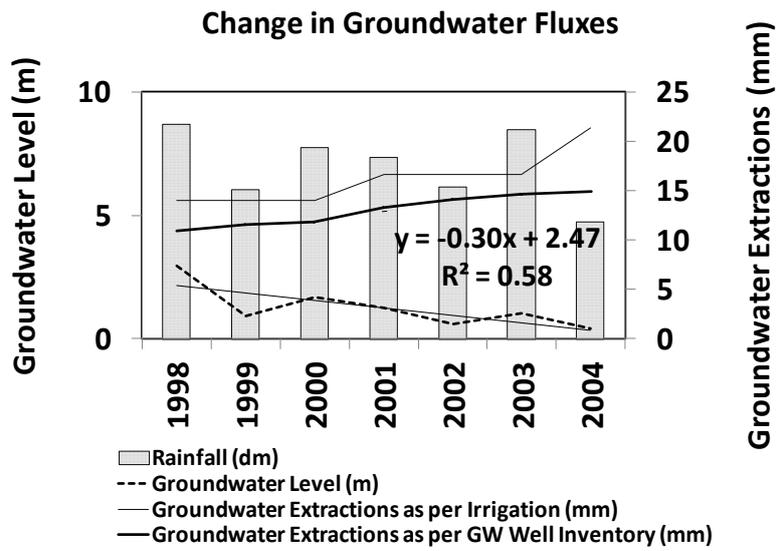


Fig. 7. The Trend of groundwater levels and extractions in HS catchment.

9335

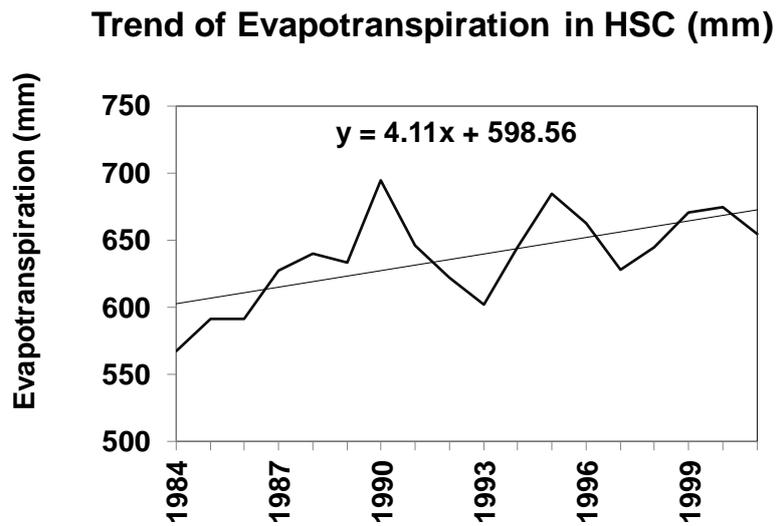


Fig. 8. Change in Evapotranspirations in the HS catchment estimated using AVHRR data and remote sensing techniques.

9336