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Manish Debnath
Ph.D. Research Scholar, Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, & Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

Arjamadutta Sarangi
Principal Scientist, Water Technology Centre, ICAR-IARI, New Delhi, India

Dipaka Ranjan Sena
Principal Scientist, Division of Agricultural Engineering, ICAR-IARI, New Delhi, India

Dhirendra Kumar Singh
Principal Scientist and Professor, Division of Agricultural Engineering, ICAR-IARI, New Delhi, India

Corresponding Author:
Manish Debnath
Ph.D. Research Scholar, Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, & Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

Temporal variation of percolation fluxes and stream flows in Moga, Barnala, Patiala, Sangrur and Ludhiana district of Punjab, India under climate change

Manish Debnath, Arjamadutta Sarangi, Dipaka Ranjan Sena and Dhirendra Kumar Singh

Abstract
Percolation fluxes from rainfall and surface water sources in a region contributes to ground water recharge. Correct estimation of percolation fluxes and recharge fluxes from stream bed would help in effective ground water recharge estimation at a region. Validated SWAT model was used for estimation of monthly and yearly variation of percolation fluxes and streamflow under climate change in the present study region comprised with Moga, Barnala, Patiala, Sangrur and Ludhiana District of Punjab, India. The variation of monthly average percolation fluxes during the base period (1983-2005) was estimated as 0.02-17.9 mm, 0-2.7 mm, 0-5.8 mm, 0-11.6 mm and 0-2.6 mm for Ludhiana, Barnala, Sangrur, Patiala and Moga district, respectively, whereas during 2006-2030 it was estimated to vary from 0-5.8 mm, 0-1.9 mm, 0-2.7 mm, 0.06-4.4 mm and 0-1.7 mm for the said districts respectively. The maximum and minimum values for monthly average percolation fluxes for the base period (1983-2005) varied from 0-32.6% of the monthly average rainfall whereas, during 2006-2030 it varied from 0-30.5% of the monthly average rainfall. Yearly total percolation flux for Ludhiana, Barnala, Sangrur, Patiala and Moga district were estimated to be reduced by 64.7%, 22.1%, 44.1%, 51% and 46.2%, respectively during 2006-2030 under RCP4.5 as compared to the base period 1983-2005. The validated SWAT model estimated monthly average streamflow was found to be reduced by 73%, 65.5%, 73.7%, 62.1%, 41.4%, 27.9%, 38.8%, 42.1%, 6.1% 13.2% and 55%, respectively for the month of January, February, March, April, May, July, August, September, October, November and December, respectively, whereas for the month of June it was estimated to increase by 44.3% during 2006-2030 over the base period from 1983-2005. Reduction of both the percolation fluxes and streamflow under climate change indicated a lesser ground water recharge potential in future in the study districts and a need for adoption of judicious groundwater management plans for sustainable crop production in the study region.

Keywords: Stream flow, percolation fluxes, ground water recharge, RCP4.5

Introduction
Changes in magnitude of rainfall and other climatic parameters at regional scales influence the hydrologic cycle and thereby the hydrological fluxes *viz.*, the stream flow, percolation fluxes etc. leading to spatio-temporal variability of water resources in a region (Epting *et al.*, 2021; Xiao *et al.*, 2021) [10, 16]. Groundwater recharge, surface runoff, and soil water content is reported to be affected due to significant decrease in rainfall and increase in air temperature in the mid of 21st century (Wu *et al.*, 2012; Abdulla *et al.*, 2009) [15, 1]. Assessment of the impact of climate change on water availability for planning and managing the water resources at regional level assumes prime importance (2022; Debnath *et al.*, 2022; Liu *et al.*, 2021) [7-9, 12]. Five districts of central Punjab India *viz.* Moga, Barnala, Sangrur, Patiala and Ludhiana cover 34.4% of the total rice cultivated area (3.1mha) in the state of Punjab and the ground water table depth depletion in these five districts were found higher amongst the 13 central Punjab districts based on the pre-monsoon groundwater table depth analysis (Anonymous, 2017) [3]. Proper estimation of ground water recharge considering the percolation fluxes from rainfall and also from the stream bed would help devising judicious ground water management plans in the study districts. Although past studies incorporated the percolation fluxes from rainfall for ground water recharge studies in the state of Punjab, but, the streambed leakage contributions for ground water recharge estimation was not considered. Moreover, a thumb rule that 25% of total rainfall (Rainfall infiltration factor of 0.25) would become potential recharge flux was assumed which may not be a plausible assumption (Miglani *et al.*, 2015) [13]. Andualem *et al.* (2021) [2] suggested incorporation of recharge fluxes from streams, rivers

along with recharge fluxes from rainfall for ground water recharge studies. Further, climate change data derived from multiple climate models were suggested by various researchers (Choudhary *et al.*, 2018; Chaturvedi *et al.*, 2012) [5, 4] for estimation of recharge flux components, which was also not considered in any of the past studies in the study districts. The present study aims at estimation of potential recharge fluxes and stream flow estimation using a validated SWAT model for the study districts using climate data from model ensembles.

Materials and Methods

Study area description

Study area is located between 29.9°N-31.07°N latitude to 74.9°E-76.8°E longitude covering an area of 10,501 Km^2 and is comprised of Barnala, Moga, Sangrur, Patiala and Ludhiana districts of Central Punjab, India. Three distinct climatic periods prominent in the study area are *viz.* the summer period (mid of April to June), the rainy period (beginning of July to the end of September) and the winter (early December to the end of February). Study area receives 80% of yearly total rainfall due to the south west monsoon (*i.e.*, from end of June to September). The average monsoon rainfall for the study area for past 30 years varied from 276.3 mm to 498.5 mm, whereas, the average annual rainfall for the study area varied from 363.4 mm to 609.8 mm for the same period. The location map of the study area is shown in Fig.1.

Temporal variability analysis of Percolation Fluxes and Stream Flow

The India Meteorological Department (IMD) gridded rainfall data for the base period of 1983-2005 and the bias corrected IITM-RegCM4 model based six model ensemble outputs *viz.*, rainfall, maximum and minimum air temperature under RCP4.5 by Debnath *et al.*, 2022 [8] for the study districts were used in the validated SWAT model for estimation of percolation fluxes and streamflow from 2006-2030. Validated SWAT model by Debnath *et al.*, 2022 [9] for the study districts was used for estimation of potential recharge fluxes from rainfall and the temporal variation of stream flow. Relative changes of percolation fluxes and stream flow during 2006-2030 over the base period were estimated over the study region. The Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) was used to detect the trend and rate of change (Dawood *et al.*, 2017) [6] of change of potential recharge fluxes and the stream flow over time.

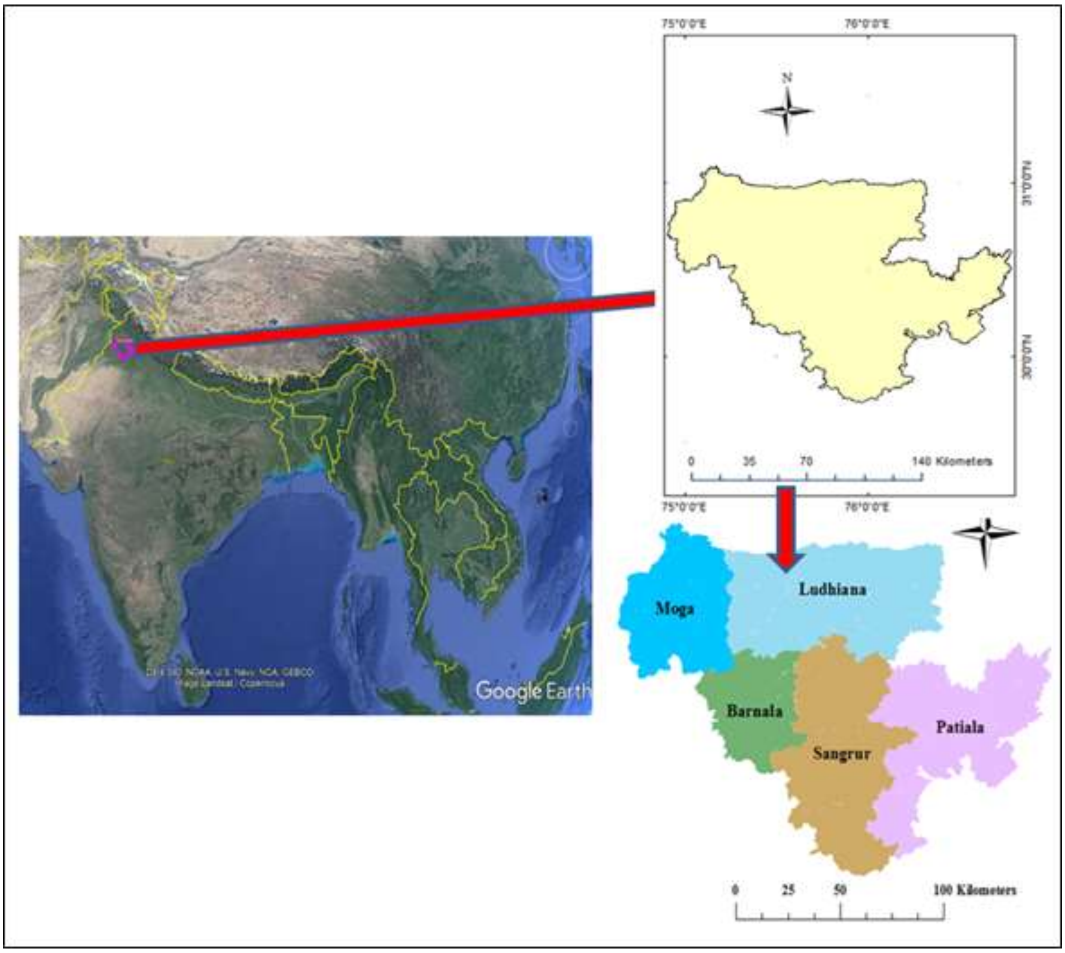

Fig 1: Location map of the study area depicting Moga, Barnala, Sangrur, Patiala and Ludhiana districts of central Punjab, India

Results

Variation of monthly percolation fluxes due to climate change

Bias corrected rainfall, maximum and minimum air temperatures were used as input to validated SWAT model to estimate the monthly percolation loss and stream flows under climate change scenarios which were further used as input to the validated GMS for ground water recharge estimation.

The average of monthly percolation fluxes for the base period (1983-2005) varied from 0.02-17.9 mm, 0-2.7 mm, 0-5.8 mm, 0-11.6 mm and 0-2.6 mm for Ludhiana, Barnala, Sangrur, Patiala and Moga district, respectively, whereas percolation flux was estimated to vary from 0-5.8 mm, 0-1.9 mm, 0-2.7 mm, 0.06-4.4 mm and 0-1.7 mm, respectively during 2006-2030. Yearly total percolation loss for Ludhiana, Barnala, Sangrur, Patiala and Moga district was 46 mm, 5.8 mm, 13.7 mm, 29.6 mm and6.5 mm for the base period whereas during 2006-2030 it was estimated as 16.3 mm, 4.5 mm, 7.6 mm, 14.5 mm and 3.5 mm, respectively. Monthly variation of percolation fluxes over the study region for 1983-2005 (base period) and 2006-2030 are shown in Fig.2 and Fig.3, respectively. It was observed that the monthly percolation fluxes for the base period (1983-2005) varied from 0-32.6% of the monthly rainfall whereas during 2006-2030 it varied from 0-30.5% of the monthly rainfall. Monthly values of percolation fluxes for the five study districts estimated through the validated SWAT model for the base period (1983-2005) and year 2006-2030 are presented in Table 1. Yearly total percolation flux for Ludhiana, Barnala, Sangrur, Patiala and Moga district were estimated to be reduced by 64.7%, 22.1%, 44.1%, 51% and 46.2%, respectively during 2006-2030 as compared to the base period 1983-2005. Fig. 4 shows district wise reduction in percolation flux values during 2006-2030 as compared to the base period.

Table 1: District wise estimated monthly percolation flux for the base period (1983-2005) and 2006-2030

Monthly average percolation flux for Base Period (mm)					
Months	Ludhiana	Barnala	Sangrur	Patiala	Moga
Jan	0.91	0.16	0.34	0.58	0.09
Feb	3.13	0.40	0.64	1.52	0.54
Mar	1.18	0.02	0.24	0.90	0.11
Apr	0.09	0.00	0.01	0.07	0.00
May	0.02	0.00	0.00	0.01	0.00
Jun	0.22	0.00	0.03	0.27	0.00
Jul	11.51	0.73	2.75	7.80	1.15
Aug	17.90	2.76	5.79	11.64	2.65
Sep	9.09	1.39	3.34	5.74	1.63
Oct	0.72	0.04	0.19	0.36	0.05
Nov	0.17	0.01	0.03	0.08	0.01
Dec	1.11	0.33	0.38	0.72	0.21
Monthly average percolation loss during2006-2030 (mm)					
Months	Ludhiana	Barnala	Sangrur	Patiala	Moga
Jan	0.02	0.00	0.01	0.14	0.00
Feb	0.20	0.00	0.03	0.08	0.00
Mar	0.12	0.00	0.02	0.07	0.05
Apr	0.12	0.00	0.11	0.19	0.00
May	0.00	0.02	0.08	0.08	0.00
Jun	1.08	0.74	0.53	1.12	0.23
Jul	3.10	0.99	1.54	3.15	0.43
Aug	5.80	1.93	2.70	4.45	1.76
Sep	4.47	0.76	2.13	3.80	0.86
Oct	0.87	0.10	0.41	0.97	0.10
Nov	0.14	0.00	0.03	0.13	0.02
Dec	0.31	0.00	0.08	0.35	0.00

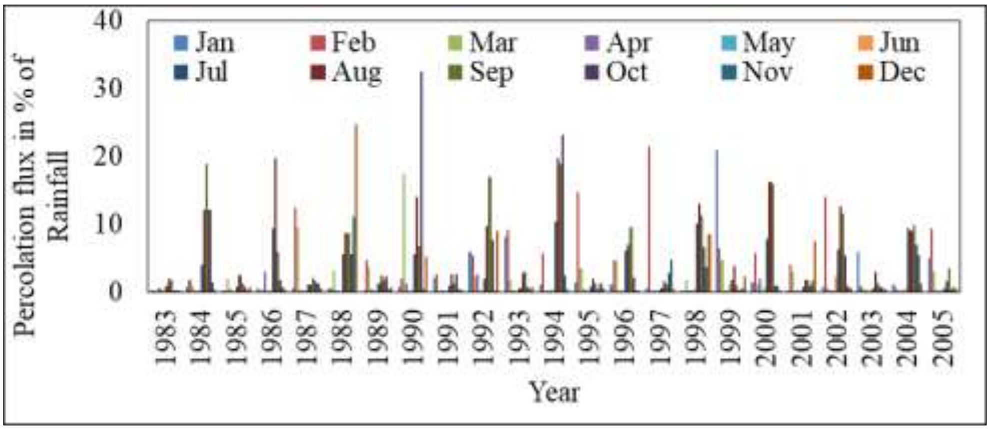

Fig 2: Monthly percentage variation of percolation fluxes for the study region during 1983-2005

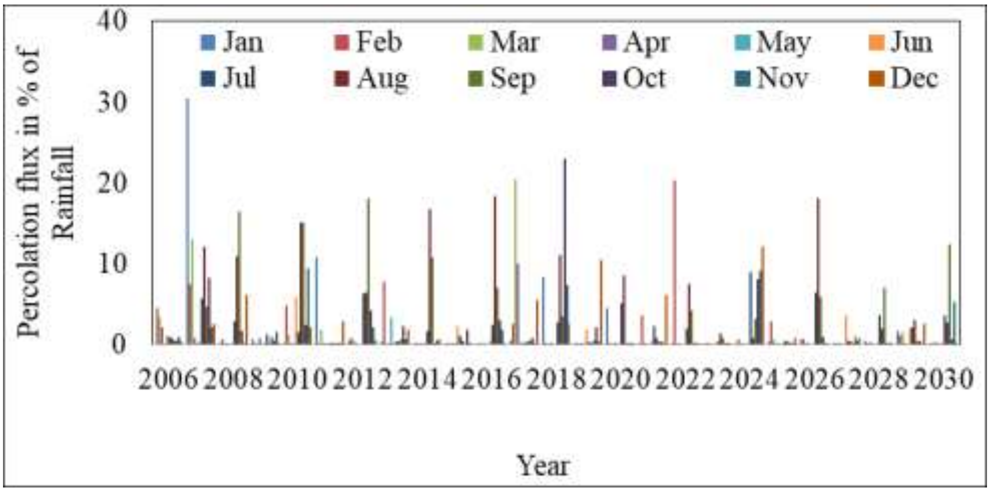

Fig 3: Monthly percentage variation of percolation fluxes for the study region during 2006-2030

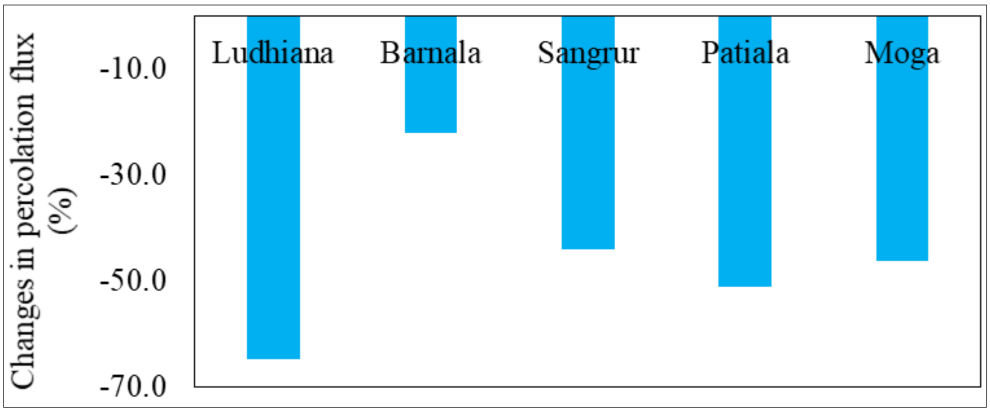

Fig 4: District wise reduction in percolation flux during 2006-2030 as compared to the base period (1983-2005).

Table 2 shows the Modified Mann-Kendall trend test statistics and Sen's slope estimator values for estimated percolation losses from 1983-2030 for all the five study districts. It was observed that there is significant reduction trend in percolation fluxes for Ludhiana, Moga, Patiala and Sangrur district at $p<0.05$. The rate of reduction in percolation losses were 0.63 mm $year^{-1}$, 0.23 mm $year^{-1}$, 0.09 mm $year^{-1}$, 0.028 mm $year^{-1}$ for the Ludhiana, Patiala, Sangrur and Moga district, respectively.

Table 2: Modified Mann-Kendall test statistics (mMK-Z) and Sen's slope estimator (SS) for estimated percolation flux from 1983-2030

Test statistics for percolation flux					
Statistics	**Barnala**	**Ludhiana**	**Moga**	**Patiala**	**Sangrur**
mMK-Z value	-0.41	-4.0*	-2.44*	-2.36*	-9.2*
p value	0.67961	0.00006	0.01464	0.01851	$2.4*10^{-20}$
Tau	-0.030	-0.30	-0.11	-0.23	-0.21
Sen's slope	-0.002	-0.629	-0.028	-0.233	-0.091

*Decreasing trend at $p<0.05$.

Variation of monthly stream flow due to climate change

Estimated monthly streamflow from 1983-2030 showed a significant decreasing trend for all months except for the month of June where a significant increasing trend was found. The monthly average stream flow for the base period (1983-2005) varied from 0.61- 41.75 $m^3 s^{-1}$, whereas for year 2030 it was estimated to be varying from 0.25-25.66 $m^3 s^{-1}$. The Modified Mann-Kendall trend test statistics and the Sen's slope estimator of the monthly average stream flow from 1983-2030 for monsoon and non-monsoon seasons are presented in Table 3 and Table 4, respectively. There was a significant decreasing trend at $p<0.05$ for all the months in non-monsoon season except for the months of May and November. Fig.5 shows yearly variation of SWAT estimated monthly stream flow with Sen's slope estimator for the period of 1983-2030. The monthly average stream flow was estimated to be reduced by 73%, 65.5%, 73.7%, 62.1%, 41.4%, 27.9%, 38.8%, 42.1%, 6.1% 13.2% and 55%, respectively for the month of January, February, March, April, May, July, August, September, October, November and December, respectively, whereas for the month of June it was estimated to increase by 44.3% during 2006-2030 over the base period from 1983-2005. Fig.6 shows the change in monthly stream flow in 2030 due to impact of climate change over the base period.

Table 3: Modified Mann-Kendall trend test statistics and the Sen's slope estimator of the monthly average stream flow for monsoon season from 1983-2030

Monsoon season				
Statistics	**June**	**July**	**Aug**	**Sept**
mMK-Z	3.57*	-0.85	-2.84*	-2.71*
P-value	0.00036	0.39	0.0045	0.0066
Tau	0.16	-0.12	-0.28	-0.27
Sen's slope	0.06	-0.19	-0.45	-0.27

*Trend at 5% significance level ($p<0.05$). Negative mMK-Z value indicates decreasing trend and the positive mMK-Z value indicates an increasing trend.

Table 4: Modified Mann-Kendall trend test statistics and the Sen's slope estimator of the monthly average stream flow for non-monsoon season from 1983-2030

Non-monsoon season								
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Oct**	**Nov**	**Dec**
mMK-Z	-1.81*	-3.09*	-5.63*	-2.11*	-0.56	-1.64	0.21	-3.57*
P-value	0.007	0.00005	0.001	0.035	0.57	0.1	0.83	0.004
Tau	-0.22	-0.23	-0.39	-0.24	-0.07	-0.16	0.03	-0.27
Sen's slope	-0.014	-0.022	-0.028	-0.006	-0.002	-0.028	0.002	-0.023

*Trend at 5% significance level ($p<0.05$). Negative mMK-Z value indicates decreasing trend

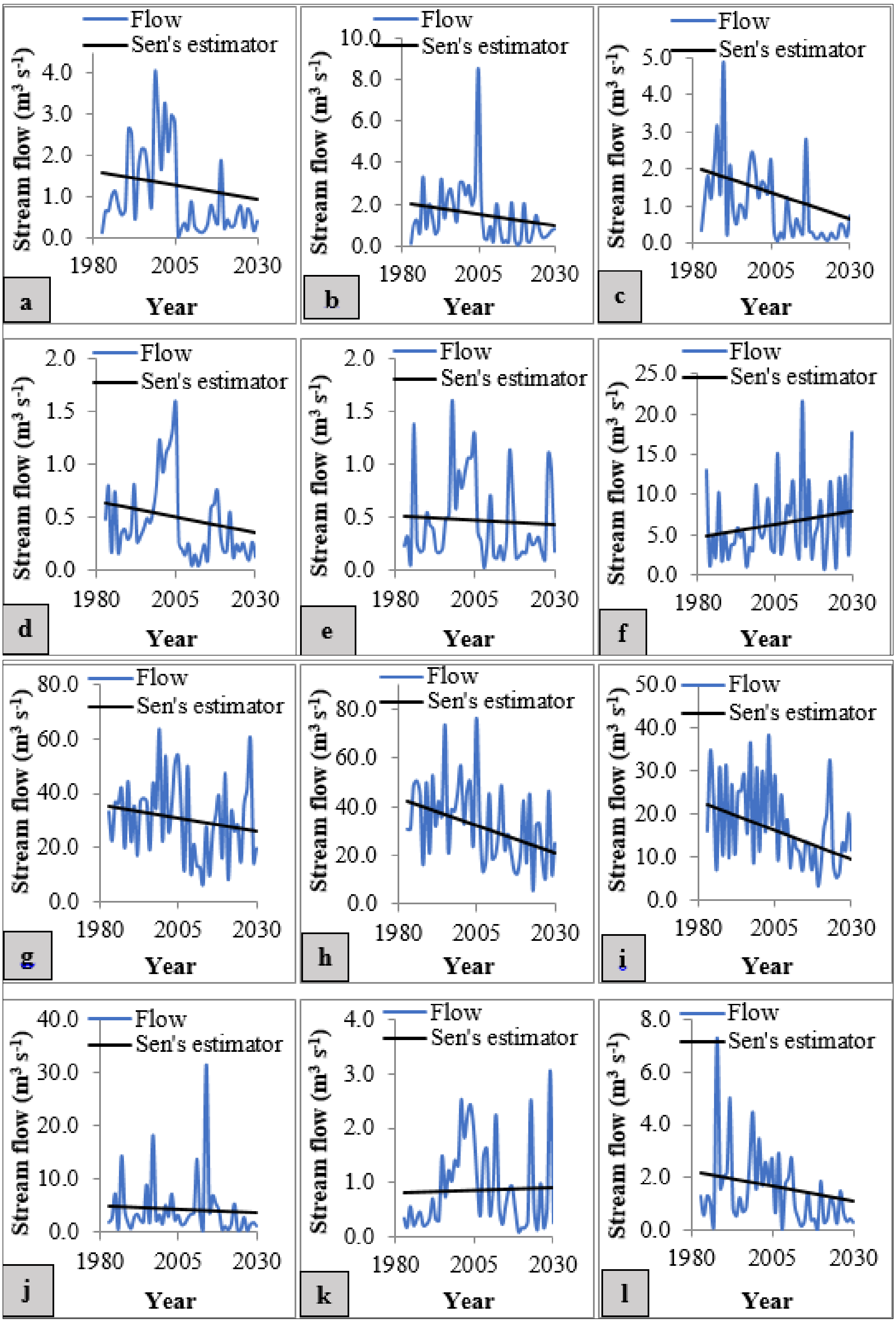

Fig 5: Yearly variation of stream flow from 1983-2030 for the month of a) January, b) February, c) March, d) April, e) May, f) June, g) July, h) August, i) September, j) October, k) November and l) December

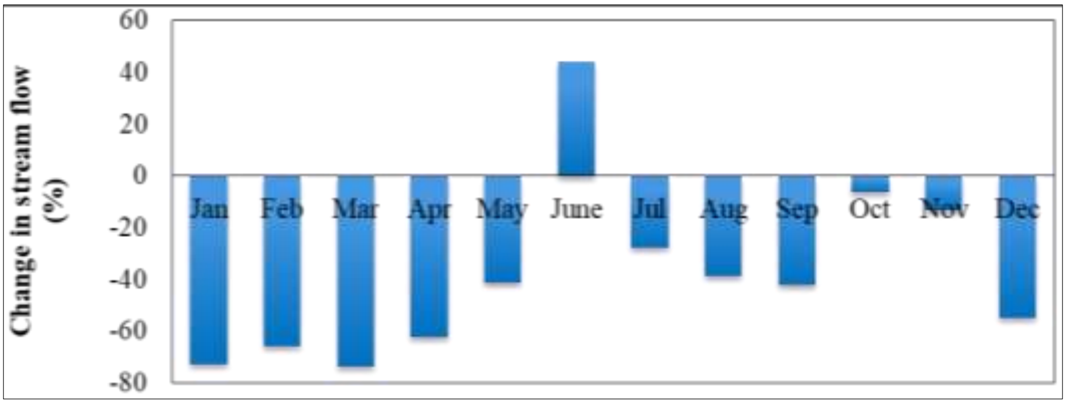

Fig 6: Percentage variation of monthly stream flow due to impact of climate change in year 2030 under RCP 4.5 over the base period

Discussion

Estimated monthly percolation fluxes and stream flow data by the validated SWAT model were used as input to GMS for ground water table simulation. Monthly percolation fluxes for the study region during the base period (1983-2005) varied from 0-32.6% whereas during 2006-2030 it varied from 0-30.5% of the monthly rainfall and this variation was due to mainly the variation in magnitude of the rainfall. Previous studies on ground water table simulation for the state of Punjab, India assumed that about 25% of rainfall becomes the potential downward percolation fluxes (Kaur & Kaur, 2019; Miglani *et al.*, 2015) [13]. However, this study indicated wide variation in percolation rate from 0-32.6% based on the variation in magnitude of rainfall and also the land use land cover indicating that 25% of rainfall converting to potential downward percolation flux may not be a realistic assumption to estimate ground water recharge under present and future climate. Hence, it was observed in this study that the surface hydrological models *viz.*, SWAT could be used for realistic estimation of downward percolation fluxes for subsequent use in ground water simulation studies. Variation in yearly total percolation fluxes in the present study could be attributable to the variation in yearly total rainfall in the study region. Reduction in yearly total rainfall by 24-31% during 2006-2030 was predicted for the study region which in turn will reduce the yearly total potential percolation flux by 22.1-64.7% during this period. Such variations in percolation fluxes were also reported in previous studies as a result of variation in yearly precipitation values. Oteng Mensah *et al.*, (2014) have reported yearly variation of percolation fluxes from 0.9% and 21% of annual precipitation due to variation in yearly rainfall for the Sedimentary Basin in Ghana. Moreover, a reduction in the monthly streamflow except the month of June was estimated in the study region due to the reduction in magnitude of total yearly rainfall in the study region.

Conclusion

Percolation fluxes and seepage from streambed in a region contributes to ground water recharge. In general, for ground water recharge studies a certain percentage of rainfall is considered as potential percolating flux which may not be a plausible assumption. Validated SWAT Model used for estimation of both the downward percolation fluxes and the streambed leakage in the present study indicated a wide variation of percolation fluxes based on rainfall and land use land cover pattern in selected five districts of central Punjab. It was concluded that for better water management purposes proper estimation of percolation fluxes and streambed leakage can be done using SWAT model instead of using a thumb rule that 25% of rainfall becomes downward percolation fluxes. Moreover, due to climate change there will be reduction in percolation fluxes and stream flow in the study region. Judicious water management plan therefore must be adopted in the study districts for sustainable crop production.

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