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ASSESSING CURRENT AND FUTURE RISK TO GROUNDWATER DUE TO CLIMATE CHANGE IN A SUGARCANE GROWING AREA

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1.0 INTRODUCTION

Water plays a crucial role in every day-to-day life for animals as well as plants. Due to increase in population, urbanization and industrialization, the demand of water is increasing continuously. As India is an agrarian and developing country, the water consumption in agriculture sector is much higher than the other sectors. Agriculture alone consumes about 83% of the available water (Mall *et. al.*, 2006). Further, due to topographical constraints leading to uneven distribution of water resources, only a part of potential surface water is effectively used in agriculture. So to fulfill the agricultural water demand, groundwater is exploited in each and every corner of India. Presently the share of groundwater in irrigation is about 62 % which is likely to increase in future years for achieving the national target of food production (CGWB, 2017).

The stage of groundwater development in India is about 62 % (CGWB, 2017) which indicates that there is further scope for development. But the development is not uniform due to undulating topography, varying aquifer system, uneven distribution pattern of rainfall, climatic condition and varying in purpose of water demand. In some parts of the country, the present stage of development is more than 100 % and these areas are categorized as over exploited areas where the replenishment is necessary. The over-exploited areas are mostly concentrated on three parts of the country. In the north western part in Punjab, Haryana, Delhi, Western UttarPradesh where though replenishable resources is abundant but there have been indiscriminate withdrawals of groundwater leading to overexploitation. In western part of the country, particularly in Rajasthan, Gujarat where due to arid climate, groundwater recharge itself is less leading to stress on the resource and in peninsular India like Karnataka, Andhra Pradesh and Tamil Nadu where due to poor aquifer properties, ground water availability is less (CGWB, 2017).

Climate change is a spontaneous process on earth surface that can never be controlled completely. But the extent of change, cause and the effect can be minimized by adopting suitable measures. The projected climate change resulting in warming of atmosphere, melting of ice and glaciers, and uneven distribution of rainfall pattern adversely affect the water balance of the country. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] ^{0}C over the period 1880 to 2012 (IPCC, 2014) (Fig. 1). The warming of atmosphere causes the melting of polar glaciers that leads to rise of sea level. Over the period 1901 to 2010, global mean sea level rose by 0.19 m (Fig. 2). The rise of sea level results in saline groundwater in costal aquifers, detoriates the surface water quality, flooding at coast and degrades the arable land. The climate change affects the groundwater both in quantitatively and qualitatively. The decline in snow melt runoff may seriously affect the recharge of groundwater causing shortage of water availability in Punjab, Haryana, Rajasthan and Uttar Pradesh. India will experience a high frequency of occurrence of extreme events (flood, cyclone, unseasonal excessive rains and drought etc.) in the coming years.

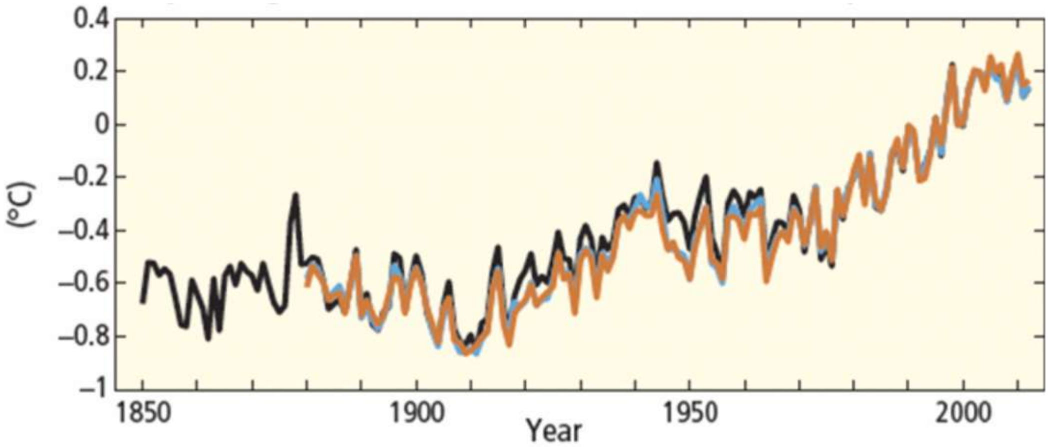

Fig 1: Change in globally averaged combined land and ocean surface temperature (IPCC, 2014). Colours indicate different data sets

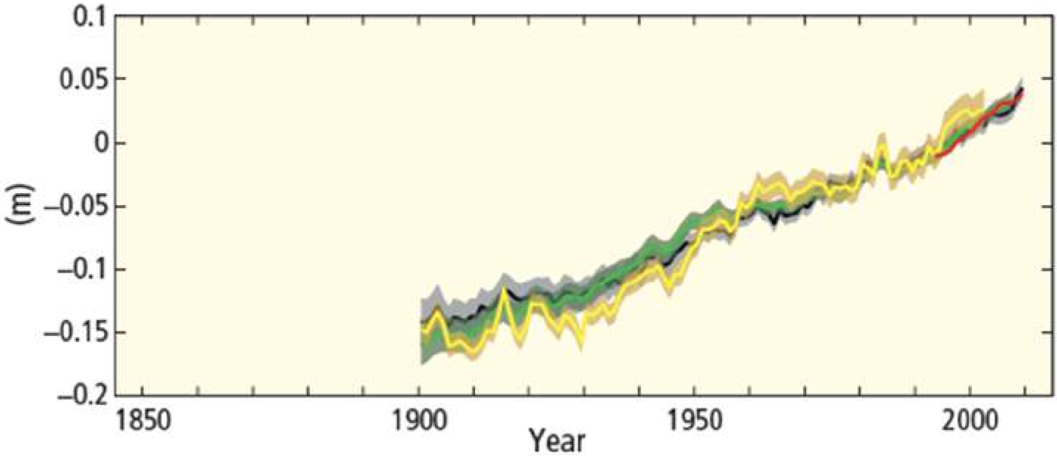

Fig 2: Change in global averaged sea level (IPCC, 2014). Colours indicate different data sets.

The climate change leads to increase the competition for land and water with rise in population, urbanization and industrialization. It has an adverse effect on agriculture. India being a large country with diverse agro-climatic regions is highly vulnerable especially in view of huge population dependent on agriculture. Climate change is a major challenge being faced by Indian agriculture. A 1˚C increase in atmospheric temperature in areas like Uttar Pradesh, Punjab and Haryana could cause a loss of about seven million tonnes of wheat annually and also the yield of other crops such as paddy, millet and maize could decrease up to 10 percent. Also 1˚C rise in temperature may reduce yield of wheat, soybean, mustard, groundnut and potato by 3–7 % (IPCC, 2014). So different adaptive measures needs to taken for reducing the impact of climate change on agriculture.

The objective of the present study is to analyze the present water balance based on the prevailing climatic conditions and evaluation of future projections of water budget due to climate change in the study village which is predominantly grown with sugarcane crop. As groundwater is the primary source of water for the study village, the area is affected with the problem of decline of groundwater table at an alarming rate. Further, due to climate change the requirement of water would increase in the agriculture sector. Therefore, in the present study emphasis was given on the efficient management the available water sources. In order to assess the requirement of irrigation water and the associated risk, the present water budgeting of study village was carried out. The climate change has an adverse effect on the water resources. In the event of climate change, the future climatic parameters were predicted and analyzed. Based on the different implemented interventions such as underground pipe conveyance system, drip and rain-gun system, recharge cavities and area under different crops, several scenarios were conceptualized and analysis was made. The future projections on water demand in agriculture & domestic sector, groundwater availability and its utilization due to climate change were assessed for different scenarios. The study gives a brief knowledge about the availability, crisis and management of water in the study area and will certainly be helpful in minimizing the impact of climate change on water management in agriculture.

2.0 STUDY AREA

The study village is situated in the state of Uttar Pradesh, India which is known as Rasulpur Jattan. It is located in Shahpur block of Muzaffarnagar district and situated in the inter basin of Kali river in the west and Hindon river in the east. Muzaffarnagar is a square shaped district, lies between 29^{0} 11' 30'' and 29^{0} 45' 15'' N latitude and between 77^{0} 3' 45'' and 78^{0} 7' E longitude with average elevation of 232 meters above msl (Fig. 3). The district is covered by river Ganges in the east and Hindon almost in the west. The district is situated in the doab of the Ganges and the Yamuna, surrounded by district of Meerut in south, Saharanpur and Haridwar in north, Bijnor in east and Shamli in west. The climate of the district is characterized as hot dry sub humid with average annual rainfall of 750 mm. About 85 % of the annual rainfall occurs in the period of July to October (monsoon season). August is the wettest month in the year. The period from November to February is the cold weather season where the temperature fluctuates between 5^{0}C to 25^{0}C. The month from March to June experiences the season of summer where temperature fluctuates between 30^{0}C to 43^{0}C. Agriculture is the main backbone of the economy of the district. Around 63 % of population depends on the agriculture as its main occupation. As being one of the highest sugarcane producers in the country, the district is also known as "Sugar bowl of India". The major rivers of the district are Ganga, Solani, Hindon and Kali. The district is one of the highly developed districts privileged with the Ganga canal system. The average irrigation intensity of the district is 151.4 %. Besides the Ganga canal system, the irrigation is also met by groundwater. Due to indiscriminate use of groundwater in some areas, the groundwater level declines alarmingly (around 1.0 m per year) in threes blocks (Shahpur, Budhana, Baghra) out of nine blocks of the district and the blocks are declared as the over exploited blocks or dark zone.

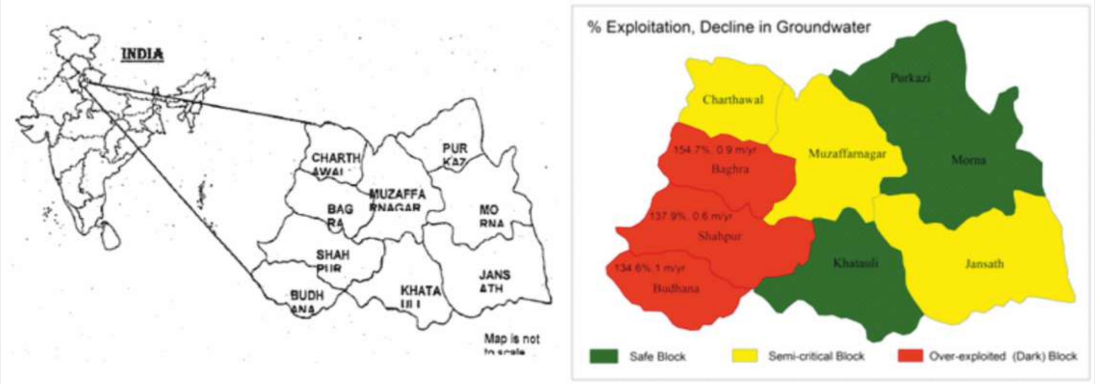

Fig 3: Location of Muzaffarnagr district, Uttar Pradesh, India

The study village Rasulpur Jattan comes under Shahpur block, covers about 300 ha of geographical area situated at 29.22^0 N latitude and 77.34^0 E longitude with elevation of 241 m above msl. The present population of the village is about 3730 and number of families is about 297. The soil of the village is of sandy alluvium. The village is agrarian. Livestock rearing is 100 % and cattle and buffalo are main livestock. Out of 300 ha of geographical area of the village, 267 ha is the cultivated area. The land holdings per family vary from 0.5 acres to 6 acres. The main source of income for the 98.82 % of families of the village is from agriculture. Ground water is the main source of water resource to meet the daily requirement for domestic as well as agricultural purpose as there is no canal network available in the village. Most of the families have their personal water pumpsets. About 67.05 % families have submersible pumpsets, 30.58 % have hand pumps for extraction of groundwater. There is lack of exposure to scientific knowledge and information to the farmers about agriculture as well as various aspects of livestock production. Farmers of the village follow traditional practices for crop cultivation and irrigation.

3.0 MATERIALS AND METHODS

3.1 Water Budgeting of Rasulpur Jattan Village

3.1.1 Analysis of climatic data

The long-term monthly climatic data such as rainfall, maximum temperature, minimum temperature, average temperature, dew point temperature, relative humidity, wind speed, average top-of-atmosphere insolation and average insolation incident on a horizontal surface for 33 years (1983–2015) for study village was downloaded from the website https://power.larc.nasa.gov/cgibin/agro.cgi and analyzed.

3.1.2 Groundwater table depth scenario

The groundwater table data in pre monsoon and post monsoon period for last 7 years (2007–2013) is obtained from an observation well near the study village. As there is no observation well present in the study village, the data taken in a well of the nearby village Kakda (lat 29^0 22' 37'' N and long 77^0 34' 13'' E) were used for Rasulpur Jattan. The groundwater level in the well was monitored during the month of May (pre-monsoon) and November (post-monsoon) to study the impact of rainfall on groundwater regime.

3.1.3 Groundwater balance

As there is no surface water source in the village, only groundwater balance for the village was carried out. The groundwater balance can be expressed as

$$(R + G_{in}) - (G_{out}) = \Delta S \qquad (1)$$

Where, R is the recharge from rainfall, G_{in} is the water inflow into the village aquifer system other than rainfall, G_{out} is the water outflow from the aquifer system or water pumped out for different purposes and ΔS is the change in groundwater storage in the village aquifer system for the period under consideration.

3.1.3.1 Estimation of natural groundwater recharge (R)

Rainfall is the purest form of fresh water that occurs naturally on the earth surface throughout the year. Some parts of rainfall gets recharged through the ground surface and increases the groundwater table. Significant amount of groundwater recharging takes place during monsoon from the rainfall as about 80% rainfall occurs in monsoon. The groundwater recharge for the entire village during monsoon is estimated by water table fluctuation (WTF) method. The water table fluctuation method (GEC, 1997) can be expressed as

$$R_M = h * S_y * A \qquad (2)$$

Where, R_M is the recharge in monsoon season (cum), h is the change in groundwater table due to monsoon rainfall (m),$S_y$is the specific yield of the aquifer which is considered for our analysis purpose as 0.16 for alluvium formation (GEC, 1997), and A is the area for computation of recharge (m^2) or the area of the village.

Apart from the monsoon recharge, a portion of the rainfall occurring in the non-monsoon period also recharges the groundwater. This amount of recharge may be estimated based on the rainfall infiltration factors provided rainfall in the non-monsoon season is greater than 10% of the normal annual rainfall. If the rainfall is less than this threshold value, the recharge due to rainfall in the non-monsoon season may be considered as zero.

Recharge from rainfall in non-monsoon season is given by

$$R_{NM} = f \text{ x } A \text{ x Average annual non-monsoon rainfall} \qquad (3)$$

Where, A is the area of computation for recharge (area of the village) and f is the rainfall infiltration factor which is taken as 0.25 for alluvium soil (GEC, 1997).

3.1.3.2 Water inflow other than rainfall (G_{in})

Water flow into the groundwater system other than rainfall includes irrigation return flow from the crop field as there is no surface water storage structures. The irrigation return flow in monsoon season is not considered here separately as this component is already taken care by the water table fluctuation method in addition to the recharge from monsoon rainfall. So the return flow from the irrigation water was considered in non-monsoon season which is expressed as the 30% of the water delivered at the outlet from groundwater source (GEC, 1997).

3.1.3.3 Groundwater outflow (G_{out})

Water flow from the groundwater storage includes groundwater pumping for domestic, livestock and irrigation utilization purposes in the village.

(i) Groundwater pumping for domestic purpose: The annual groundwater draft for domestic purpose (GW_D) can be estimated by multiplying the average water requirement per person per day to the number of population and number of days in a year. The per capita daily water requirement in rural areas and the population of the village are taken as 80 litres/day and 3730, respectively.

(ii) Groundwater pumping for livestock purpose: The annual water consumption for different livestock's was estimated by considering the number of population of each livestock and the per capita daily water requirement for that livestock. The present population of cow, buffalo and pig in the village are 250, 800 and 40, respectively (Krishi Vigyan Kendra, 2014) and their daily per capita water consumptions are 35, 65 and 25 litres/day, respectively (Anonymous, 2016).

(iii) Groundwater pumping for irrigation purpose

A questionnaire survey was conducted for 30 farmers (sample size) in the village Rasulpur Jattan. Data on prevailing cropping pattern, horse power of pump sets, number of pumps used for irrigation, number of irrigations required for different crops and duration of each irrigation for different crops etc. were collected.

The total cultivated area and gross cultivated area of the village are about 267 ha and 402 ha, respectively. Out of total cultivated area, sugarcane is cultivated in about 63% of the area that is about 168 ha. Besides sugarcane, cereals such as paddy and wheat; pulses such as black gram; oil seeds such as mustard; and fodder crops such as sorghum and berseem are also grown. These crops are grown in three different seasons i.e. *kharif*, *rabi* and *zayad*. But sugarcane is cultivated throughout the year. The sorghum and berseem are grown almost in 0.5 acre/family and 0.17 acre/family, respectively. In a year, wheat is cultivated in 80 ha, paddy in 47 ha, black gram in 20 ha, mustard in 8 ha, sorghum in 59 ha and berseem in 20 ha (Table 1).

Table 1 : Area under different crops in Rasulpur Jattan

Sl. No.	Crop	Gross cultivated area, ha
1	Sugarcane	168
3	Paddy	47
2	Wheat	80
4	Sorghum	59
5	Black gram	20
6	Mustard	8
7	Berseem	20
Total		**402**

The discharge from a 10 hp was recorded in the field in the survey period. Using the discharge data of 10 hp pumpset, the discharge for other pumps i.e. 1.5 hp, 7.5 hp, 12 hp, 12.5 hp and 15 hp were estimated using the following relation:

$$\frac{Q}{Q_1} = \sqrt[3]{\frac{P}{P_1}} \qquad (4)$$

Where, Q & Q_1 are pump discharges (litres/second), and P & P_1 are power of the pump (hp). The weighted average discharge of the pump was calculated. This weighted average discharge of the pump was used along with the time, frequency of irrigation and cultivated area under different major crops (sugarcane, paddy, wheat, black gram, mustard, sorghum and berseem) to calculate the annual groundwater pumping for irrigation purpose.

3.1.3.4 Change in storage: The net change in groundwater storage of the village is computed by differentiating the annual water discharge from annual water recharge. It gives a brief idea about the extent of groundwater exploitation in the study village.

3.1.4 Estimation of annual irrigation water demand for major crops

The annual irrigation water demand for the major crops of the village is calculated using climatic and crop parameters. The ET_{crop} was estimated by multiplying reference evapotranspiration with crop coefficients. For all other crops except paddy, ET_{crop} is considered as crop water requirement. In case of paddy, about 200 mm of water is added (for puddling and nursery raising)to its ET_{crop} to compute the crop water requirement of paddy. The irrigation water requirement for all the crops are estimated by deducting the effective rainfall from the crop water requirements.

3.1.4.1 Calculation of effective rainfall

There are several methods to calculate the effective rainfall from the average annual rainfall. In the present study, USDA SCS (U. S. Department of Agriculture's Soil Conservation Service) method (Dastane, 1978) is used. Here, the effective rainfall is a function of the mean monthly rainfall and mean monthly consumptive use as shown in Table 2.

Table 2 : Calculation of effective rainfall from monthly mean rainfall and mean monthly consumptive use

Monthly mean rainfall, mm	Mean monthly consumptive use, mm													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Mean monthly effective rainfall, mm													
12.5	7.5	8.0	8.7	9.0	9.2	10.0	10.5	11.2	11.7	12.5	12.5	12.5	12.5	12.5
25.0	16.2	17.5	18.0	18.5	19.7	20.5	22.0	24.5	25.0	25.0	25.0	25.0	25.0	25.0
37.5	22.5	24.0	26.2	27.5	28.2	29.2	30.5	33.0	36.2	37.5	37.5	37.5	37.5	37.5
50.0	25	32.2	34.5	35.7	36.7	39.0	40.5	43.7	47.0	50.0	50.0	50.0	50.0	50.0
62.5	At 41.7	39.7	42.5	44.5	46.0	48.5	50.5	53.7	57.5	62.5	62.5	62.5	62.5	62.5
75.0		46.2	49.7	52.7	55.0	57.5	60.2	63.7	67.5	73.7	75.0	75.0	75.0	75.0
87.5		50.0	56.7	60.2	63.7	66.0	69.7	73.7	77.7	84.5	87.5	87.5	87.5	87.5
100.0		At 80.7	63.7	67.7	72.0	74.2	78.7	83.0	87.7	95.0	100	100	100	100
112.5			70.5	75.0	80.2	82.5	87.2	92.7	98.0	105	111	112	112	112
125.0			0.75	81.5	87.7	90.5	95.7	102	108	115	121	125	125	125
137.5			At 122	88.7	95.2	98.7	104	111	118	126	132	137	137	137
150.0				95.2	102	106	112	120	127	136	143	150	150	150
162.5				100	109	113	120	128	135	145	153	160	162	162
175.0				160	115	120	127	135	143	154	164	170	175	175
187.5					121	126	134	142	151	161	170	179	185	187
200.0					125	133	140	148	158	168	178	188	196	200
225.0					At 197	144	151	160	171	182				
250						150	161	170	183	194				
275						At 240	171	181	194	205				
300							175	190	203	215				
325							At 287	198	213	224				
350								200	220	232				
375								At 331	225	240				
400									At 372	247				
425										250				
										At 412				
450	25	50	75	100	125	150	175	200	225	250				

3.1.5 Annual change in groundwater table due to exploitation of groundwater

The annual drop or rise in depth of groundwater reservoir in the village due to change in groundwater storage can be estimated by using the following formula (Raghunath, 1987):

Change in storage = Area of the village * Drop / Rise in groundwater table * specific yield

The change in water table depth can be found out using the above equation.

3.2 Future projection for Rasulpur Jattan in the event of climate change

3.2.1 Future projections of climatic data for Rasulpur Jattan village

Agriculture being the major consumer of water, the future projections on the water demand for the study village was focused on agriculture sector only. In order to predict the future water demand in agriculture, the predicted future climatic data on daily rainfall, maximum temperature, minimum temperature and solar radiation on earth's surface were collected from the MarkSim Global Climate Model (GCM) at Representative Concentration Pathway (RCP) - 4.5 for the years of 2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090 using the model developed at Geophysical Fluid Dynamics Laboratory (GFDL) – Global Coupled Model-CM3.

MarkSim GCM is a tool to generate daily data that are characteristic (to some extent) of future climatic parameters for any point on the globe, to drive agricultural impact models. It is a web-based tool that uses downscaling and data generation methods with an user interface in Google Earth (http://gismap.ciat.cgiar.org/MarkSimGCM/) and provides the user with daily weather data for current and future climatology, which can then be used directly to run some widely-used crop models. MarkSim is a spatially explicit daily weather generator that was developed at International Centre for Tropical Agriculture (CIAT) and was released in 2004. For any location, MarkSim makes use of a climate record. MarkSim typically calculates daily precipitation first and then uses this information to guide the other weather variables such as daily solar radiation, maximum temperature and minimum temperature. It estimates daily maximum and minimum air temperatures and daily solar radiation values from monthly means of these variables (Jones et. al., 2013). There are 17 Global Climate Models available in MarkSim GCM. In the present study, Geophysical Fluid Dynamics Laboratory (GFDL) – Global Coupled Model-CM3 is selected to download the future climatic data for Rasulpur Jattan village.

Representative Concentration Pathway (RCP)-4.5 was developed by the GCM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radioactive forcing is stabilized shortly after 2100, without overshooting the long-run radioactive forcing target level (Wayne, 2013). The radioactive forcing will be 4.5 W/m^2 post 2100 and emission concentration will be carbon dioxide equivalent 650 ppm. It is medium emission scenario where carbon dioxide emission increases slightly before decline commences around 2040, stabilize the methane emission, strong reforestation pragrammes are taken and the use of crop lands and grass lands are decreasing due to increase in yield and dietary changes. The temperature in this scenario rises faster until mid-century and slows down afterwards.

3.2.2 Analysis of future climatic parameters

The daily predicted climatic data such as rainfall, maximum temperature, and minimum temperature for different years (2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090) were obtained from MarkSim model and analyzed.

The climatic parameter reference evapotranspiration plays a crucial role in water demand for the crops. So the reference evapotranspiration was computed by using future data of temperature and solar radiation, through Hargreaves equation(Michael, 2007), expressed as follows:

$$ET_0 = 0.0023\,(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}R_a \quad (5)$$

Where, $ET_0$is the reference evapotranspiration (mm/day), $T_{mean} = (T_{max} + T_{min})/2$, T_{max} is the daily maximum temperature (°C), T_{min} is the daily minimum temperature (°C), and R_a is the extraterrestrial radiation (mm/day).

The solar radiation data that obtained from MarkSim model is the occurrence of solar radiation on earth surface which needs to be converted to extraterrestrial radiation by using the following relationship,

$$R_s = K\,(T_{max} - T_{min})^{0.5}R_a \quad (6)$$

Where, R_s is the solar radiation on earth surface ($MJ/m^2/day$), R_a is the extraterrestrial solar radiation ($MJ/m^2/day$), and K is the adjustment coefficient (an empirical value = 0.16 for interior regions where land mass is predominant and air masses are not significantly influenced by a large water body like sea or ocean or large lake). The unit of extraterrestrial solar radiation (R_a) that is used in the equation (5) is converted from $MJ/m^2/day$ to mm/day by multiplying a conversion factor 0.408.

3.2.3 Analysis of impact of climate change in groundwater stabilization

As groundwater is the only source of water for use in domestic as well as irrigation purpose in Rasulpur Jattan village, there is a need for sustainable use of groundwater. Based on the future predicted climatic data and the irrigation water requirement for crops, the groundwater balance for the village was carried out for the future years (2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090) using the above mentioned mass balance equation (equation 1). The groundwater balance for these years and the change in groundwater storage due to climate change for the study village was estimated.

3.2.3.1 Recharge from rainfall (R): The rainfall recharge to groundwater includes recharge in monsoon season and non-monsoon season. As per the recommendation of Central Groundwater Board (CGWB), monsoon recharge is generally estimated using the groundwater table fluctuation data of pre- and post-monsoon season, and non-monsoon recharge from rainfall data. But due to non-availability of future predicted data on groundwater table, the annual recharge was estimated by using the rainfall infiltration factor method, considering rainfall data.

3.2.3.2 Water inflow other than rainfall (G_{in}): Water flow into the groundwater system other than rainfall includes irrigation return flow from the cropped field as there are no surface water storage structures available in the village. As per the recommendation of CGWB, the return flow from the irrigation water may be estimated as follows:

(a) From paddy field: 35% of the water delivered at outlet from groundwater source is taken as return flow.

(b) From the crop field other than paddy: 30% of the water delivered at the outlet from groundwater source is taken as return flow.

3.2.3.3 Artificial recharge through recharge cavity well: The groundwater is artificially recharged through the recharge cavity well. Two recharge cavity wells were installed at the study village having 9'' (22.5 cm) diameter and the depth of 135-145 ft to180-190 ft. The recharge is considered to occur only during monsoon season of four months (120 days) in a year when enough water is available near the cavity well for recharge.

3.2.3.4 Groundwater outflow (G_{out}): Water flow from the groundwater storage includes groundwater pumping for domestic, livestock and irrigation purposes.

(i) Groundwater pumping for domestic utilization: The annual groundwater draft for domestic purpose will change on the basis of number of population of the village. But the number of population is assumed to be constant in future years.

(ii) Groundwater pumping for livestock utilization: The water consumption for livestock population of the village is kept constant in future years as negligible change in their population is expected.

(iii) Irrigation water requirement for major crops: The water consumption in agriculture sector will be changed in future years due to the effect of climate change. That's why there is a need for efficient utilization of water in this sector. The irrigation water demand was assessed for different scenarios keeping in mind to choose the best scenario for maintaining sustainable use of groundwater.

The crop water requirement and the irrigation water requirement for the major crops (sugarcane, wheat, paddy, sorghum, black gram, mustard and berseem) grown in Rasulpur Jattan village were estimated using the predicted reference evapotranspiration of future years and stage wise crop coefficient values of respective crops. The irrigation water requirement was computed by deducting the effective rainfall value from crop water requirement. The effective rainfall was calculated by using USDA SCS (U. S. Department of Agriculture's Soil Conservation Service) method (Dastane, 1978).

Initially, five different scenarios were conceptualized considering demand side management i.e., area under different crops, provision of underground pipeline conveyance system, use of improved irrigation application methods such as drip and raingun etc. for assessment of the future water demand in agriculture for the study village for different years (2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090). Subsequently, two more scenarios were conceptualized considering supply side management i.e., use of recharge cavities for recharging groundwater in the village. The irrigation water demand for the scenario 6 and scenario 7 remains same as that of scenario 4 and scenario 5, respectively. The scenarios considered are as follows:

(a) **Scenario 1:** Business As Usual (BAU)

(b) **Scenario 2:** 50 % reduction of sugarcane cultivated area.

(c) **Scenario 3:** 50 % of total cultivated area is considered having provision of underground pipeline conveyance system and improved irrigation methods (drip and raingun system).

(d) **Scenario 4:** It is combination of scenario 2 and 3, where the sugarcane cultivated area is reduced by 50 %, and 50 % of total cultivated area is considered to have conveyance pipeline system and improved irrigation methods such as drip and raingun system.

(e) **Scenario 5:** 100% sugarcane cultivated area is considered to be provided with underground conveyance pipeline system and improved irrigation methods (drip and raingun system).

(f) **Scenario 6:** It is the combination of scenario 4 along with provision of recharge cavity wells of different densities.

(g) **Scenario 7:** It is the combination of scenario 5 along with provision of recharge cavity wells of different densities.

(a) Scenario 1: In this scenario of Business As Usual (BAU), the existing area under different crops and the prevailing irrigation practices are assumed to be continuing in future. Therefore, the present cultivated area under different crops (Table 3), supply of irrigation water from the pumping unit to the crop field through open earthen channel and the flooding irrigation practice are considered for the estimation of future crop water requirement and irrigation water requirement for the study village.

Table 3 : Area under different crops at Rasulpur Jattan village

Sl. No.	Crop grown	Area, ha
1	Sugarcane	168
2	Paddy	47
3	Wheat	80
4	Sorghum	59
5	Black gram	20
6	Mustard	8
7	Berseem	20
	Gross cropped area	**402**

(b) Scenario 2: In this scenario, the cultivated area of sugarcane is reduced by 50 % and the reduced cultivated area of sugarcane is distributed to the other crops proportionately (Table 4). Then crop water requirement and irrigation water requirement for different crops were estimated using the changed cropping pattern.

Table 4 : Changed cropping pattern for Rasulpur Jattan village

Sl. No.	Crop grown	Area, ha
1	Sugarcane	84
2	Paddy	64
3	Wheat	109
4	Sorghum	80
5	Black gram	27
6	Mustard	11
7	Berseem	27
	Gross cropped area	**402**

(c) Scenario 3: In this case, 50 % of total cultivated area is considered with provision of underground conveyance pipeline system along with improved irrigation methods (drip and rain-gun system). Out of 267 ha of cultivated area of the village, 134 ha is considered having underground conveyance pipeline system. Half of 134 ha area is considered under drip and remaining half under rain-gun systems. Thus, out of the total sugarcane cultivated area of 168 ha, 67 ha is considered with underground pipeline and drip irrigation system, another 67 ha is considered with underground pipeline with rain-gun system and the remaining 34 ha is considered with conventional irrigation conveyance and application practices (Table 5).

Table 5 : Irrigation practices and area under different crops

Sl. No.	Crops	Area with underground pipeline system, ha		Area under conventional system, ha	Total area, ha
		along with drip system	along with rain-gun system		
1	Sugarcane	67	67	34	168
2	Paddy			47	47
3	Wheat			80	80
4	Sorghum			59	59
5	Black gram			20	20
6	Mustard			8	8
7	Berseem			20	20
	Gross cultivated area			**268**	**402**

The conveyance efficiency of earthen water course system was estimated as 93% over underground pipeline conveyance system (for a distance of approximately 75 m), at Rasulpur Jattan village as reported by WTC, IARI, New Delhi. By considering this conveyance efficiency, the irrigation water demand for sugarcane crop was estimated. The irrigation water demand for other crops was estimated considering conventional method (supply through earthen channel). The water saving in sugarcane crop due to provision of drip and raingun system is found to be 49.21 % and 21.76 %, respectively (Shekinah et. al., 2011). Using the value of conveyance efficiency mentioned above, and water saving percentage of drip and raingun system, the irrigation water requirement for sugarcane crop was estimated for 134 ha. The irrigation water demand for the remaining 34 ha of sugarcane and for other crops, was estimated assuming conventional method of practice (supply through earthen channel).

(d) Scenario 4: This scenario is the combination of scenario 2 and 3, where the sugarcane area is reduced by 50 %, and 50 % area of total cultivated area is put under conveyance pipeline system and improved irrigation application methods such as drip and raingun system. In this scenario, 67 ha of sugarcane area is considered to have underground conveyance pipeline with drip irrigation system and the remaining 17 ha of sugarcane area will have underground pipeline with raingun system. Further, 50 ha of wheat is considered to have underground pipeline with raingun system (Table 6). Thus, the total cultivated area of sugarcane is fully covered with underground conveyance pipeline system and improved irrigation systems.

Table 6 : Area under different crops and irrigation practices considered

Sl. No.	Crops	Area with underground pipeline system, ha		Area under conventional irrigation method, ha
		along with drip system	along with rain-gun system	
1	Sugarcane	67	17	0
2	Paddy			64
3	Wheat		50	59
4	Sorghum			80
5	Black gram			27
6	Mustard			11
7	Berseem			27
	Gross cultivated area	**67**	**67**	**268**

The water saving in wheat crop with raingun system is about 56 % (Kahlown et. al., 2007). Considering the water saving percentage due to underground pipeline, drip and raingun system, the irrigation water requirement for sugarcane and wheat crops were estimated. Also using the conventional method, the irrigation water demand for rest of the cultivated area of wheat and other crops were estimated.

(e) Scenario 5: In this scenario, 100 % sugarcane cultivated area (168 ha) is considered to have underground conveyance pipeline, drip and raingun systems. Out of 168 ha of sugarcane cultivated area, 84 ha is to have underground conveyance pipeline with drip system and other 84 ha will have underground conveyance pipeline with raingun system (Table 7). Thus, the total cultivated area of sugarcane crop is fully covered under conveyance pipeline and improved irrigation systems.

Table 7 : Cultivated area under different crops in Rasulpur Jattan village

Sl. No.	Crops	Area with underground pipeline system, ha		Area under conventional irrigation method, ha
		along with drip system	along with rain-gun system	
1	Sugarcane	84	84	0
2	Paddy			47
3	Wheat			80
4	Sorghum			59
5	Black gram			20
6	Mustard			8
7	Berseem			20
	Gross cultivated area	**84**	**84**	**234**

By considering the water saving percentage of conveyance pipeline, drip and raingun system, the irrigation water requirement for sugarcane was estimated. Further, using conventional method, the irrigation water demands for other crops were calculated.

(f) Scenario 6: In this scenario, for augmenting groundwater resources, provision of water recharging structures such as recharge cavity wells is considered along with scenario 4 (where the sugarcane area is reduced by 50 % and 50 % of total cultivated area is put under conveyance pipeline and improved irrigation application methods such as drip and raingun system). As the irrigation requirement for the scenario 6 is same as the irrigation water demand for scenario 4, no separate calculation was made. This scenario is further divided into three sub groups:

- **(i) Scenario 6 (i):** One recharge cavity is considered for each 100 ha of land. As the village has a geographical area of 300 ha, so the total number of recharge cavities considered is three.
- **(ii) Scenario 6 (ii):** One recharge cavity is considered for each 75 ha of land. So the total number of recharge cavities is four.
- **(iii) Scenario 6 (iii):** One recharge cavity is considered for each 50 ha of land. So the total number of recharge cavities is six.

From the observation we recorded in the field, the recharge rate of a recharge cavity well ranges from 4 to 12 lit/sec. Thus, for our calculation purpose, an average value of 8 lit/sec has been considered. The recharge through recharge cavity well is possible only during the monsoon period. Therefore, for finding out the total volume of water recharged in a year, recharge days of 120 days (4 months monsoon period) has been considered in the entire year.

(g) Scenario 7: In this scenario, for augmenting groundwater resources, provision of water recharging structures such as recharge cavity wells are considered along with the scenario 5 (where the 100 % sugarcane area is put under conveyance pipeline and improved irrigation application methods such as drip and raingun system). The irrigation requirement for scenario 7 is same as the irrigation water demand of scenario 5. This scenario is further divided into three sub groups:

- **(i) Scenario 7 (i):** One recharge cavity is considered for each 100 ha of land. As the village has a geographical area of 300 ha, so total number of recharge cavities considered is three.
- **(ii) Scenario 7 (ii):** One recharge cavity is considered for each 75 ha of land. So the total number of recharge cavities is four.
- **(iii) Scenario 7 (iii):** One recharge cavity is considered for each 50 ha of land. So the total number of recharge cavities is six.

The future water demands in agriculture, domestic sector and change in groundwater storage under different scenarios were calculated to decide the best and feasible method to overcome the water scarcity condition of the village.

4.0 RESULTS AND DISCUSSION

4.1 Present Water Budgeting for Rasulpur Jattan

4.1.1 Analysis of climatic data

The analysis of daily rainfall data of 19 years (1997–2015) showed that the average annual rainfall of the village is 768 mm with a standard deviation of 173 mm. Highest rainfall is received in the month of July (214 mm) followed by the month of August (189 mm). During the period of July to September, a rainfall amount of 520 mm is received. Table 8 presents the monthly average climatic parameters of Rasulpur Jattan village. The average monthly rainfall varies from a minimum of 4.49 mm in the month of November to 214.12 mm in the month of July. The maximum temperature varies from 20.18˚C in the month of January to 37.19 ˚C in the month of May. The minimum temperature varies from 6.69 ˚C in the month of January to 26.50 ˚C in the month of June. The monthly average temperature varies from 12.51 ˚C in the month of January to 31.61 ˚C in the month of June. The reference evapotranspiration is estimated using Penman–Monteith method. The average reference crop evapotranspiration is found to be varying from a minimum of 2.57 mm/day in the month of January to a maximum of 7.94 mm/day in the month of May.

Table 8 : Average monthly climatic parameters of Rasulpur Jattan village

Month	Rainfall, mm	Maximum Temp, °C	Minimum Temp, °C	Average Temp, °C	ETo, mm/day
January	18.22	**20.18**	**6.69**	**12.51**	**2.57**
February	33.00	23.14	9.87	15.89	3.57
March	27.00	29.21	15.00	21.84	5.38
April	20.84	34.55	20.36	27.49	7.20
May	30.81	**37.19**	24.35	30.94	**7.94**
June	86.80	36.44	**26.50**	**31.61**	7.20
July	**214.12**	32.33	25.53	28.93	4.92
August	188.65	30.99	24.38	27.56	4.16
September	117.45	30.45	22.06	26.03	4.23
October	20.48	29.44	17.03	22.80	4.05
November	**4.49**	26.16	12.06	18.28	3.26
December	6.22	22.06	8.01	13.92	2.61

Fig 4 shows the distribution of mean rainfall in different months along with standard deviation in the Rasulpur Jattan village. The trend analysis of the annual rainfall of the Rasulpur Jattan village showed that there is increasing trend in annual rainfall and annual monsoon rainfall over the years (Figs. 5 & 6). The equations show that the annual rainfall is increasing at a rate of 1.614 mm per year (Fig 5) and annual monsoon rainfall is increasing at a rate of 2.128 mm per year (Fig 6).

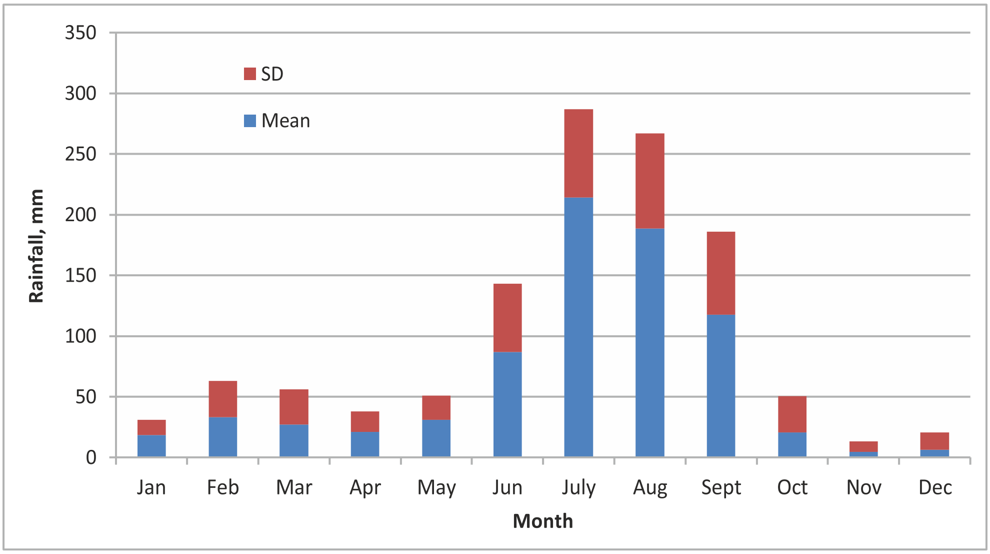

Fig 4: Distribution of mean rainfall in different months along with standard deviation for Rasulpur Jattan village

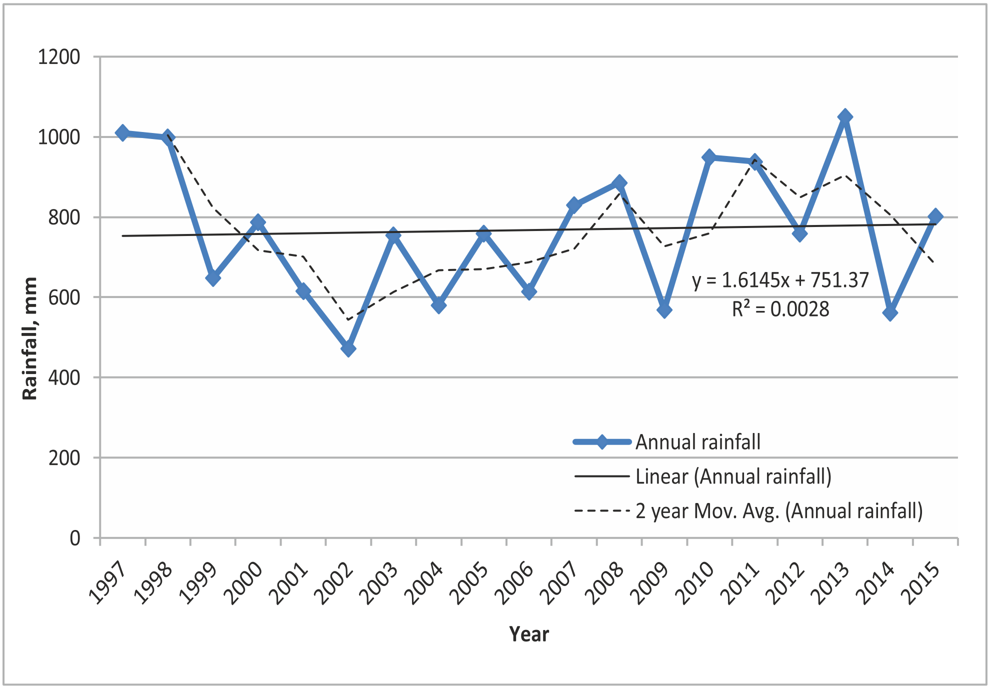

Fig 5 : Trend analysis of annual rainfall of Rasulpur Jattan village

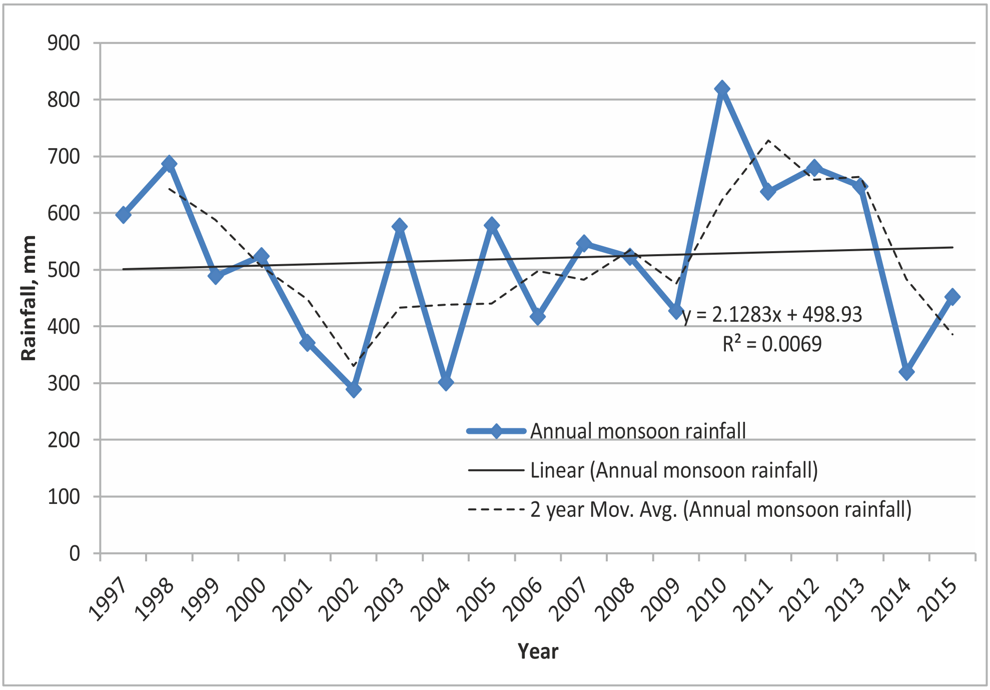

Fig 6 : Trend analysis of annual monsoon rainfall of Rasulpur Jattan village

The trend analysis of the maximum temperature in the month of May, minimum temperature in the month January, average temperature in the month of May and January, and reference crop evapotranspiration in the month of May and January were carried out. The 33 years data were plotted along with 5 years moving average. The linear trend over the years along with the equation is shown in the graph.

The trend analysis of maximum temperature in the month of May and minimum temperature in the month of January is shown in Fig. 7and Fig. 8, respectively. The figures show that there is an increasing trend in maximum temperature in the month of May and minimum temperature in the month of January over the years in Rasulpur Jattan village. The equations show that the maximum temperature in the month of May rises at the rate of 0.213 ˚C per year. The minimum temperature in the month of January rises at the rate of 0.015 ˚C per year.

The trend analysis of average temperature in the month of May and January is shown in Fig. 9 and Fig. 10, respectively. The figures show that the average temperature rises at the rate of 0.108 ˚C per year in the month in May and at the rate of 0.042 ˚C per year in the month of January.

The trend analysis of average reference crop evapotranspiration (ETo) in the month of May and January is shown in Fig. 11 and Fig. 12, respectively. The equations show that the average reference crop evapotranspiration in the month of May rises at the rate of 0.056 mm/day per year. The reference crop evapotranspiration in the month of January rises at the rate of 0.020 mm/day per year in Rasulpur Jattan village.

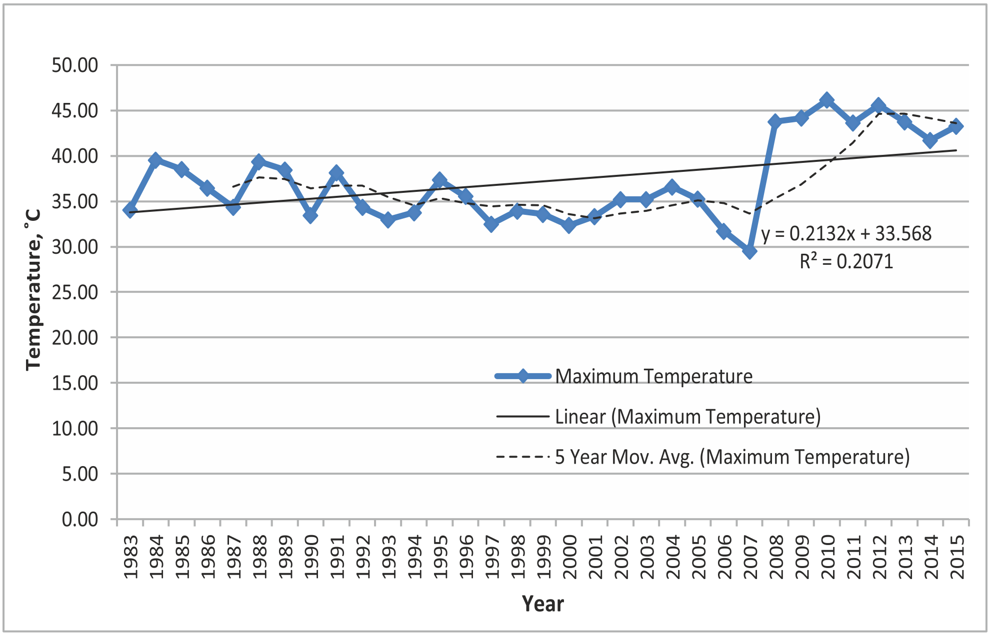

Fig 7 : Trend analysis of maximum temperature in month of May of Rasulpur Jattan

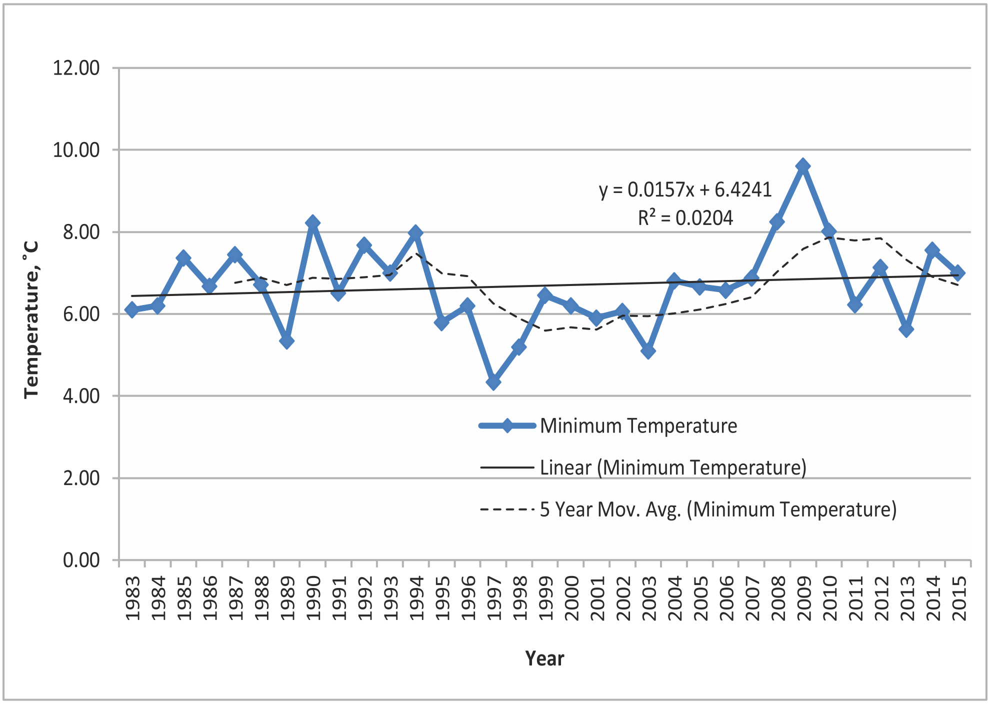

Fig 8 : Trend analysis of minimum temperature in month of January of Rasulpur Jattan

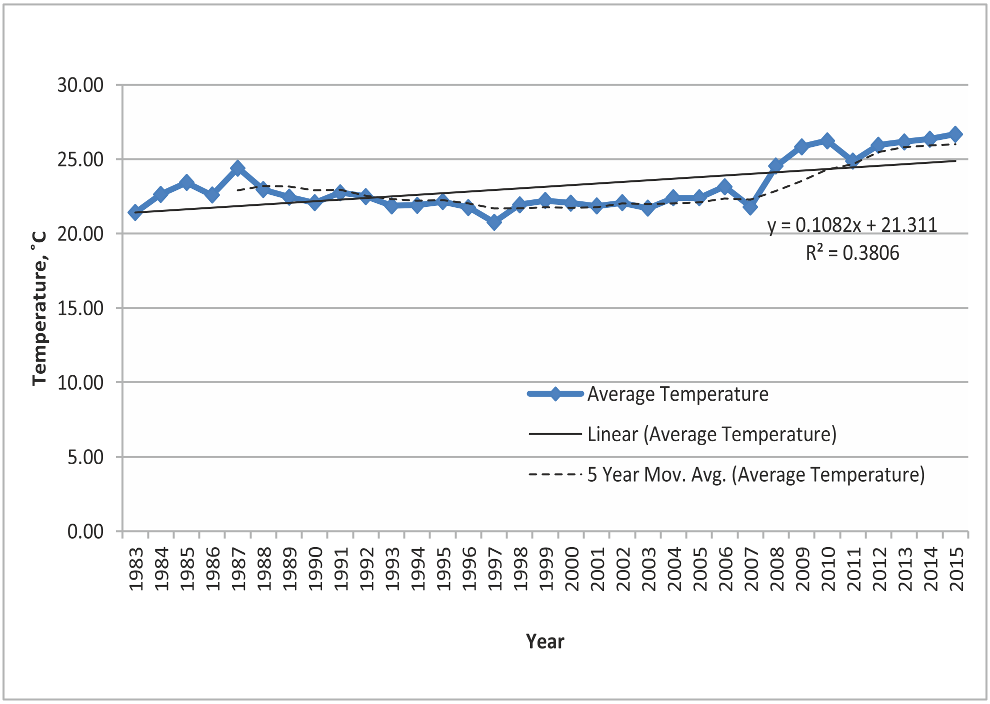

Fig 9 : Trend analysis of average temperature in month of May of Rasulpur Jattan

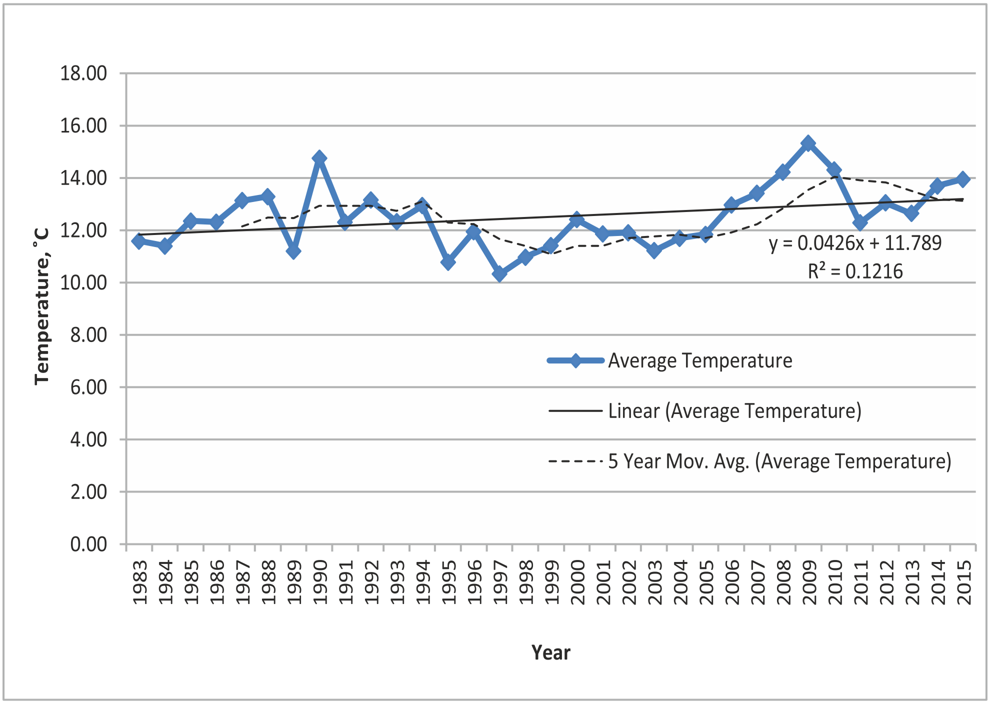

Fig 10 : Trend analysis of average temperature in month of January of Rasulpur Jattan

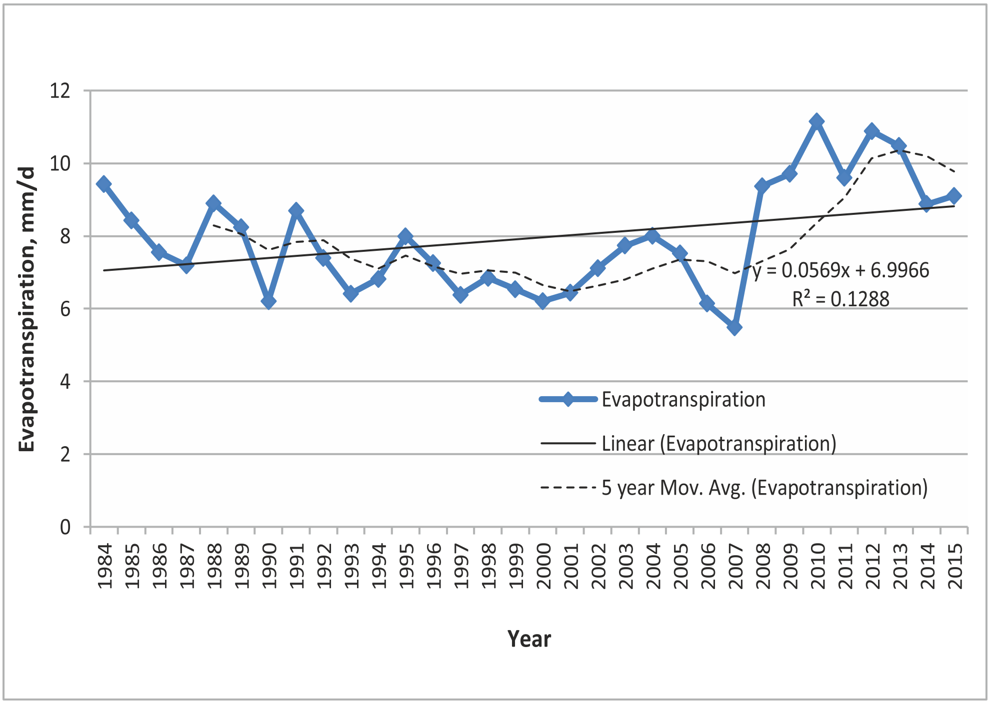

Fig 11 : Trend analysis of average ETo in month of May of Rasulpur Jattan village

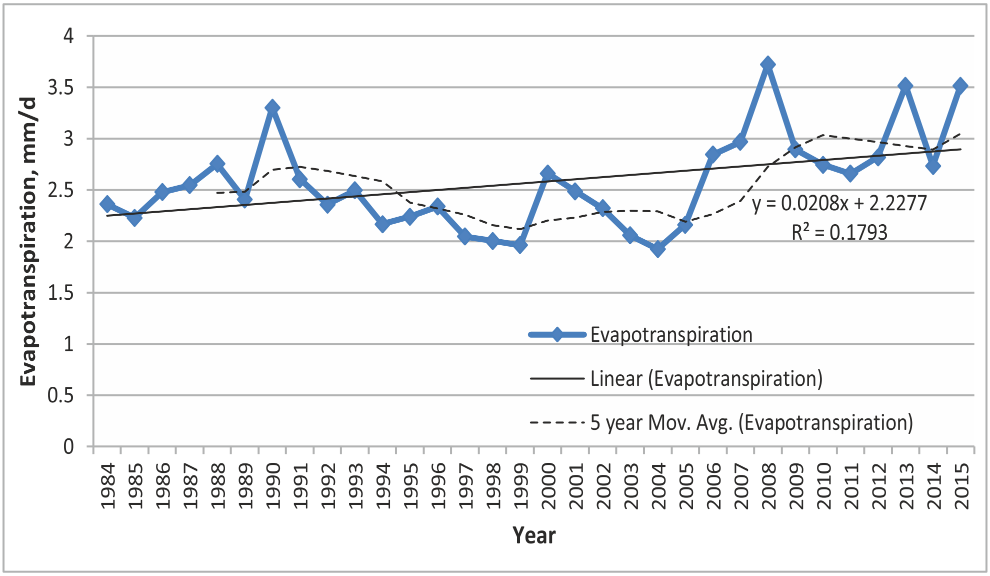

Fig 12 : Trend analysis of average ETo in month of January of Rasulpur Jattan village

4.1.2 Groundwater table depth scenario

The depth of groundwater table in pre-monsoon and post-monsoon over 7 years period for the village Kakada (nearby village of Rasulpur Jattan) is shown in Fig 13. It shows that the pre monsoon water table declines at a rate of 0.355 m per year and post monsoon water table rises at a rate 0.014 m per year.

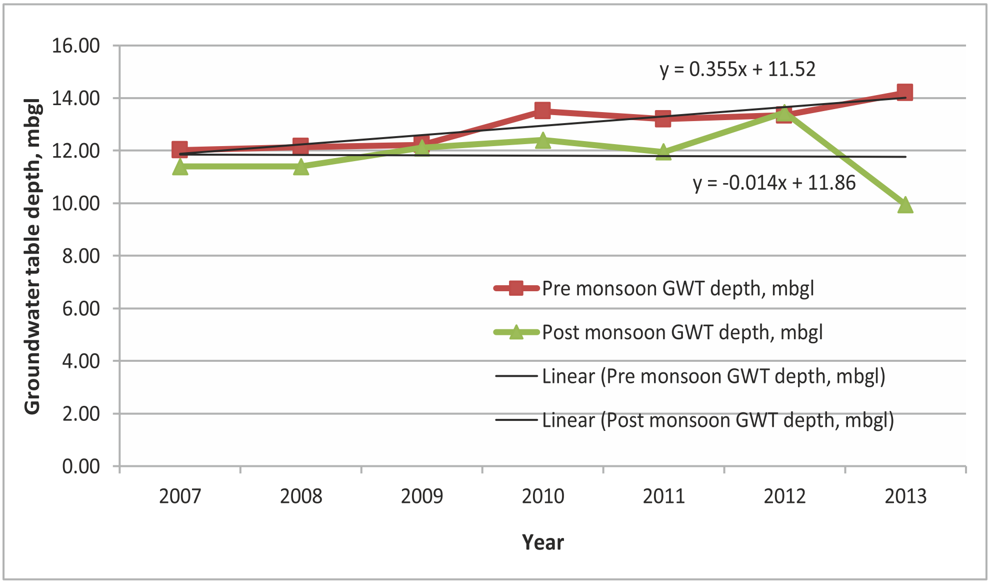

Fig 13 : Groundwater table depth in pre- and post-monsoon season

4.1.3 Estimation of natural groundwater recharge

The average annual groundwater recharge in monsoon season is found to be 0.1824 m or 547200 cum. The recharge is found to be maximum 2040000 cum in the year 2013 and negligible in the year 2012 (Fig 14). Using the rainfall data of 19 years, the average annual non-monsoon rainfall is found to be 248 mm. The average annual non-monsoon recharge is found as 0.0618 m that is equal to 185482 cum for the village. The recharge is maximum as 309487.50 cum in the year 1997 and minimum 59572.50 cum in the year 2012 (Fig 15). Thus, the average annual recharge in monsoon and non-monsoon season is found to be 0.1824 m and 0.0618 m, respectively. The total annual groundwater recharge is found as 0.2442 m or 732682 cum which is about 32 % of total average annual rainfall occurring over the village. From the total recharge, the monsoon recharge is about 75 % of the total annual recharge where non-monsoon recharge is about 25%.

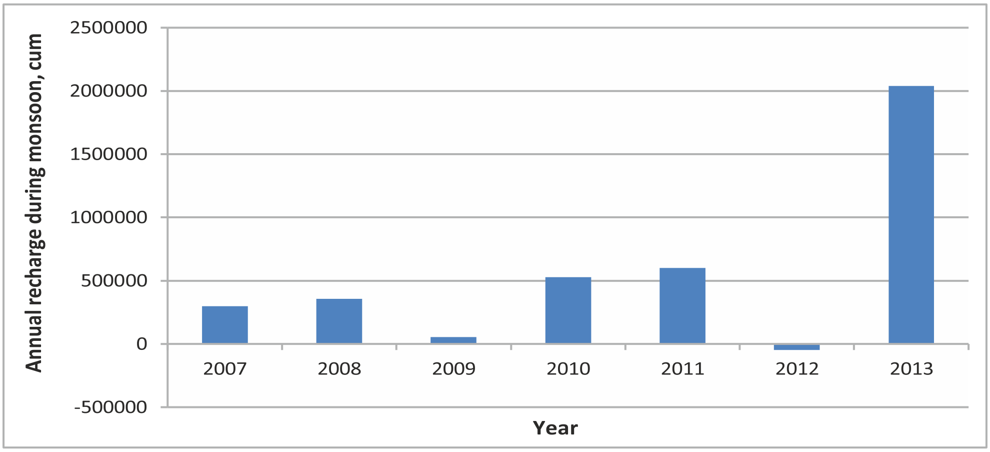

Fig 14 : Groundwater recharge during monsoon in Rasulpur Jattan

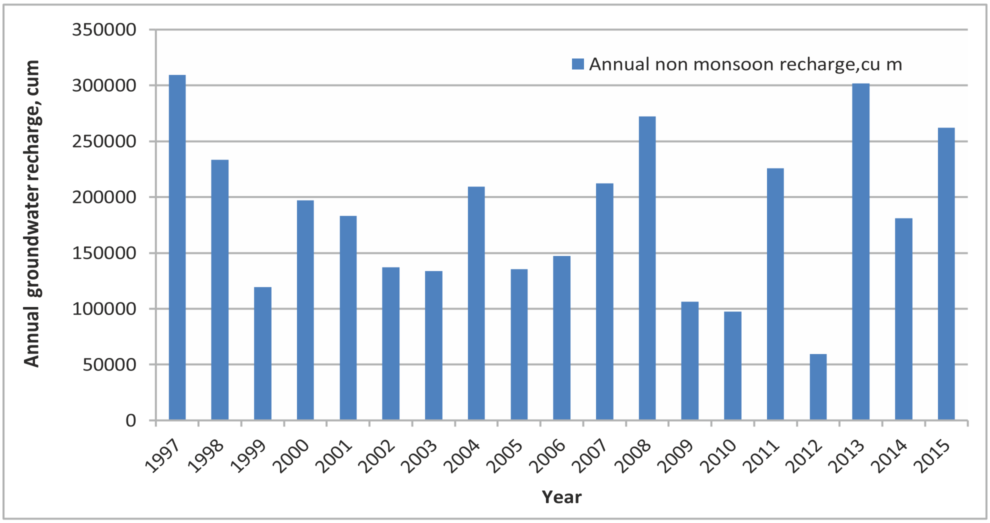

Fig 15 : Groundwater recharge during non-monsoon in Rasulpur Jattan

4.1.4 Water flow into the aquifer system other than rainfall

The irrigation return flow from the cropped field is estimated as 431758 cum which is about 26 % of the total annual draft for irrigation.

4.1.5 Groundwater draft for domestic and livestock

The annual groundwater draft for domestic purpose and livestock population were found to be 108916 cum and 22539 cum, respectively. The annual water use for different livestock population is presented in Table 9.

Table 9: Annual groundwater utilization for livestock population

Sl. No.	Livestock	Population	Water requirement, liters/day	Annual water use, litres	Annual water use, cum
1	Cow	250	35	3193750	3194
2	Buffalo	800	65	18980000	18980
3	Pig	40	25	365000	365
	Total			**22538750**	**22539**

4.1.6 Estimation of annual water requirement for major crops

From the average annual rainfall of 768 mm for the village, about 545 mm rainfall was estimated as effective rainfall which could be used by the crops. The annual crop water requirement for different crops was estimated. The monthly irrigation water requirement was estimated by deducting the effective rainfall from the total crop water requirement (Table 10).

Table 10 : Monthly irrigation water requirement of different crops (in mm)

Month	Sugarcane	Paddy	Wheat	Sorghum	Black gram	Mustard	Berseem
Jan	47.06	0	78.95	74.97	0	0	59.02
Feb	50.93	0	15.93	30.93	0	0	60.94
Mar	45.48	0	45.48	70.49	0	0	120.52
Apr	68.05	0	0	0	0	0	165.32
May	68.45	0	0	0	0	0	0
Jun	196.98	153.76	0	0	0	0	0
Jul	45.16	214.66	0	0	0	0	0
Aug	39.89	33.44	0	0	14.09	0	0
Sep	75.45	31.04	0	0	0	0	0
Oct	141.65	97.75	0	0	0	129.11	35.03
Nov	122.28	0	68.48	0	0	24.46	39.13
Dec	101.22	0	56.68	0	0	20.24	72.87
Total	**1002.60**	**530.65**	**265.52**	**176.39**	**14.09**	**173.81**	**552.83**

The annual crop water requirement and irrigation water requirement for the village were estimated as 3638215 cum and 2377551 cum, respectively. Fig. 16 shows the monthly irrigation requirement for Rasulpur Jattan village. Irrigation requirement is minimum in the month of August due to occurrence of high rainfall. The *rabi* and *zayad* crops are supplemented with irrigation water because of less rainfall in these periods. About 35% of total crop water requirement is met from the rainfall and 65% is supplemented by irrigation from groundwater. Due to over drafting of the groundwater, the water level declines over the years. Hence, there is a need to adopt new technologies for efficient utilization of available water resources. The efficiency of water utilization can be increased by adopting the climate resilient irrigation systems such as provision of underground conveyance pipeline system and adoption of micro irrigation systems like drip, sprinkler and rain gun.

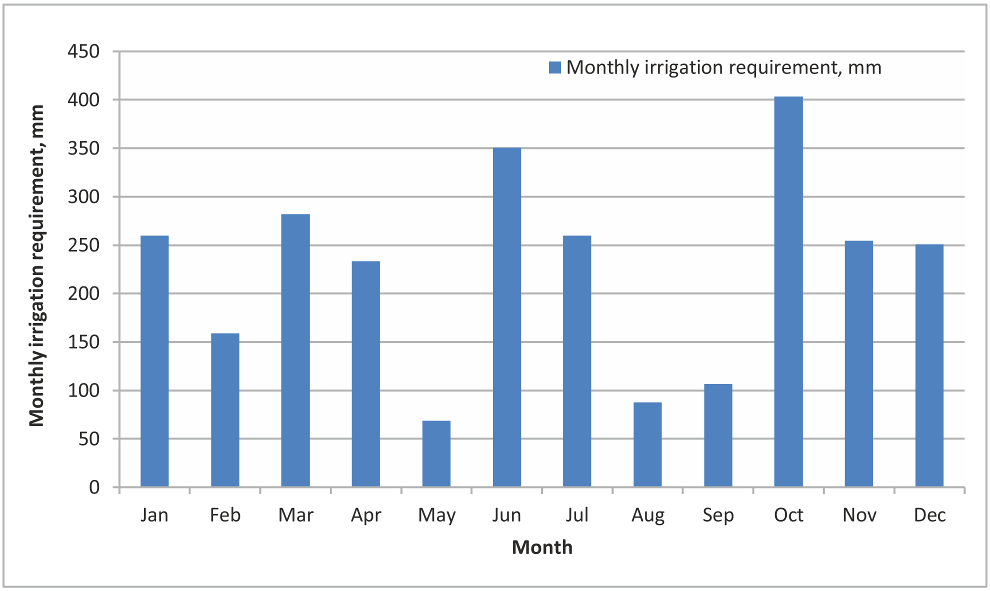

Fig 16 : Monthly irrigation requirement for different crops in Rasulpur Jattan village

4.1.7 Estimation of total actual annual water pumping for irrigation

The actual annual groundwater pumping for irrigation was computed by using the dataset obtained from the field survey. From the survey, the rate of discharge for the 10 hp is calculated as 13.587 lit/sec (Table 11).

Table 11 : Observations and results of the field experiment

HP of motor	Width of tank (cm)	Length of tank (cm)	Depth of tank (cm)	Time to fill the tank (sec.)	Discharge (liters/sec)	Discharge, cum/h
10	86	105	37	24.59	13.587	48.91

The pump discharges are estimated by considering the discharge of 10 hp pump. Then the discharge (Q) is calculated as

$$Q = \frac{13.587}{\sqrt[3]{10}} \sqrt[3]{P} = 6.308 \sqrt[3]{P} \qquad (7)$$

The calculations of discharge from different pumpsets are presented in Table 12.

Table 12 : Discharge calculation for different pump size

Horse power of pump, hp	Number of pumps	Calculated discharge, litres/sec	Total discharge, litres/sec
1	**2**	**3**	**6 = (2*3)**
1.5	1	7.223	7.223
7.5	6	12.345	74.07
10	13	13.587	176.631
12	4	14.439	57.756
12.5	7	14.641	102.487
15	22	15.556	342.232
Total	**53**		**760.399**

The weighted average discharge of the pump may be calculated as =

$\frac{760.399}{53} = 14.35$ litres/second $= 51.66\ m^3/h$. This weighted average discharge of the pump is used for our subsequent calculation of groundwater pumping (Table 13).

Table 13 : Annual groundwater pumping for irrigation

Crops	Avg. number of irrigations applied during crop growing season	Avg. time required to irrigate one ha area, hours/ha	Area under each crop, ha	Total irrigation time for whole cropping period for the village, hour	Total ground water draft, cum
1	**2**	**3**	**4**	**5 (2*3*4)**	**6 (51.66 * Col. 5)**
Sugarcane	12.62	11.25	168	23852	1232184
Paddy	10.91	9	47	4615	238407
Wheat	3.79	8.25	80	2501	129222
Mustard	1.25	7.5	8	75	3875
Black gram	1.04	6	20	125	6447
Sorghum	1.86	6.75	59	741	38267
Berseem	5	6.9	20	690	35645
Total			**402**		**1684048**

The annual groundwater pumping for irrigation utilization is found to be 1684048 cubic meters which is about 30 % less than the irrigation water requirement of the crops for the village.

4.1.8 Groundwater balance

The groundwater balance is the difference between water recharge and discharge of the village system. The total annual groundwater recharge from rainfall and irrigation return flow for the village is found to be 1164440 cum. The total annual groundwater pumping for domestic, livestock and irrigation use is found as 1815503 cum for the village. Thus, the annual change in groundwater storage is obtained as (-) 651063 cum which indicates that the pumping is more than the recharge of the aquifer of the village. It is found that the recharge or inflow to the groundwater reservoir is about 64% of annual discharge. As there is no surface water source, the water requirement is fulfilled by groundwater source that results into the decline in groundwater table.

4.1.9 Annual change in groundwater storage due to over exploitation of groundwater

In order to have annual over extraction of 651063 cum of water from the aquifer of Rasulpur Jattan village, the depth of groundwater table is expected to decline by 1.36 m. However, the observed value from the nearby village indicates that the water table depletion in that area is around 0.35 m which is quite lesser than the computed value. This difference in observed and computed value could be due to the recharge effect from adjoining areas which possibly has canal networks.

4.2 Assessment of future projections for Rasulpur Jattan

4.2.1 Analysis of future climatic parameters

The daily predicted climatic data such as rainfall, maximum temperature, and minimum temperature for different years (2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090) were obtained from MarkSim model and analyzed. Table 14 shows the predicted monthly rainfall values for different years. In the month of April and November, no predicted rainfall was obtained. The annual rainfall found decreasing till mid-century and thereafter found increasing. The annual rainfall again declines in the year 2090. The trend analysis shows that the annual rainfall and monsoon rainfall is expected to rise at a rate of 7.979 mm per decade (Fig. 17) and 7.551 mm per decade (Fig. 18), respectively.

Table 14 : Monthly rainfall for Rasulpur Jattan in different years

Month	2020	2030	2040	2050	2060	2070	2080	2090
Jan	43.9	35.1	13.1	31.3	17.8	40.3	40.6	23.2
Feb	13.4	16.7	9	8.2	2.9	24.5	28.3	14.2
Mar	15	16	15.9	4.6	8.7	11.4	10.2	7.7
Apr	0	0	0	0	0	0	0	0
May	54.7	66.6	60.9	38.8	30.5	46.9	55.7	22.3

Jun	24.3	22.4	26.8	24.9	23.1	41.7	41.7	41.5
Jul	548.7	512	482.1	457	440.9	510	513	501.9
Aug	218.7	209.3	200.8	194.9	188.2	186.8	190.3	192.9
Sep	52.3	50.5	50.1	49.3	56.2	97.4	139	141.2
Oct	27.1	26.3	26.2	26.7	111.7	61.5	73	25.3
Nov	0	0	0	0	0	0	0	0
Dec	13.1	31.2	14.2	0	1.3	2.5	2.3	0
Total	**1011.2**	**986.1**	**899.1**	**835.7**	**881.3**	**1023**	**1094.1**	**970.2**

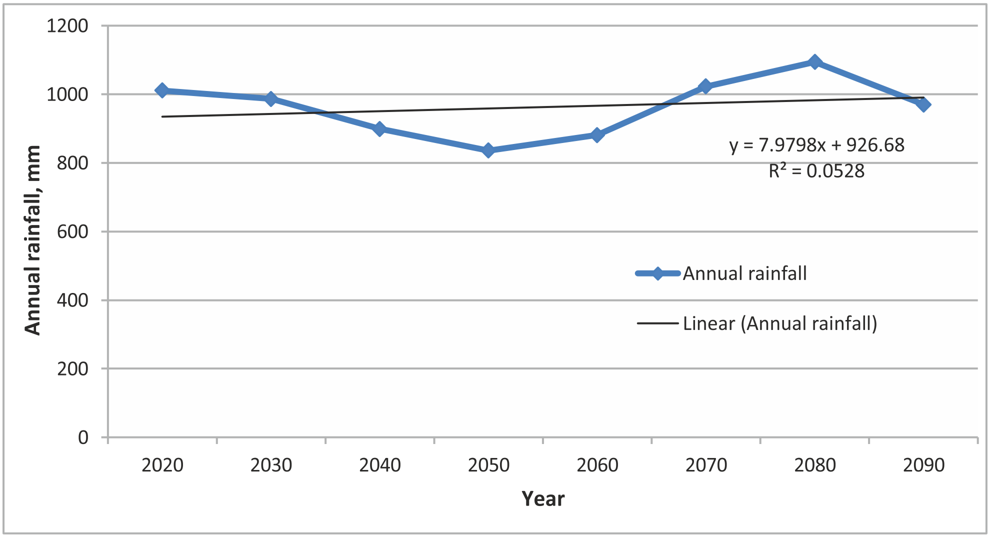

Fig 17 : Predicted average annual rainfall over future years of Rasulpur Jattan

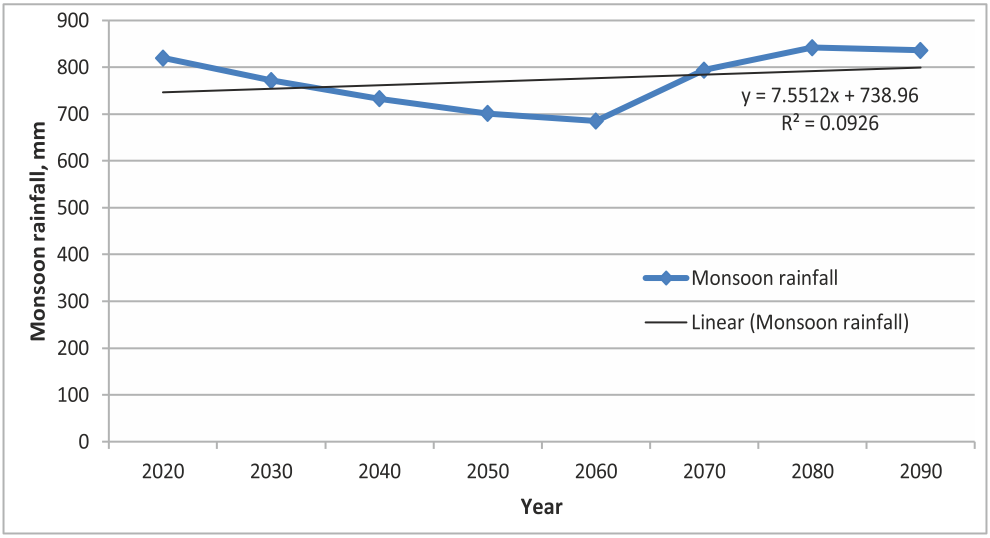

Fig 18 : Predicted average monsoon rainfall over future years of Rasulpur Jattan

The trend analysis of maximum temperature in the month of May and minimum temperature in the month of January is shown in Fig. 19 and Fig. 20, respectively. The figures show that the maximum temperature in the month of May and minimum temperature in the month of January will rise at the rate of 0.544 °C per decade (Fig. 19) and 0.230 °C per decade (Fig. 20), respectively.

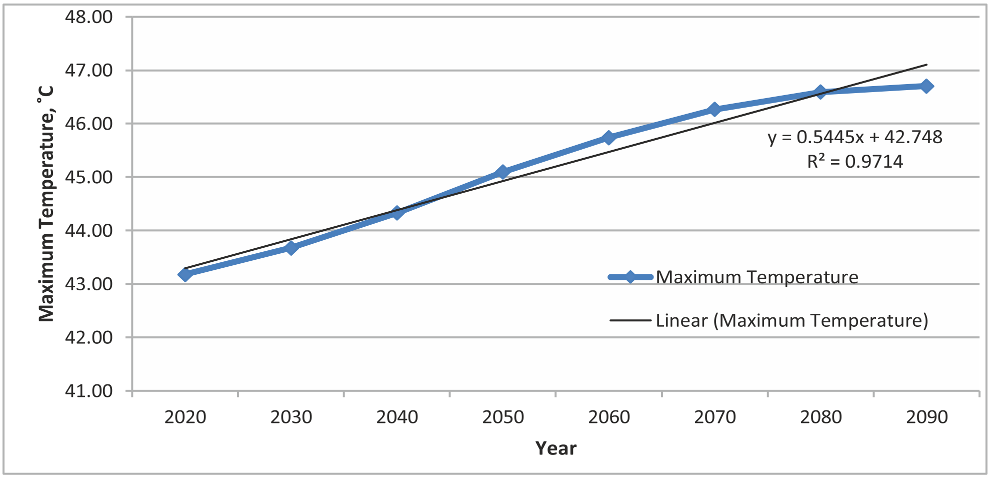

Fig 19 : Predicted maximum temperature in May over future years of Rasulpur Jattan

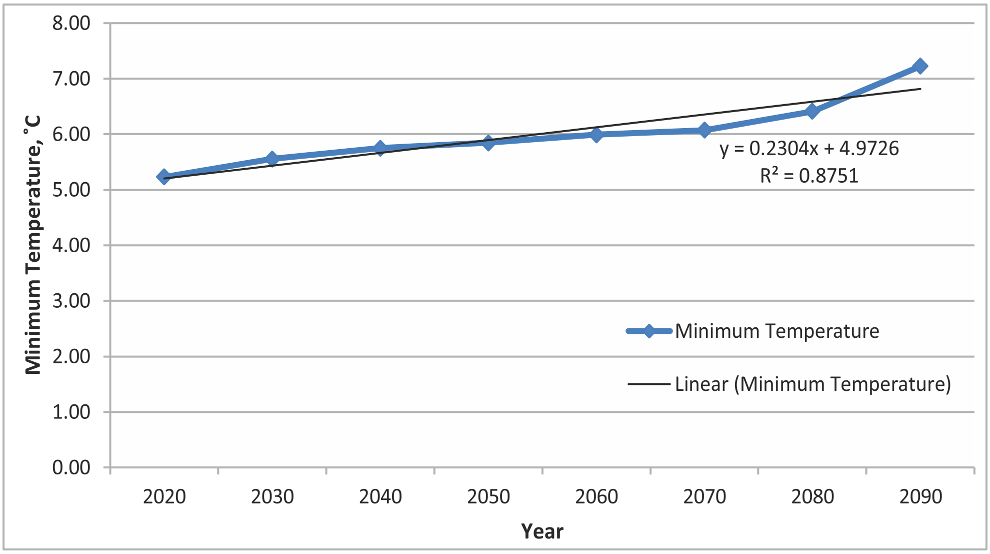

Fig 20 : Predicted minimum temperature in January over future years of Rasulpur Jattan

The trend analysis of predicted reference evapotranspiration (ET_0) in the month of May and January for future decades are shown in Fig. 21 and Fig. 22, respectively. The equations show that the reference evapotranspiration in the month of May will increase at the rate of 0.092 mm/decade (Fig. 21). The reference crop evapotranspiration in the month of January will also increase at the rate of 0.024 mm/decade in Rasulpur Jattan village (Fig. 22).

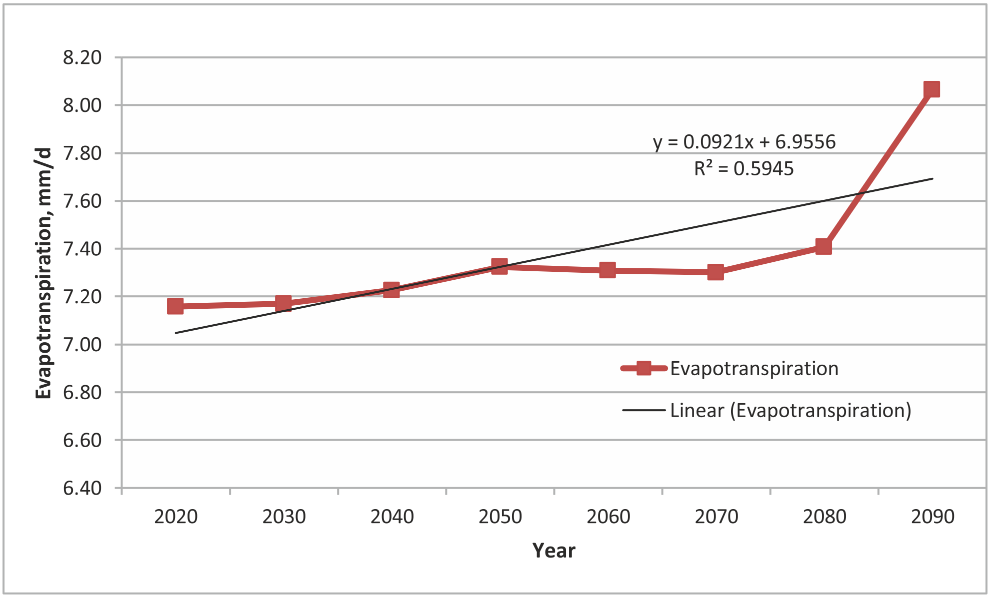

Fig 21 : Future trend of evapotranspiration in May over the years

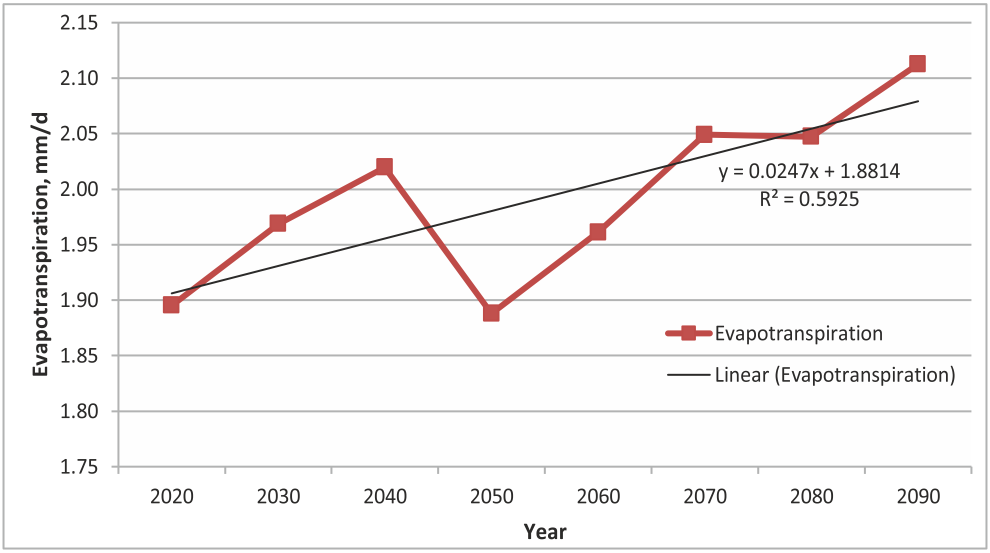

Fig 22 : Future trend of evapotranspiration in January over the years

4.2.2 Irrigation water requirement for major crops

The water irrigation demand of the major crops for future years were estimated for different scenarios considered for the study village is given bellow.

(a) Scenario 1: The crop water requirement is found increasing over the years. However, the irrigation demand increases till 2050, then decreases up to 2080 and again rises up to 2090 (Fig. 23). Future irrigation demand fluctuates as per the predicted future rainfall pattern of the village. The highest and the lowest irrigation demand were found as 2932226 and 2401799 cum in 2050 and 2080, respectively.

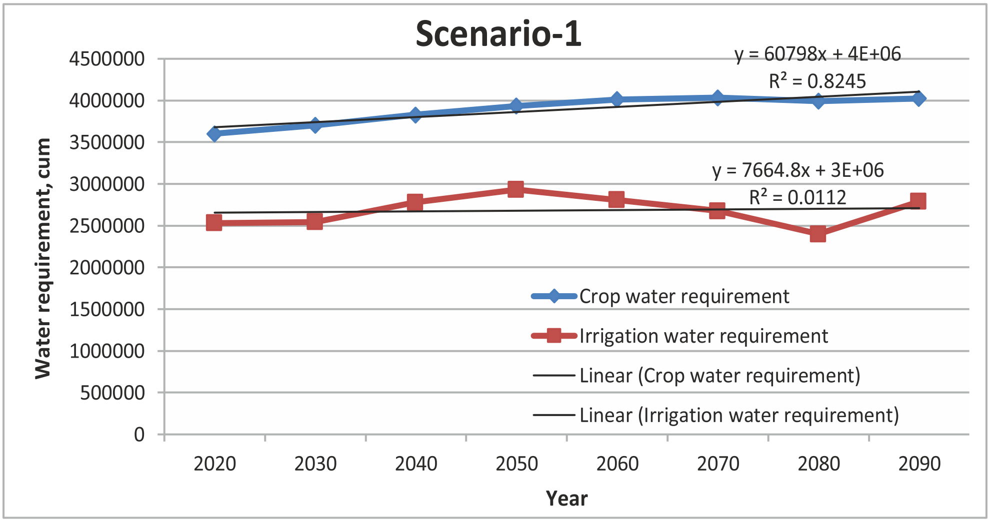

Fig 23 : Crop water and irrigation water requirement of Rasulpur Jattanfor future years (scenario-1)

(b) **Scenario 2:** In this case, the total crop water demand value of respective years is lesser than that of scenario 1 due to reduction in sugarcane area by 50%. The crop water demand increases till mid-century and thereafter flattens up. However, the irrigation demand rises till mid century (2173432 cum) and thereafter decreases till 2080 (1810275 cum). Subsequently, there is a rise in irrigation demand from 2080 to 2090 which is due to reduction of annual rainfall in this decade (Fig. 24).

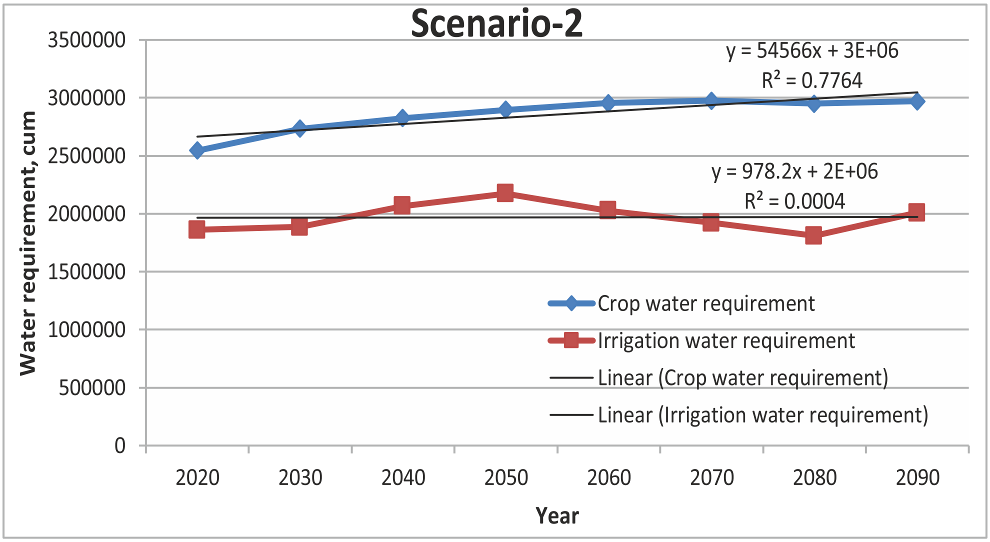

Fig 24 : Crop water and irrigation water requirement of Rasulpur Jattanfor future years (scenario-2)

(c) **Scenario 3:** In this scenario, since it is assumed that the area under different crops is same as that of scenario 1 i.e., BAU, the crop water demand remains same as of scenario 1. The irrigation water demand increases till mid century and there after decreases till 2080 (Fig. 25) as has happened in earlier two scenarios.

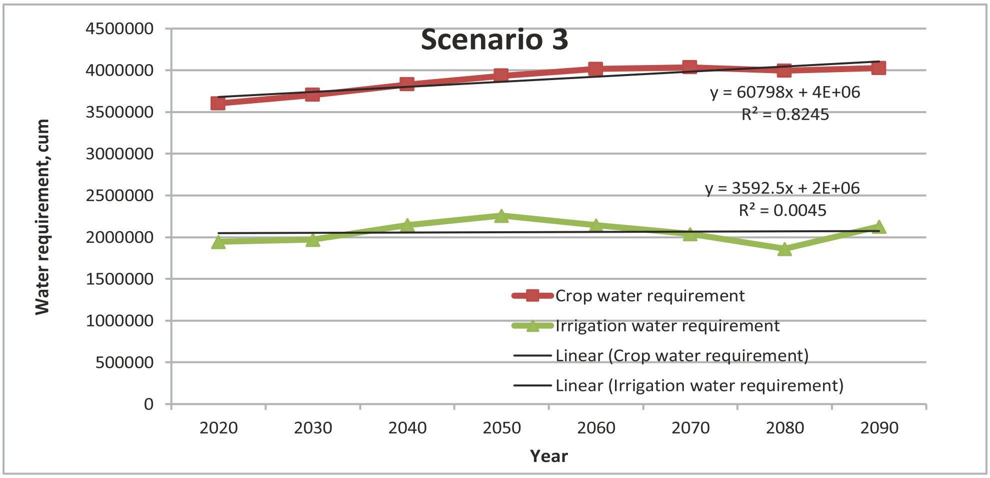

Fig 25 : Crop water and irrigation water requirement of Rasulpur Jattanfor future years (scenario-3)

(d) **Scenario 4 :** In this case, the irrigation water requirement for sugarcane and wheat crops were estimated using the percent of water saving because of underground pipeline, drip and raingun system. Also using the conventional method, the irrigation water demand for rest of the cultivated area of wheat and other crops were computed. In this scenario, the highest water demand is found as 1593459 cum in 2050 and lowest as 1332035 cum in 2080 which is quite lesser than the value computed in previous scenarios. The trend of water demand follows the same path as of earlier scenarios but the magnitude has reduced substantially due to adoption of water saving interventions (Fig. 26).

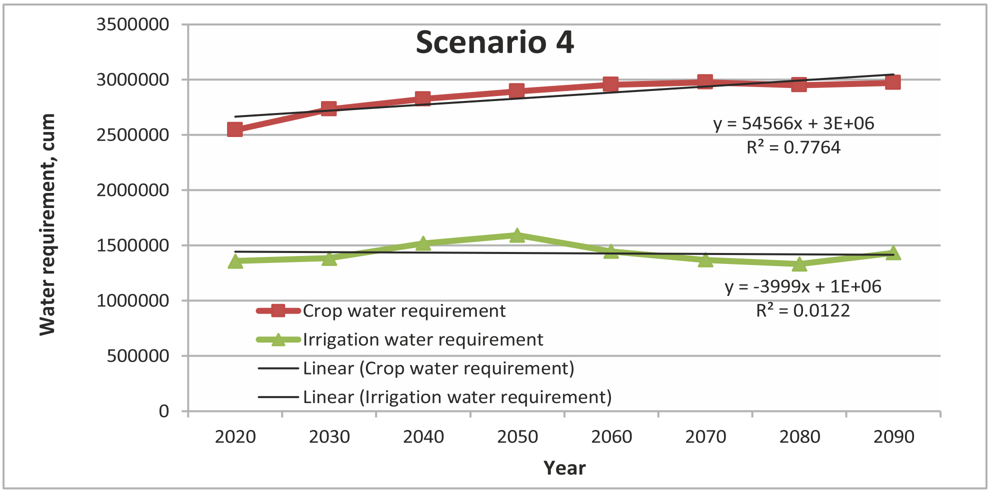

Fig 26 : Crop water and irrigation water requirement of Rasulpur Jattanfor future years (scenario-4)

(e) **Scenario 5:** In this scenario, there is no change in the area covered under different crops from the prevailing one. The sugarcane area of 168 ha is provided with underground pipe line system with either drip or raingun system. The crop water requirement kept increasing till 2070 and thereafter flattens up. The irrigation water demand increases till mid-century where demand is highest as 2088479 cum in 2050, then the value decreases to 1724664 cum in 2080 (Fig. 27).

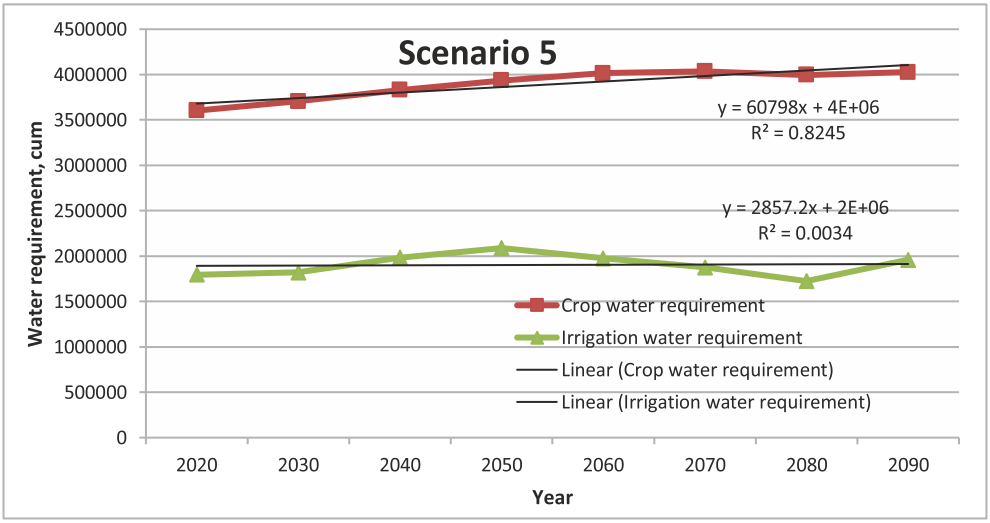

Fig 27 : Crop water and irrigation water requirement of Rasulpur Jattanfor future years (scenario-5)

The irrigation requirement for the scenario 6 and scenario 7 are same as the irrigation water demand for scenario 4 and scenario 5, respectively, so no separate calculation has been made. Tables 15 and 16 presents the crop water requirement and irrigation water demand respectively for different scenarios.

Table 15 : Crop water requirement under different scenarios (in cum)

Scenario	2020	2030	2040	2050	2060	2070	2080	2090
Scenario–1	3603020	3704484	3830660	3934600	4014612	4034950	3995213	4025952
Scenario–2	2544497	2733320	2825790	2895617	2955434	2976123	2950134	2971449
Scenario–3	3603020	3704484	3830660	3934600	4014612	4034950	3995213	4025952
Scenario–4	2544497	2733320	2825790	2895617	2955434	2976123	2950134	2971449
Scenario–5	3603020	3704484	3830660	3934600	4014612	4034950	3995213	4025952

Table 16 : Irrigation water requirement under different scenarios (in cum)

Scenarios	2020	2030	2040	2050	2060	2070	2080	2090
Scenario–1	2533213	2544527	2781537	2932226	2808128	2676486	2401799	2789889
Scenario–2	1860448	1885459	2066654	2173432	2025515	1921020	1810275	2009435
Scenario–3	1945392	1970044	2144956	2259237	2142973	2038936	1861703	2127934
Scenario–4	1359694	1383335	1518411	1593459	1446844	1370045	1332035	1432880
Scenario–5	1796243	1819272	1983436	2088479	1974203	1877170	1724664	1959975

Graphical representation of the irrigation water requirement is given in Fig. 28. In case of all the scenarios, the irrigation water requirement rises till mid century, and thereafter declines up to 2080. Amongst all the scenarios, the lowest irrigation demand is found for scenario 4, where sugarcane area is reduced by 50 % and about 50 % of total cultivated area was considered under conveyance pipeline and improved irrigation methods. The second lowest irrigation water demand is observed for scenario 5. The highest irrigation demand is noticed in scenario 1 i.e., under the prevailing practice of crop cultivation and irrigation application.

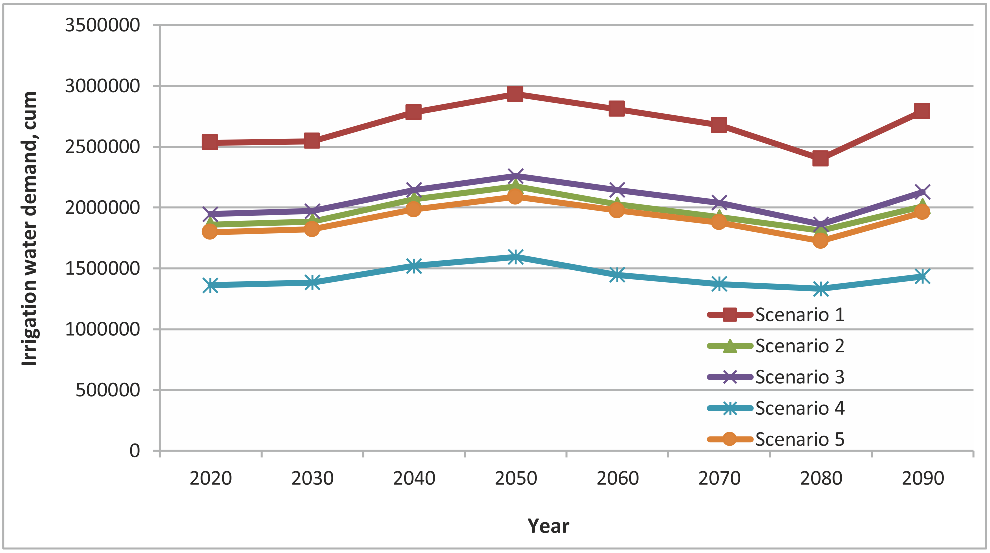

Fig 28 : Irrigation water requirement of Rasulpur Jattan for future years (scenario 1to5)

4.2.3 Reduction of irrigation water demand

The irrigation water demand for different scenarios have been reduced from Business As Usual (BAU) scenario due to adaption of various water saving interventions. Table 17 shows the percentage reduction of irrigation water demand from the BAU scenario for different years. It is found that on an average 46.69% of irrigation water requirement can be reduced in scenario 4. Thus, there is need to reduce the sugarcane area as well as apply irrigation in sugarcane and other crops through improved conveyance (underground pipe line system) as well as application system (drip, sprinkler and raingun system). Similarly, about 23 % of irrigation water requirement can be curtailed by adapting scenario 3 (50 % of total cultivated area under conveyance pipeline system and improved irrigation methods). Graphical representation of the reduction in irrigation water demand is presented in Fig 29.

Table 17 : Percentage reduction of irrigation water demand from BAU scenario

Year	2020	2030	2040	2050	2060	2070	2080	2090	Average
Scenario-2	26.56	25.90	25.70	25.88	27.87	28.23	24.63	27.97	26.59
Scenario-3	23.20	22.58	22.89	22.95	23.69	23.82	22.49	23.73	23.17
Scenario-4	46.33	45.63	45.41	45.66	48.48	48.81	44.54	48.64	46.69
Scenario-5	29.09	28.50	28.69	28.77	29.70	29.86	28.19	29.75	29.07

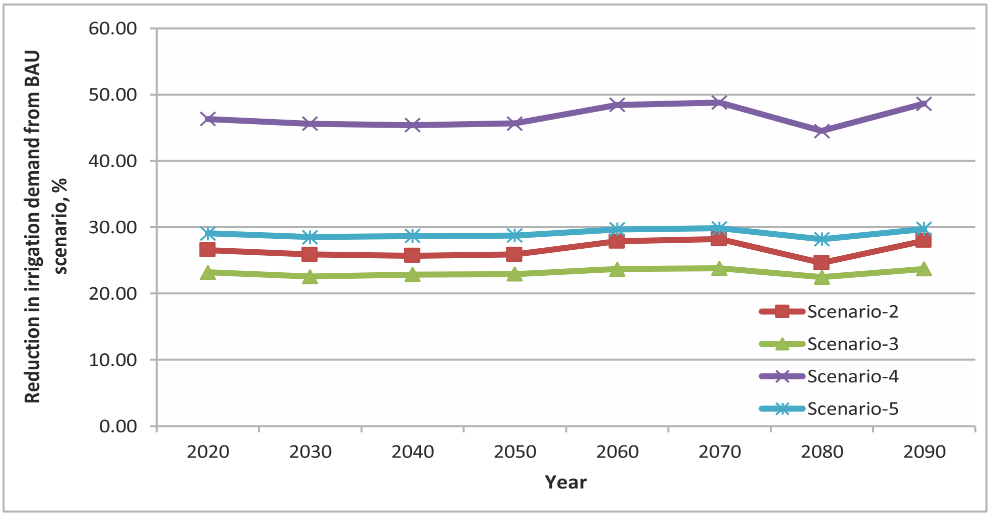

Fig 29 : Percent reduction of irrigation water requirement

4.2.4 Impact of climate change on groundwater

Based on the predicted futureclimatic data and irrigation water requirement in different scenarios considered above, the groundwater balance for the study village was carried out for the future years (2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090).

4.2.4.1 Recharge from rainfall

The rainfall recharges are obtained for different years. The maximum recharge is expected to occur in the year 2080 (as 820575 cum) and minimum in 2050 (as 626775 cum) (Fig. 30). The annual recharge pattern follows the pattern of rainfall occurrence over the years.

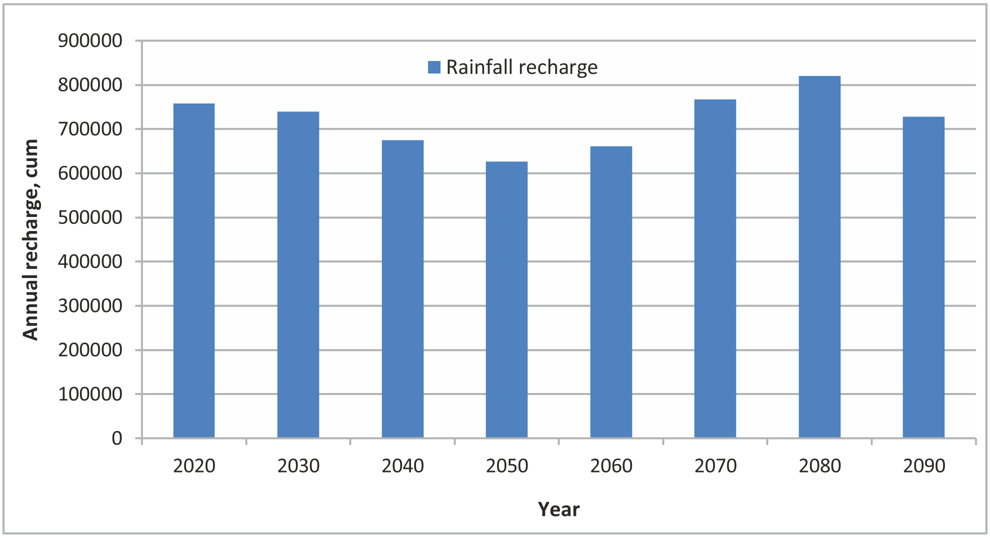

Fig 30 : Annual recharge from rainfall in Rasulpur Jattan village

4.2.4.2 Water inflow other than rainfall

The total irrigation return flow from the crop field to the groundwater reservoir is shown in Table 18. Irrigation return flow for scenario 6 and 7 are same as that of scenario 4 and 5, respectively.

Table 18 : Total irrigation return flow under different scenarios

Year	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**
Scenario-1	775711	780415	851780	897431	854505	814631	734315	848407
Scenario-2	579577	588864	643580	676217	624086	592218	561841	618409
Scenario-3	599365	608070	660806	695534	654959	623366	572287	649820
Scenario-4	429351	438226	479107	502225	450484	426925	418369	445442
Scenario-5	554620	562838	612350	644306	604327	574836	531175	599433

4.2.4.3 Groundwater inflow from recharge cavities

The groundwater is recharged with a rate of 4 to 12 litres/sec through recharge cavities for the study area. Here, an average value of 8 litres/sec is considered as the recharge rate for the calculation of groundwater recharge through cavity well. The water is assumed to be recharged during monsoon period of four months (120 days) only in a year. So the annual groundwater recharge through a cavity well is calculated as ((8 * 60 * 60 * 24 * 120) / 1000) = 82944 cum. The recharge through cavity well is only used to estimate the water balance under scenario 6 and scenario 7.

4.2.4.4 Groundwater outflow

The groundwater outflow includes the water demand for irrigation, domestic and livestock utilization. The irrigation water demands under different scenarios were estimated separately as per the condition assumed for each scenarios. However, as there is no future predicted data on human and livestock population for the study village, the present water demand for domestic and livestock utilization is assumed to remain same for future years. The total annual water utilization for the domestic and livestock population of the village are found as 108916 cum and 22539 cum, respectively which is met from groundwater resource.

4.2.4.5 Change in groundwater storage

The annual change in groundwater storage is the difference between the total annual recharge and the total annual discharge. The changes in groundwater storage in different scenarios follows a similar pattern over the years where the water pumping increases till mid century and thereafter declines till 2080 (Fig. 31). The storage pattern changes as per the demand. The outflow of the groundwater is found to be always more than the inflow which indicates that over exploitation condition will continue to exist in future years even though its magnitude will vary with different scenarios. In order to achieve sustainable use of groundwater, there is a need for construction of several artificial recharge structures to augment groundwater resource. In case of scenario 6 and scenario 7 where cavity wells are constructed for recharge of aquifer, the recharge exceeds the discharge which indicates the increase in water table in the study village. Scenario 6 (ii) and scenario 6 (iii) are found to be the best scenarios in arresting the groundwater table decline. Therefore, in most of the future years considered, the net storage is in positive side. The situation further improves after 2050 till 2080.

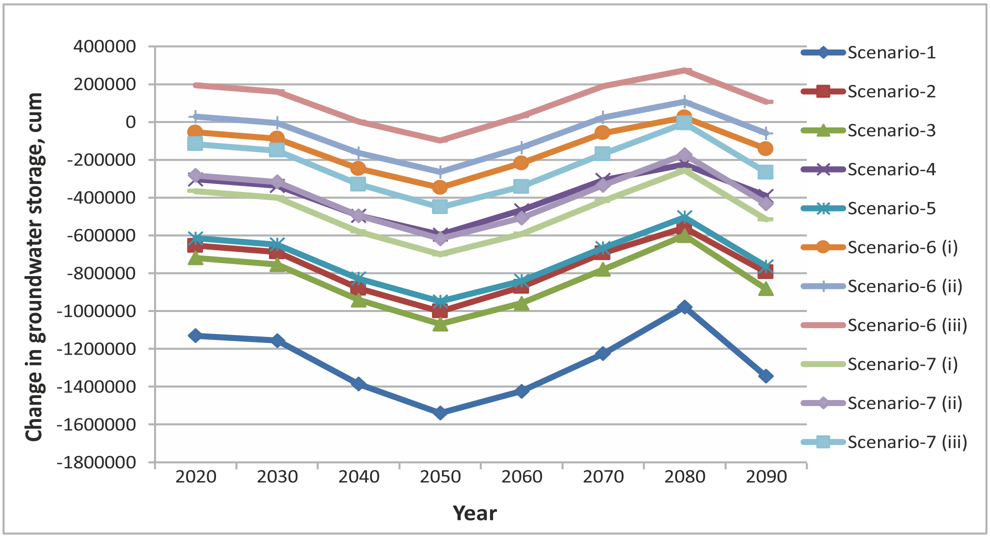

Fig 31 : Change in groundwater storage for Rasulpur Jattan village for future years

4.2.5 Change in groundwater table

The annual change in the depth of groundwater table in the study village for different years was computed for various scenarios considered. Fig. 32 presents the change in groundwater table depth under different scenarios for the future years. It is observed that the decline of depth of water table is maximum for BAU scenario and minimum for scenario 6 (iii) (Fig. 32).

In scenario 6 (iii), the recharge is always found to be in excess of the discharge except in the year 2040 to 2060 (Fig. 32). Thus, there is a need to reduce the area under sugarcane and simultaneously construct artificial recharge structures and improved irrigation conveyance & application methods to arrest the falling of groundwater table.

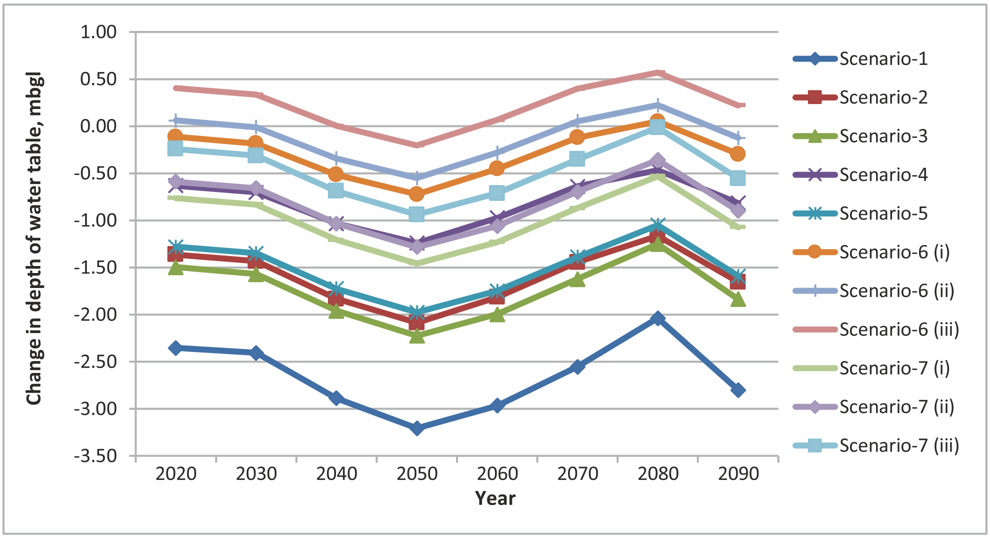

Fig 32 : Change in depth of groundwater table for future years

5.0 CONCLUSION

It has been estimated that the groundwater table at Rasulpur Jattan village declines at about 1.36 m annually due to excessive drafting for irrigation purpose. Adaption of climate resilient irrigation system and change in cropping pattern leads to higher water use efficiency. It minimizes the wastage of water in the agricultural field. The changed cropping pattern, adoption of underground conveyance pipeline system and improved irrigation practices like drip and raingun could save irrigation water to the tune of 50% in the village. The groundwater recharge through recharge structures such as cavity well is found to be an appropriate method of artificial recharge for improvement of the aquifer storage. Based on the above analysis, the study recommends reducing the area under sugarcane, bringing more area under improved irrigation application and conveyance system, and establishment of artificial recharge structures such as recharge cavities to reverse the groundwater table falling trend in the study area. The installation of about six numbers of recharge cavities in the village may be most suitable for achieving the sustainable groundwater balance in future years.

6.0 ACKNOWLEDGMENT

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7.0 REFERENCES

Anonymous. (2016). District Irrigation Plan (DIP), Muzaffarnagar, under Pradhan Mantri Krishi Sinchayee Yojana, Dept. of Agriculture, Govt. of UP, 174p.

Central Groundwater Board (CGWB), (2017). Dynamic Groundwater Resources of India, Ministry of Water Resources, River Development and Ganga Rejuvenation, Govt. of India, Faridabad, 280p.

Dastane N. G. (1978). Effective rainfall, FAO Irrigation and Drainage Paper No. 25. Food and Agriculture Organization of United Nations, Rome.

Groundwater Report Estimation Committee (GEC). (1997). (Reprint, 2009). Groundwater Resource Estimation Methodology. Central Ground Water Board (CGWB), Ministry of Water Resources, Govt. of India, New Delhi, 107p.

Intergovernmental Panel on Climate Change (IPCC). (2014). Climate Change 2014: Synthesis Report, IPCC, Geneva, Switzerland, 151p.

Jones P. G. and Thornton P. K. (2013). Generating downscaled weather data from a suite of climate models for agricultural modelling applications. *Agricultural Systems*, 114, pp.1-5.

Kahlown M. A., Raoof A., Zubair M. and Kemper W. D. (2007). Water use efficiency and economic feasibility of growing rice and wheat with sprinkler irrigation in the Indus Basin of Pakistan. *Agricultural Water Management*, 87 (3):292-298.

Mall R. K., Gupta A., Singh R., Singh R. S. and Rathore, L. S. (2006). Water Resources and Climate Change: An Indian Perspective. *Current Science,* 90 (12): 1610-1626.

Michael A. M. (2007). Irrigation Theory and Practice, Second Edition, Vikas Publishing House Pvt Ltd, Noida, UP, India, 772p.

Raghunath H. M. (1987). Groundwater. 2nd edition, Wiley Eastern Limited, 456p.

Shekinah D. E. and Rakkiyappan P. (2011). Conventional and Micro-irrigation Systems in Sugarcane Agriculture in India. *Sugar Tech*. 13(4): 299–309.

Krishi Vigyan Kendra. (2014).Survey report of Saansad Adarsh Gram Rasulpur Jattan. Muzaffarnagar, Directorate of extension, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh.

Wayne G. (2013).The Beginner's Guide to Representative Concentration Pathways, Skeptical Science, 24p.

Website: https://power.larc.nasa.gov/cgibin/agro.cgi.

Website: http://gismap.ciat.cgiar.org/MarkSimGCM/