Original research paper

Rainfall Variability and Rice Production: An Assessment based on the variability in Indian Monsoon and Ground Water Level of Punjab, India

Abstract:
In Punjab, 99 per cent of total cultivated area is under irrigation but it is at the cost of declining ground water table. Due to rainfall variability and very highrequirement of waterin rice crop, which occupy large area in the state during *kharif* season, has further deteriorated the situation of water resources. Therefore, this study was conducted to identify the relationship between declining groundwater level, variable monsoonal rainfall and rice yield of different agroclimatic zones of Punjab. The historical data of rainfall for different locations of Punjab viz. Amritsar (1998-2017), BallowalSaunkhri (1998-2017), Bathinda (1998-2017), Ludhiana (1998-2017) and Patiala (1998-2017) was collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana and Met Centre, IMD Chandigarh. The productivity data of rice was collected from indiastat.com and Statistical Abstract of Punjab whereas the data related to groundwater table (1998-2017) were collected from the Central Ground Water Board, Punjab.It was observed that the ground water table level showed significant decrease after 2005 at all locations and there was a positive correlation between rice yield and ground water table at all the locations except at Amritsar where it was negatively correlated. The deficit rainfall years showed very less impact on rice yield which has increased continuously. However, the relationshipbetween groundwater table and rainfall indicated that deficit monsoonal rainfall led to further decline in groundwater table as it was not recharged.
Key words: Groundwater table depletion, rice yield, monsoon, rainfall, Punjab

Introduction:

Punjab, which ispre dominantly an agrarian state covers only 1.5 percent of the geographical area of the country but it contributes around two third of the food grains productionof country. Highly intensive agriculture is followed inthe state which has heavy water requirement for irrigation. Due to climate variability the share of surface water resources is decreasing and dependence on ground water is increasing. On the other hand, the ground water resources are facing problem of falling water table in north-western, central, southern and south-eastern parts of Punjab. Sustainable management of groundwater resources is vital for ensuring food and water security for millions of people. The erratic monsoon rainfall and rice area are major determinants of the extent to which the water table gets recharged during the monsoon season. Rice is irrigated through tube wells which puts a lot of pressure on ground water table during deficit rainfall years. Increased energy cost for pumping and deterioration of ground water quality are indications that the water availability would emerge soon as a limiting factor even to sustain the present production levels unless remedial measures are undertaken immediately.

The Central Ground Water Board (CGWB 2017) compared the ground water level data of Punjab during pre-monsoon period of 2017 with decadal mean pre monsoon period during 2007-2016 showed that there was decline in water level in almost entire state. The decline in ground water level was observed in 75 per cent wells under analysis. Out of these, 49 per centwells showed fall in the range of 0-2 meter, 17 per cent in the range of 2-4 meter and 9 per cent showed fall in the range of more than 4 meter.Krishan *et al*(2015) revealed that in Amritsar district during monsoon season, the highest increase of 6.22 per cent in groundwater level depth was found in the Ajanala block and least increase of 0.36 per cent in Tarshika. The increase in groundwater level depth during monsoon seasons was found due to excess irrigation water requirement for rice crop and the recharging of aquifers was not speedy.The depth of ground water level at Amritsar ranges from 6.41 to 22.98 mbgl (meter below ground level) during pre-

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monsoon period and between 4.91 to 22.98 mbgl during post monsoon period (CGWB 2007). Kaur *et al*(2017) also observed average groundwater level decline of 41.6 cm/ year from 1998 to 2008 in Punjab. The rate of decline was highest (50 cm/ year) in central zone of Punjab followed by south west zone (36 cm/ year) and northeast zone (33 cm/ year). Singh *et al* (2015) indicated that in Jalandhar district (1996-2010) the average water level depth during pre-monsoon season ranges from 7.60 m to 18.69 m, whereas during post-monsoon season, the average water level depth ranges from 5.45 m to 19.30 m. The fluctuation in mean water level during pre and post-monsoon seasons was found to be -8.36 m and -8.06 m, respectively. The problem is most critical in central Punjab. The worst affected districts are Moga, Sangrur, Nawanshahar, Ludhiana and Jalandhar (Aggarwal*et al* 2009). Srivastava*et al* (2017)observedthe effect of rainfall on groundwater recharge was weaker than recharge potential of canal irrigation. Rainfall contributes only 32 per cent of total groundwater recharge due to low annual precipitation and surface water is the predominant source of groundwater recharge in Punjab. According to Asoka *et al* (2018) in the northwest and north central India, the monsoon season groundwater recharge was linked with the low-intensity precipitation while in south India high-intensity precipitation wasthe major source of groundwater recharge. They also revealed long-term changes in precipitation characteristics which showed a decline in the low-intensity rain in the northwest and northcentral India which are strongly driven by sea surface temperature over the Pacific Ocean. However,increase in the high-intensity precipitation in south India is linked with the sea surface temperatures in the Atlantic Ocean.Keeping all this in view the present investigation was carried out to study the groundwater depletion, rainfall variability and rice yield at different locations of Punjab.

Material and method:

The climate of Punjab is mainly sub-tropical, semi-arid and monsoon type. The mean annual rainfall varies between 400-1300 mm and 75 per cent of rainfall is contributed by South West Monsoon and rest by Western Disturbances. The state is divided into six agro-climatic zones on the basis of physiography, rainfall and underground water quality and quantity. In this study five different locations were taken viz. Amritsar, BallowalSaunkhri, Bathinda, Ludhiana and Patialarepresenting different agroclimatic zones (Table 1). The central plain region comprises of Amritsar, Ludhiana and Patiala.BallowalSaunkhri is located in undulating plain region and Bathinda is situated in the western region of agroclimatic zone of Punjab (Fig 1.1). Long term data (1998-2017) of meteorological parameter viz. rainfall for different locations of Punjab were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana and Regional Met Centre, IMD, Chandigarh. Rice productivity data (1998-2017) were collected from indiastat.com and Statistical Abstract of Punjab. The data (1998-2017) related to groundwater table were collected from Central Ground Water Board, Chandigarh. The fluctuation level in ground water was taken between observation in the month of June and October. The relationships between ground water table (June and October) and rainfall for all the locations were calculated and the correlation coefficient between rice yield and water table for same locations were computed.

Results and discussion:

Rice being a water loving crop has high water demand which is met by ground water in a Punjab which is 99 per cent irrigated state. Erratic rainfall has further deteriorated the condition of declining ground water level as water is not recharged in the absence of rain. The relationshipsbetween groundwater table depth, rainfall during monsoon months and rice yield from 1998-2017 at Amritsar, BallowalSaunkhri, Bathinda, Ludhiana and Patiala were computed and presentedas under:

Amritsar

At Amritsar, the highest rainfall occurred in 2008 (948.90 mm) followed by 2006 (908.00 mm) which were weak *La Nina* and weak *El Nino* years respectively(Fig.2). There was rise in ground water level from 1998 to 2005 butmonsoon rainfall was below normal as a result rice yield decreased continuously during this period. The highest rice yield was observedin 2017 (37.60 q/ha) but at the cost of ground water level which has reached 15 m deep. Groundwater level fluctuation between the two months was highest during October, 2011 with rise in groundwater table of 1.58 m. This may have occurred due to excess rainfall (19.6 per cent excess of normal).The month of June and October showed decreasing trend in groundwater level at the rate of 0.67 m per year and 0.66 m per year respectively with R^2 value of 0.78 (Table 2).The average of five years water table and rainfall data from 1998-2017 was computed to compare the changes that have occurred in different pentad at Amritsar (Table 3). During 2008-12 water table has improved by 0.32 m between June and October whereas it again decreased by 0.04 m in recent pentad (2013-17) whereas rainfall was the highest during 2013-17. Krishan *et al* (2015) also revealed that in Amritsar district during monsoon season, the highest increase of 6.22 per cent in groundwater level depth and least increase of 0.36 per cent was recorded. The increase in groundwater level depth in monsoon seasons was found due to excessive use of irrigation water for rice crop and the recharging of aquifers was not speedy.The CGWB (2007) reported that depth in water level at Amritsar ranges from 6.41 to 22.98 mbgl (meter below ground level) during pre-monsoon period and between 4.91 to 22.98 mbgl during post monsoon period.

The correlation coefficients between rice yield and ground water table difference (June and October) were negatively correlated at Amritsarbut contrary to that rice yield was positively correlated with rainfall (Table 4). It can be concluded that rice yield is more in this region when rainfall is normal during monsoon season.

BallowalSaunkhri

At BallowalSaunkhri, the highest rainfall was observed in 1998 (1216.50 mm) followed by 2011 (1087.00 mm) which were strong*La Nina* and moderate*La Nina* years (Fig.3). The fluctuation between water level of June and October was highest during 2008 (4.28 m) followed by 2011 (2.48 m). It might have occurred because rainfall during both the years was above normal (26.12 per cent in 2008 and 29.20 per cent in 2011), thus more ground water recharge would have occurred during monsoon months of these years. Ground water level from 1998 to 2005 was around 10 m deep but due to continuous rainfall deficit years and increase in rice yield there was fall in water level up to 20 m in 2008 in June. There was rise in ground water level from October 2008 to 2013 after that it again started falling and has again reached 20 m in 2017. The highest rice yield was observed in 2017 (46.94 q/ ha) but at the cost of ground water level which has reached 20 m deep besides having rainfall above normal by 5.43 per cent. Moderate and weak *El Nino* years showed more rice grain yield except 2017 which was weak *La Nina* year and deficit rainfall in monsoon months. Groundwater level in the month of June is decreasing at the rate of 0.44 m per year with R^2 value of 0.63 (Table 2). The month of October showed water level decreasing at rate of 0.51 m per year with R^2 value of 0.74.The average of five years water table and rainfall data of BallowalSaunkhri from 1998-2017 was computed to compare the changes that have occurred in different pentads (Table 3). During 2008-2012 water table has improved by 0.90 m between June and October whereas it decreased by 0.59 m during 2013-17 whereas rainfall was highest during 1998-2002. The worst affected districts are Moga, Sangrur, Nawanshahar, Ludhiana and Jalandhar (Aggarwal *et al* 2009).

Rice yield was positively correlated with water table (June- Oct) and negatively Correlated with monsoon rainfall at BallowalSaunkhri (Table 4). It might be due to the high intensity and erratic rainfall.

Bathinda

The highest rainfall occurred in 1998 (558.50 mm) followed by 2013 (526.90 mm) at Bathinda which were strong*La Nina* and neutral year(Fig.4). There was rise in ground water level from 1998 to 2005 but after that it hasgone deeper reaching up to 17 m in 2017. The highest rice yield was observed in 2017 (46.67 q/ha) but at the cost of ground water level. The fluctuation between observations taken in the month of June and October was highest in 2005 with a fall of 3.8 m even after receiving excess than normal rainfall during monsoon months. The reason behind this fluctuation could be that the rice yield has increased continuously and rainfall was below normal. During 2002 which was moderate *El Nino* year the rainfall was 40 per cent deficit, groundwater level was also high as a result rice yield decreased. Ground water level in the month of June and October are decreasing at the rate of 0.56 m and 0.57 m per year with the R^2 value of 0.84 and 0.87 respectively (Table 2).The average of five years water table and rainfall data from 1998-2017 was computed to compare the change that has occurred in different pentads (Table 3) at Bathinda. The ground water table was found to be decreasing in all pentads between month

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of June and October except during 1998-2002 when it improved by 0.18 m. The highest decrease (0.72 m) was observed during 2003-07 and rainfall was highest during 2013-17. Krishan *et al* (2015) found that during the period 2006-2013,the maximum decline in the ground water level was found in Patiala, followed by Bathinda and least decline was found in Jalandhar. They also reported that in northern parts of Punjab ground water level decreased from 0.15m to 1.80 m with an annual decrease of 0.02 m to 0.23 m.

At Bathinda rice yield was positively correlated with both water table and monsoon rainfall (Table 4) whereas the yield was heavily depended on ground water compared to rainfall as monsoon rainfall of Bathinda is very less compared to other locations of the study.

Ludhiana

At Ludhiana, the highest rise in groundwater level between June and October observationsoccurred in 2008 (1.70 m) which was a weak *La Nina*year with above normal monsoon rainfall(Fig.5). Monsoon rainfall was highest in 2011 (1157.60 mm) followed by 2008 (867.50 mm). Rice yield was highest in 2016 (48.15 q/ha) but at the cost of excessive ground water usage to meet its water requirement as rainfall during monsoon months was 17 per cent deficit.During these years the ground water level varied between 5.57 m (2005) to 19.34 m (2017). Ground water level was decreasing at the rate of 0.70 m per year in the month of June with R^2 value of 0.83 whereas; during the month of October the rate of decrease was 0.77 m per year with 0.87 as value of R^2(Table 2). The average of five years water table, rainfall and rice yield data from 1998-2017 was done to compare the change that has occurred in different pentads at Ludhiana (Table 3). The highest rise in water table between June and October month was observed during 1998-03 (0.41 m) and highest decline was during 2013-17 (0.78 m) whereas rainfall was highest during 2008-12 (769.34 mm).Srivastava *et al* (2017) observed the effect of rainfall on groundwater recharge was weaker than recharge potential of canal irrigation.

It was observed that rice yield at Ludhiana was correlated positively with water table level and negatively correlated with monsoon rainfall (Table 4).

Patiala

At Patiala, the highest rainfall was observed in 2008 (1072.90 mm) followed by 2010 (880.10 mm) which were weak*La Nina* and strong*La Nina* years (Fig.6). The fluctuation between water level of June and October was highest during 2004 (1.71 m) followed by 2003 (1.33 m). Ground water level from 1998 to 2005 was around 13 m deep. With deficit rainfall years and increase in rice yield, water level has further reached down to 29.72 m in 2017. The four rainfall deficit years didn't show any significant change in rice yield during 2017 (42.98 q/ha) but ground water level was affected as it reached 29 m deep. The higher grain yield was obtained mostly in *LaNina* years. Groundwater level in the month of June was found to be decreasing at the rate of 1.19 m per year with R^2 value of 0.94. The month of October showed water level decreasing at rate of 1.23 m per year with R^2value of 0.95(Table 2). The average of five years water table and rainfall data from 1998-2017 was calculated to compare the changes that has occurred in different pentads (Table 3) at Patiala. The highest rise in water table between June and October month was observed during 2003-2007 (0.07 m) and the highest decline occurred during 2013-17 (0.46 m) whereas rainfall was highest during 2008-2012 (754.78 mm).

Water table showed positive correlation with rice yield and negative correlation with monsoon rainfall at Patiala (Table 4).

Conclusion:

It can be concluded that monsoon plays an important role in recharging of aquifers. In the absence of good amount and intensity of rainfall ground water level further decreases. It can be concluded that ground water table was decreasing at different rates at all the locations of Punjab both in June and October even when rainfall during monsoon season was above normal. The rise in ground water level was observedonly when there was sufficient amount and intensity of rainfall during monsoon months.

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Tables

Table 1 Period of study and coordinates of different locations of Punjab

Location	Period of study	Latitude	Longitude	Height above mean sea level (m)
Amritsar	1998-2017	31°63’N	74°87’	234
BallowalSaunkhri	1998-2017	31°09’N	76°38’	355
Bathinda	1998-2017	30°21’N	74°94’	207
Ludhiana	1998-2017	30°54’N	75°48’	247
Patiala	1998-2017	30°33’N	76°38’	258

Table 2 Rate of change per year in ground water level during June and October month along with rainfall from 1998-2017

Location	June water table (m)	October water table (m)	Total Rainfall (mm)
Amritsar	Y= -0.67X -2.844 R^2 = 0.79	Y= -0.66X -2.574 R^2 = 0.79	Y = 9.34X + 433.8 R^2 = 0.09
Ballowalsaunkhri	Y= -0.44X-10.03 R^2 = 0.63	Y= -0.51X-9.009 R^2 = 0.74	Y= -9.95X + 863.4 R^2 = 0.07
Bathinda	Y = -0.56X-3.83 R^2 = 0.85	Y = -0.57X-3.91 R^2 = 0.87	Y = 2.02X + 333.0 R^2 = 0.01
Ludhiana	Y= -0.70X-4.78 R^2 = 0.83	Y = -0.77X-4.14 R^2 = 0.87	Y = -1.38X+596.4 R^2 = 0.01
Patiala	Y = -1.19X-6.10 R^2 = 0.94	Y = -1.23X-5.87 R^2 = 0.95	Y = -3.36X+599.9 R^2 = 0.01

Table 3Ground water table and monsoon rainfall at different locations of Punjab

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Pentad	Avg. June water table (m)	Avg. Oct. water table (m)	Avg. rainfall (mm)
Amritsar			
1998-2002	5.34	5.02	456.44
2003-2007	6.94	6.62	508.44
2008-2012	13.01	12.69	533.38
2013-2017	14.33	14.05	629.58
BallowalSaunkhri			
1998-2002	11.18	10.29	923.58
2003-2007	13.28	14.03	598.50
2008-2012	17.03	14.95	793.54
2013-2017	17.42	18.28	720.08
Bathinda			
1998-2002	6.33	6.15	339.38
2003-2007	7.11	7.83	343.42
2008-2012	11.25	11.31	327.20
2013-2017	14.43	14.61	411.08
Ludhiana			
1998-2002	7.62	7.20	575.08
2003-2007	8.77	9.00	479.32
2008-2012	15.15	14.83	769.34
2013-2017	17.32	18.10	504.12
Patiala			
1998-2002	10.43	10.36	565.86
2003-2007	13.98	14.39	450.52
2008-2012	22.82	22.86	754.78
2013-2017	26.78	27.24	485.35

Table 4 Correlation coefficient of rice yield with water table difference and rainfall at different locations

Location	Water table (June- October)	Monsoon Rainfall
Amritsar	-0.22	0.06
Ballowalsaunkhri	0.17	-0.45
Bathinda	0.16	0.01
Ludhiana	0.46	-0.24
Patiala	0.25	-0.15

Figures

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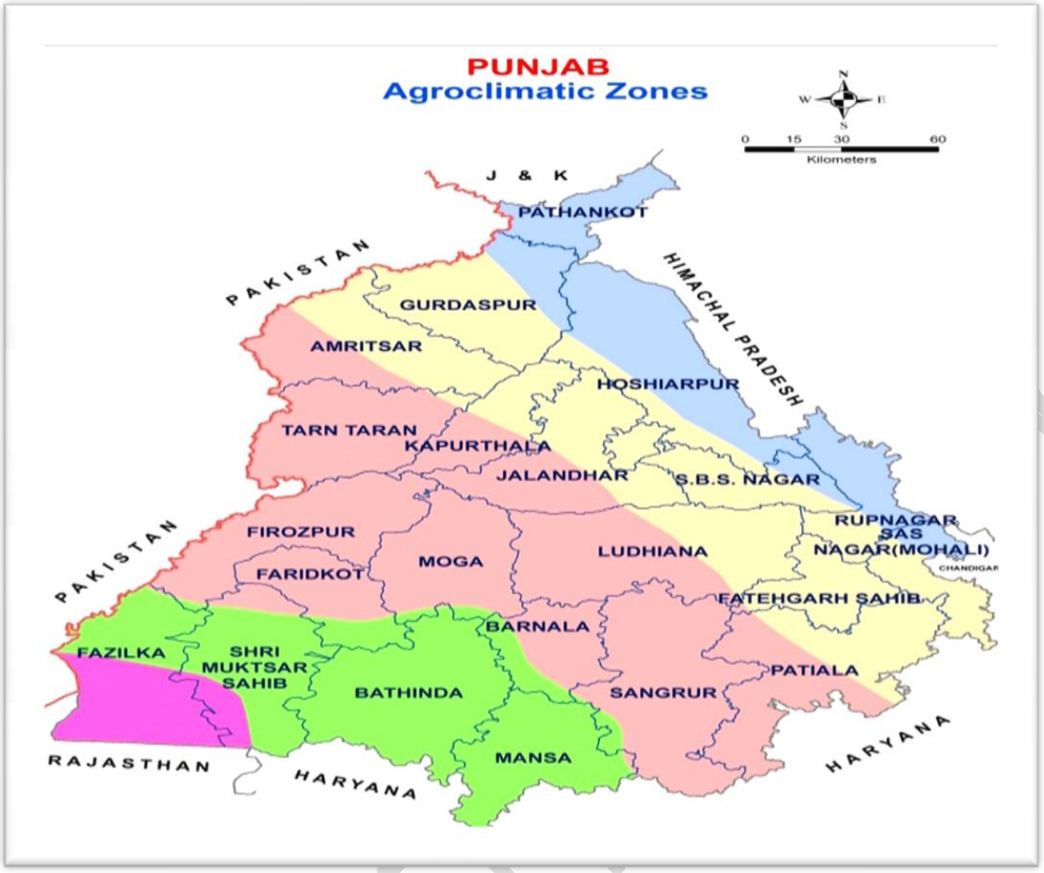

Fig. 1 Map of different agro-climatic zones of Punjab.

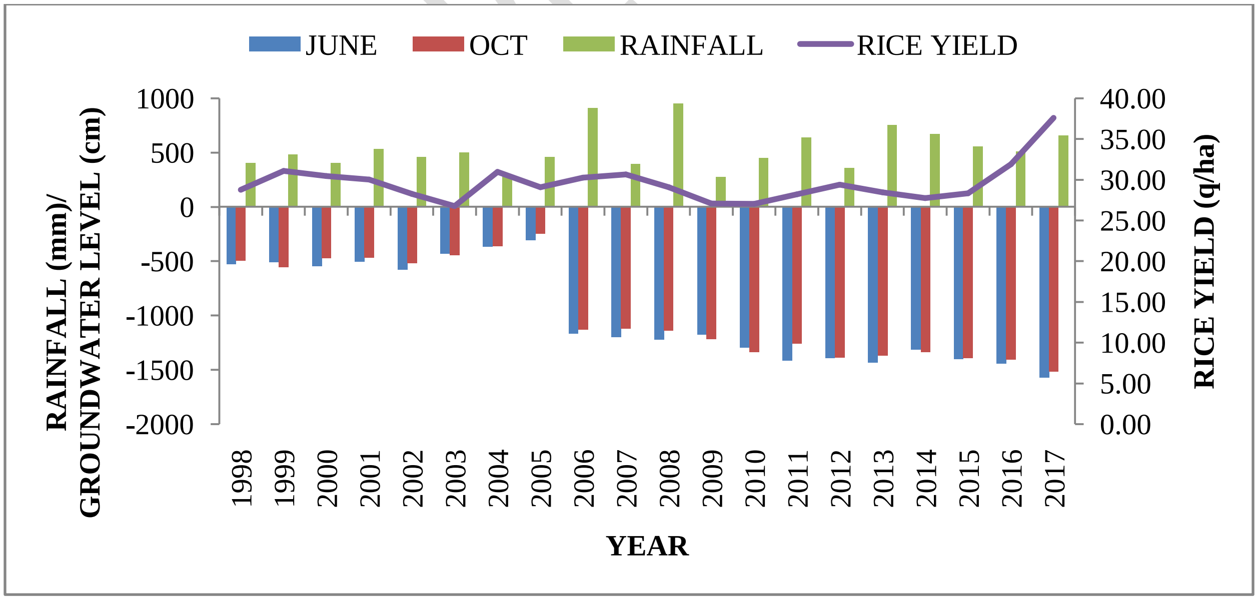

Fig. 2 Relationship of monsoon rainfall with groundwater level and rice productivity at Amritsar

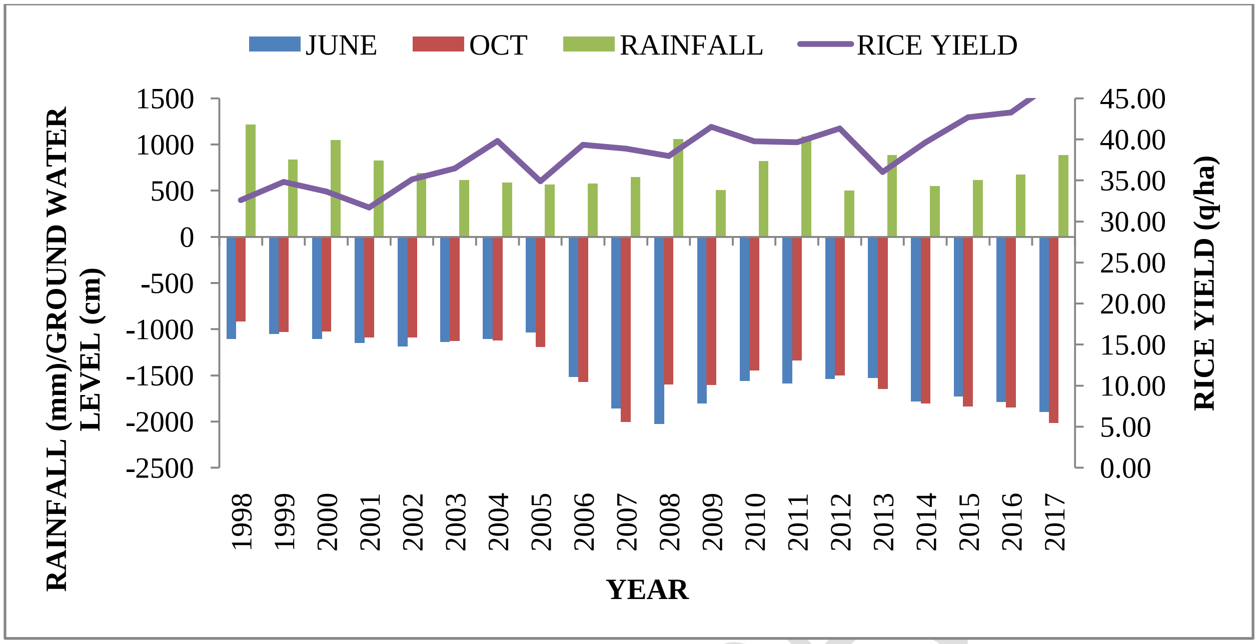

Fig. 3 Relationship of monsoon rainfall with groundwater level and rice productivity at BallowalSaunkhri

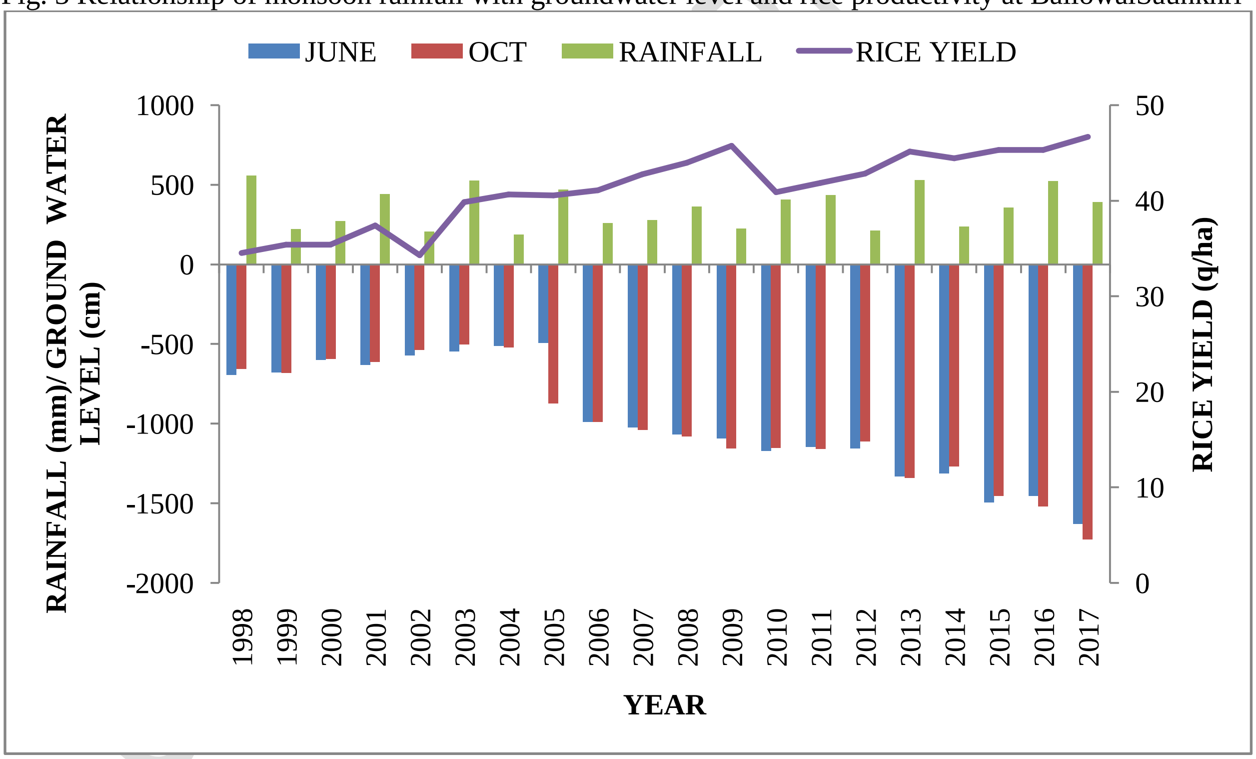

Fig. 4 Relationship of monsoon rainfall with groundwater level and rice productivity at Bathinda

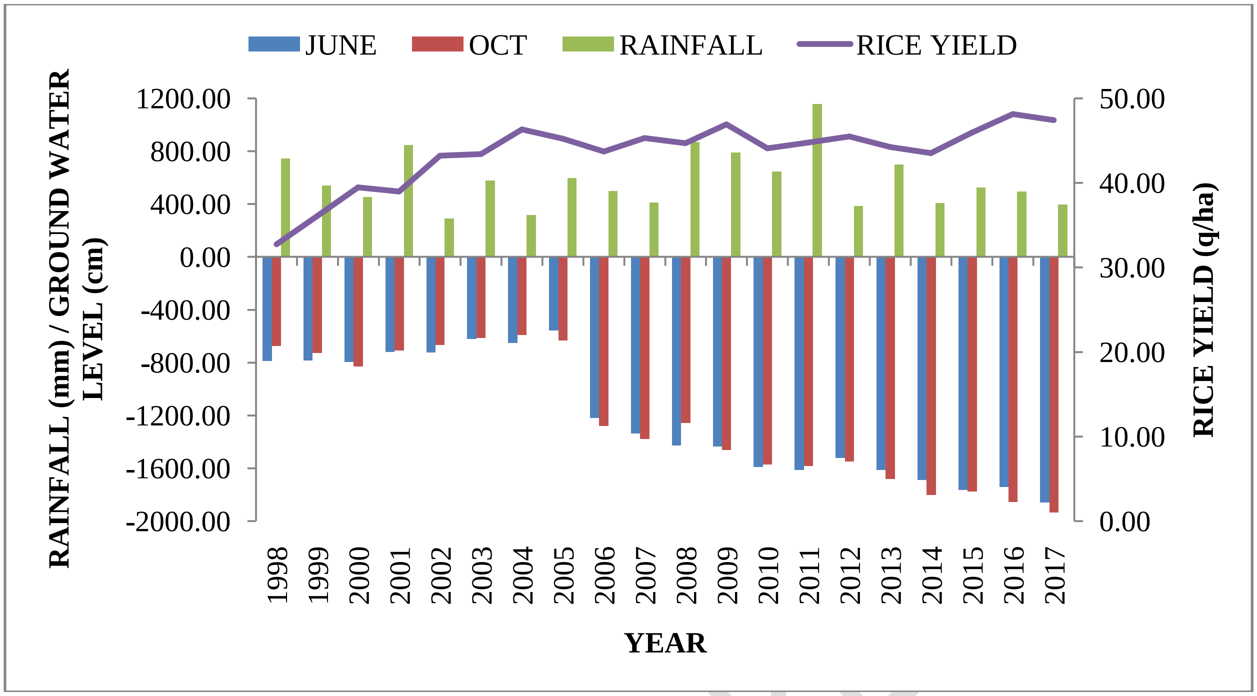

Fig. 5 Relationship of monsoon rainfall with groundwater level and rice productivity at Ludhiana

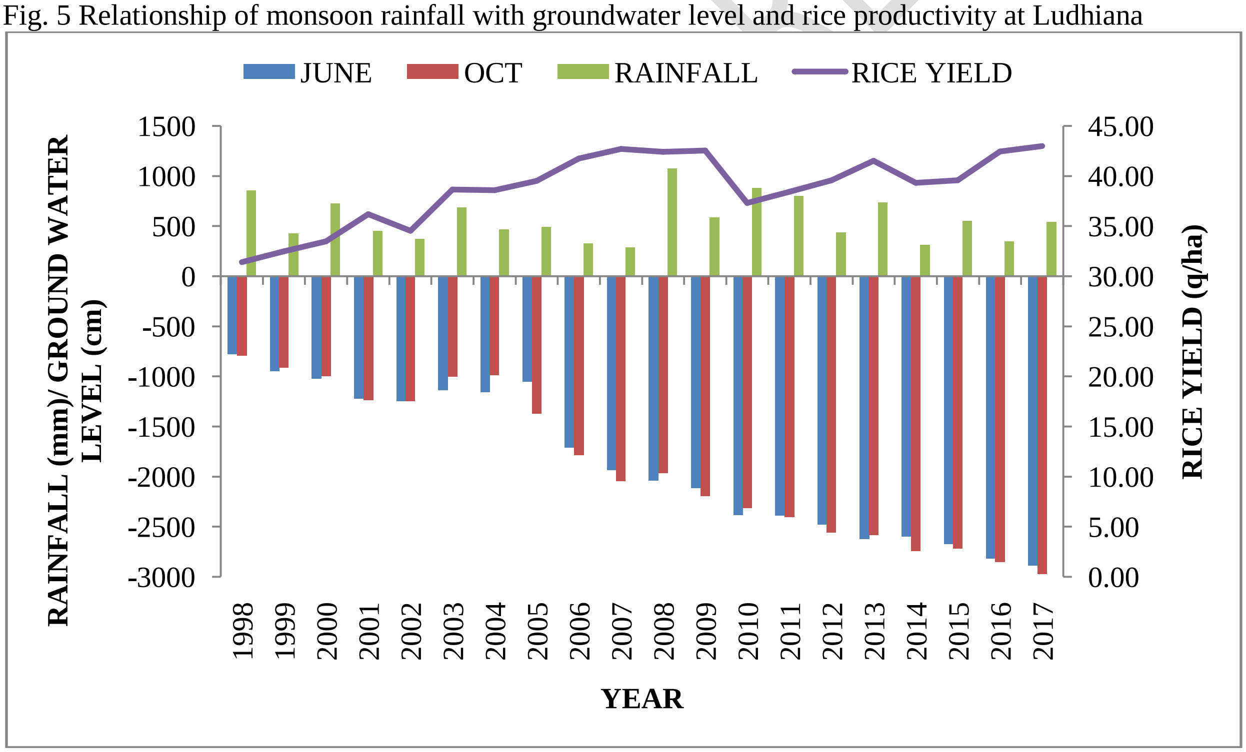

Fig. 6 Relationship of monsoon rainfall with groundwater level and rice productivity at Patiala