Investigating and addressing groundwater depletion in Punjab

Under the guidance of Dr. Ickkshanshu Sonkar

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Motivation:

- To assess the status of groundwater resources in Punjab, including the trends in groundwater depletion, and the factors contributing to this depletion.
- Rapidly decreasing groundwater level in Punjab.
- Of the total 138 number of blocks in the state of Punjab, 109 (79%) are "overexploited", apparently reaching the threshold limit.
- Economy of Punjab largely depends on agriculture; a decrease in groundwater level will make a direct impact on the ecosystem as well as the economy.

Introduction:

- Groundwater depletion in Punjab is a significant problem that has been progressing for several decades.

- Punjab is one of India's most agriculturally productive regions, with a considerable portion of its land under irrigation.

- However, the overexploitation of groundwater resources has led to a decline in the water table, which has had severe consequences for agriculture and the environment.

- There are several reasons for the depletion of groundwater in Punjab. The rapid expansion of tube wells and other irrigation technologies has led to a massive increase in the demand for groundwater.

Outline:

- **Causes of groundwater depletion**
- **Pre mid sem approach**
- **Post mid sem approach**
- **Methodology**
- **Results**
- **Inference**
- **Solutions**

Causes of groundwater depletion

1. **Over-extraction:** Over-extraction of groundwater for various uses, such as irrigation, drinking water, and industrial purposes, or free electricity by the Punjab Government can lead to the depletion of groundwater resources.
2. **Land-use changes:** Changes in land use, such as urbanization, deforestation, and conversion of agricultural land to other uses, can reduce the amount of water available for recharge.
3. **Lack of regulation:** Lack of regulations and ineffective management of groundwater resources can also contribute to groundwater depletion. In some areas, there may be no regulations on groundwater extraction, or regulations may not be enforced effectively.

Pre mid sem approach

Outline:

- **Crop area**
- **Precipitation**
- **Evapotranspiration**
- **Extracted groundwater**
- **Groundwater depletion**
- **Methodology**
- **Results and observations**

Crop area:-

Definition:- Crop area refers to the total land area used for agricultural production, including crops such as cereals, vegetables, fruits, and other plants. It is typically measured in hectares or acres.

- Crop area and groundwater extraction are closely related because irrigation is one of the primary uses of groundwater in agriculture. Groundwater extraction for irrigation is a significant water source for crops in many regions, mainly where surface water is scarce.

- Calculating the crop area is essential in groundwater analysis because it helps determine the overall water demand for agricultural purposes. Knowing the crop area allows for estimating the amount of water required for irrigation and the recharge rates for groundwater in the area.

- By determining the crop area, groundwater analysis can be done to assess the impact of irrigation on groundwater levels and the potential for resource depletion. Crop area data can help identify areas where groundwater recharge may be low or high, allowing for the development of targeted strategies for groundwater management and conservation strategies. Calculating the crop area is an essential component of groundwater analysis, as it provides valuable insights into the dynamics of the water balance in a given area, which is necessary for sustainable groundwater management

- The data for the crop area in Punjab has been taken from the site India-WRIS.India-WRIS provides comprehensive data on water resources and land use patterns in India, including the crop area of different states and regions. To obtain the crop area data for Punjab state, It provides the total crop area including agricultural land,forests, etc for the Kharif crops and rabi crops grown in the region of Punjab

Fig 1: Overview of India-WRIS

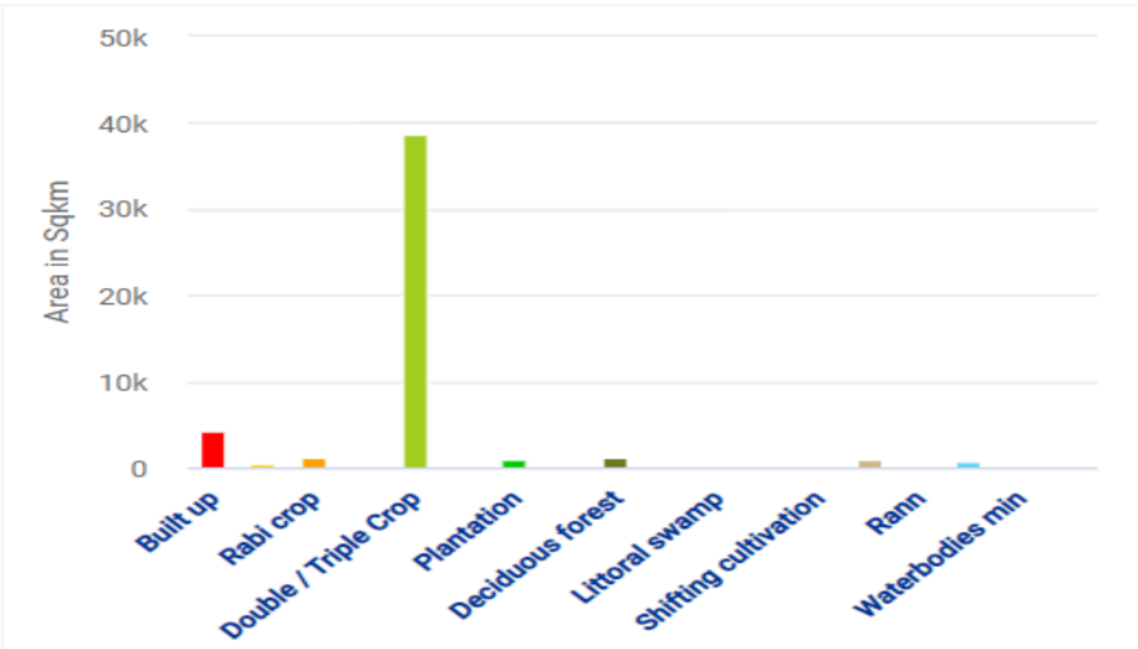
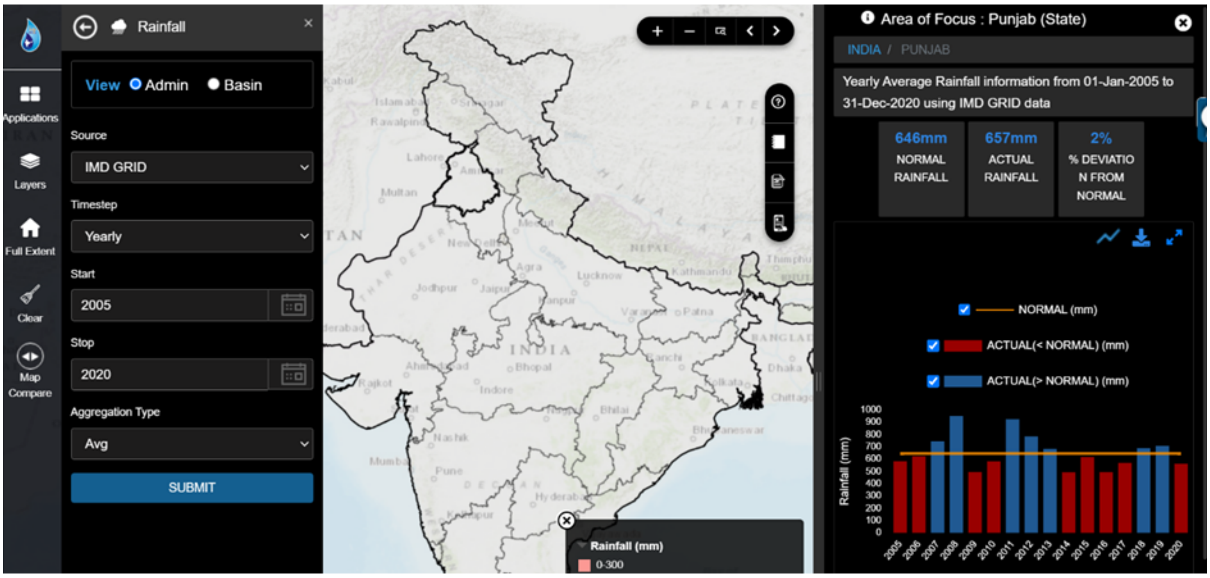


Fig 2: Bar Graph for Punjab Area Distribution (Source:India-WRIS)

Precipitation:-

Definition:- Precipitation refers to water that falls from the atmosphere and reaches the earth's surface.

- This can include rain, snow, rain, hail or other moisture falling from the sky. Precipitation is an important part of the water cycle, which describes the movement of water across the Earth's surface, through the atmosphere, and back again.
- Generally, the rainy season in Punjab starts in the first few weeks of July. Range from 250mm to 1000mm. Agriculture in the state is heavily dependent on precipitation. About 70% of the annual precipitation in Punjab occurs in these three months (July, August, and September).
- We collected 16-year data from WRIS for precipitation for Punjab(India Water Resources Information System).



- Above collecting data average yearly precipitation in Punjab is 646 mm.
- If we talk about monthly average, minimum and maximum precipitation in Punjab, it is 102mm,18mm and 301mm according to WRIS.

Effective precipitation:

Definition:- It is the amount of precipitation that is not lost through runoff. In other words, it is the amount of water that actually penetrates the soil and is stored as groundwater or is used by plants for their growth.

- It helps determine the amount of water available for crop growth and irrigation. It is often used in hydrological modeling and water resources planning to assess water availability and predict the impact of climate change on water resources.
- Using precipitation value we calculated Effective rainfall.
- **For Calculating Effective Rainfall:-**

Collected rainfall data of 16 years annually.

Effective rainfall (in mm/year) calculation**:**

Using USDA's soil conservation service method

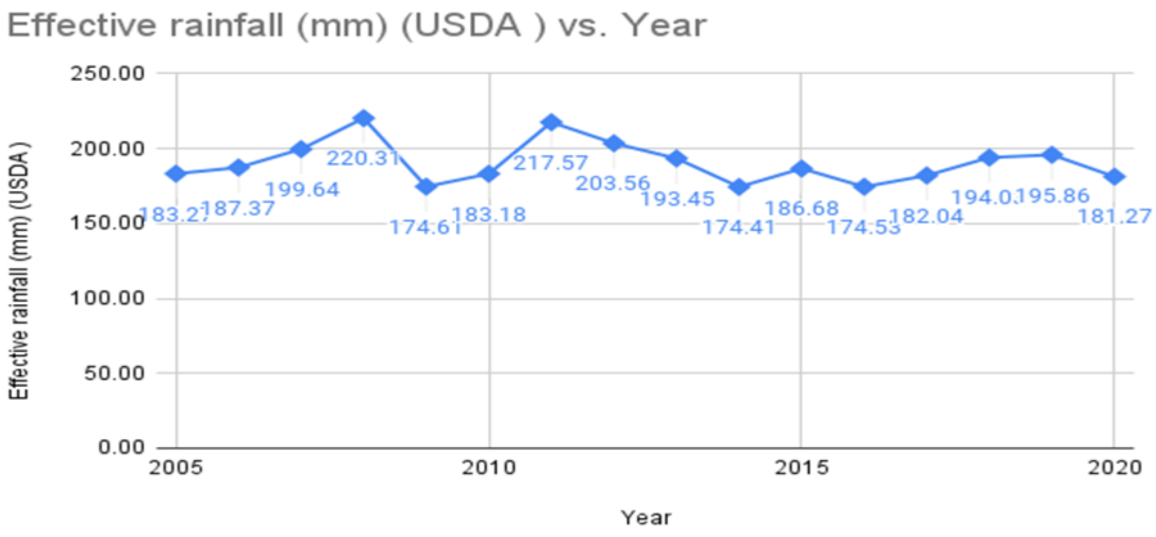
here, Pe = Effective rainfall

P = Rainfall.

- *USDA. Soil Conservation Service Method*
- $P_e = P \times (125-0.2P)/125$ for P< 250mm
- $P_e = 125 + 0.1P$ for P> 250mm

(link)

- After calculating effective rainfall from actual rainfall data using USDA's soil conservation service method, we have plotted a graph between time and effective rainfall and we got the average yearly effective rainfall in Punjab is 190.73mm.



(link)

Evapotranspiration:

- Evapotranspiration is the transfer of water from the soil to the surface through soil evaporation and plant transpiration. It is the combination of two processes: evaporation and transpiration.
- It varies depending on the season and the local climatic conditions. During the summer months, when temperatures are high, and rainfall is low, evapotranspiration rates tend to be higher. In contrast, during the winter months, when temperatures are cooler, and humidity levels are higher, evapotranspiration rates are lower.

- Evapotranspiration plays a vital role in the water cycle and the climate system, as it affects the amount of water that is available for surface runoff and groundwater recharge, as well as the exchange of heat and water vapor between the land and the atmosphere.

- It affects crop yields and irrigation requirements. The amount of evapotranspiration that occurs in a given area depends on a variety of factors, including temperature, humidity, wind speed, solar radiation, soil moisture, and vegetation cover. Various methods are used to estimate evapotranspiration, including weather station measurements, satellite remote sensing, and modeling techniques.

Reference evapotranspiration:

- The evapotranspiration value of the crop without water deficiency is called the reference evapotranspiration (ETo).

- The concept of ETo was introduced to study the need of air evaporation regardless of crop type, crop growth, and management. Soils do not affect ETo due to the high water content in surface evapotranspiration. Associating evapotranspiration processes with specific locations provides a reference to evapotranspiration processes at other locations. Eliminates the need to calculate evapotranspiration levels separately for each crop and growth. ETo values measured or calculated in different places or in different seasons can be compared as they represent evapotranspiration from the same place of use.
- The only thing that affects ETo is the weather forecast. We use the Hargreaves-Samani equation, a widely used empirical equation to estimate evapotranspiration (ETo).

- The Hargreaves-Samani equation is relatively simple and requires only temperature data as input, making it a useful tool in situations where other weather data (such as solar radiation) may not be available. The equation is as follows:

$$ET_0 = 0.0023 \times R_a \times (T_{mean} + 17.8)\sqrt{(T_{max} - T_{min})}$$

where:
ETo = reference evapotranspiration (mm/day)
Ra = extraterrestrial radiation (mm/day)
Tmean = mean daily temperature (°C)
Tmax = maximum temperature (°C)
Tmin = minimum temperature (°C)

Extraterrestrial radiation (Ra) represents the radiation received at the top of the earth's atmosphere on a horizontal surface, depending on latitude, date, and time of the day.

Actual evapotranspiration:

- Actual evapotranspiration (ETc) refers to the amount of water that is tranched by plants and evaporated from the soil surface over a given area over a given period of time.
- The ETc is determined by the crop coefficient, which incorporates the effects of various weather conditions in the ETo and the characteristics of the crop into the Kc coefficient:

$$ET_c = K_c \times ET_0$$

The crop coefficient (Kc) includes the results of the characteristics that distinguish certain crops from others. clipping system. (link)

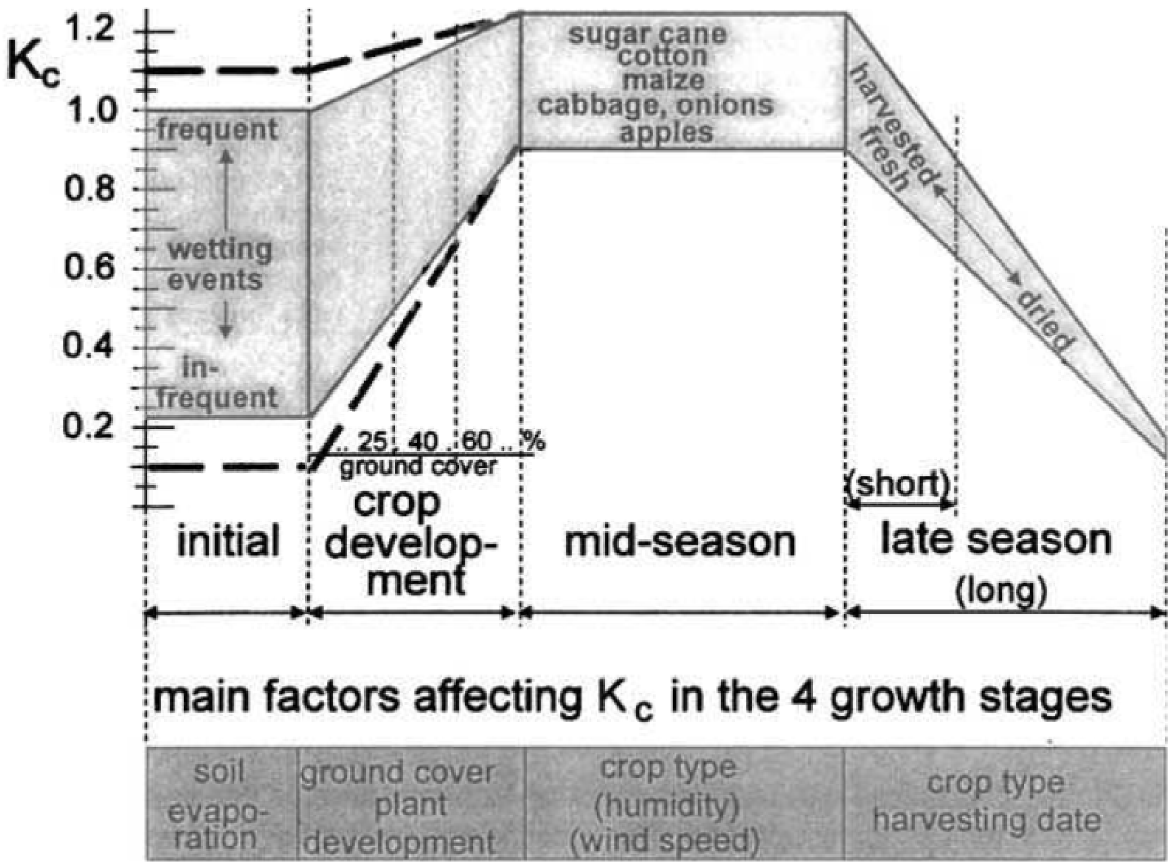
Kc values during the development and late season stages are interpolated.

- First period (Beginning): In this period, the leaf area is small and soil evaporation is dominant in evapotranspiration. Therefore, the Kc threshold is greater when the soil is wet or rainy, and lower when the soil is dry.
- Development stage (Deve): As the crop matures and more soil shade is used, evaporation becomes more and more limited, and gradually transpiration becomes the main process.
- Mid-season stage (Mid): In this phase, Kc reaches its maximum.
- Late season stage (Late): Kc values at the end of the late phase indicate crop production and water management. This value is high if the crop is watered frequently before the new harvest. If the crops are allowed to age and dry in the field before harvesting, the Kc value will be small because the stomatal conductivity of the leaves is very low.

Crop	$K_{c\,ini}$[1]	$K_{c\,mid}$	$K_{c\,end}$	Maximum Crop Height (h) (m)
Rice	1.05	1.20	0.90-0.60	1
i. Cereals	**0.3**	**1.15**	**0.4**	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Barley/Oats/Wheat	15	25	50	30	120	November	Central India
Rice	30	30	60	30	150	Dec; May	Tropics; Mediterranean

We use the crop coefficients of wheat and rice to calculate true evapotranspiration.



Calculation of actual evapotranspiration:

YEAR	MAX TEMP	MIN TEMERATURE	MEAN TEMP	sun radition in mm / day	Reference ET (mm per day)	sun radition (cropwat,	ET (per year)	actual evapotranspirat
2005	43.5	1.048286	22.274143	8.2	4.891684738	20	1761.006506	1826.432789
2006	45.3	0.329714	22.814857	8.2	5.102633247	20	1836.947969	1905.195689
2007	44.4	-0.42543	21.987285	8.2	4.99060432	20	1796.617555	1863.366888
2008	43.2	-1.81486	20.69257	8.2	4.838396566	20	1741.822764	1806.536318
2009	44.6	2.935143	23.7675715	8.2	5.02673744	20	1809.625478	1876.858092
2010	43	1.357143	22.1785715	8.2	4.833304225	20	1739.989521	1804.634965
2011	44.2	-0.87886	21.66057	8.2	4.963595907	20	1786.894526	1853.282622
2012	45.4	-0.53857	22.430715	8.2	5.108496361	20	1839.05869	1907.384829
2013	43.7	-1.28	21.21	8.2	4.901536906	20	1764.553286	1830.111342
2014	45.6	0.514286	23.057143	8.2	5.139656228	20	1850.276242	1919.019144
2015	43.8	1.320571	22.5602855	8.2	4.928220899	20	1774.159524	1840.074478
2016	44.9	1.863143	23.3815715	8.2	5.061389853	20	1822.100347	1889.796437
2017	46	-0.192	22.904	8.2	5.182831314	20	1865.819273	1935.139642
2018	43.7	0.064857	21.8824285	8.2	4.910922102	20	1767.931957	1833.61554
2019	45.6	-0.90816	22.34592	8.2	5.129234975	20	1846.524591	1915.128109
2020	45.9	-1.56086	22.16957	8.2	5.158742838	20	1857.147422	1926.145607

Extracted groundwater:

1)Extracted groundwater refers to water that has been pumped or otherwise removed from underground aquifers or other natural sources of groundwater. This water can be used for a variety of purposes, such as drinking, irrigation, and industrial processes. Over-extraction of groundwater can lead to a wide range of problems, one of which is the depletion of aquifers.

Finding extracted groundwater data of Punjab:
Data related to extracted groundwater of Punjab is collected for a span of 16 years (2005-2020).(link)

Irrigation: The process of applying water to crops artificially to supplement natural rainfall and ensure crop growth.

- **Irrigation through canal**

The Punjab state has an extensive network of irrigation canals that are fed by the rivers Sutlej, Beas, and Ravi. The canals are managed by the state government and provide water to farmers for their agricultural needs.

- **Irrigation through canals**: The canal system in Punjab has played a crucial role in the development of agriculture in the state. The availability of water through canals has facilitated the cultivation of high-yielding crops such as wheat, rice, and cotton. The canals also provide water for horticultural crops such as fruits and vegetables. However, the canal system in Punjab has faced some challenges in recent years. One of the major issues is the depletion of groundwater resources due to excessive use of water for irrigation. This has led to a decline in water levels in the canals and reduced their capacity to provide water for irrigation.

Canal regulates groundwater level in two ways

Groundwater recharge
Due to deep percolation
bed
During irrigation

groundwater recharge
due to seepage from canal

➢ Most of the canal length is unlined seepage losses that occur through the canal bed as per **the International Research Journal of Modernization in Engineering Technology and Science** Average seepage losses in the unlined canal are 0.415 cumec.
Yearly seepage is obtained as 0.0131 billion cubic meters (bcm)(link)

➢Punjab's total arable land is 42.90 hectares, of which 30.88 hectares are managed by the canal network, meaning that 70% of the total irrigation is done by the canal alone. This implies that 70% of evapotranspiration is fulfilled by canals. Water discharged from the canal goes to the fields, part of the water is taken crops and the other part deep percolates to recharge the groundwater. The amount of water infiltrating the soil depends upon the permeability of the soil in the fields. The higher the permeability, the higher is water recharging to the groundwater. Lower permeability leads to higher runoff which ultimately leads to more loss of water.

Reference: Department of Water resource, the government of Punjab, India (link)

Irrigation through groundwater extraction

- Groundwater is extracted for various purposes such as irrigation, domestic, industrial, and drinking, etc. While groundwater extraction can be a reliable source of irrigation, it can also have negative environmental impacts.

- According to ENVIS Center: Environmental Situation and Issues in Punjab, 95% of all groundwater withdrawn in the state is used for irrigation. Some of the groundwater is absorbed by the crops and the rest seeps deep into the ground, causing the water table to recede. Link

Groundwater depletion:

- Groundwater depletion occurs when the rate at which groundwater is extracted exceeds the rate at which it is replenished.
- Groundwater is a valuable resource for human consumption, irrigation, and industry, but excessive pumping can lead to different problems of which one main problem is the lowering of water tables, which can cause wells to dry up and reduce the amount of water available for irrigation and domestic use

1)This can have severe economic and social impacts, especially in rural areas, where agriculture is the primary source of livelihood.

2)Groundwater depletion can also lead to land subsidence, where the ground surface sinks as a result of the reduced water pressure in underlying aquifers. This can cause infrastructure damage, increased flood risk, and other environmental problems.

3)Furthermore, excessive pumping can result in the intrusion of saltwater into coastal aquifers, which can lead to saltwater contamination of freshwater resources.

4)Decreased streamflow: As groundwater levels decline, the amount of water that flows into streams and rivers can decrease.

5)Socio-economic impacts: Groundwater depletion can have significant impacts on local communities, particularly those that rely on groundwater for their livelihoods. This can include reduced agricultural productivity, decreased income for farmers, and other socio-economic impacts.

6)Several factors have contributed to groundwater depletion in Punjab, including the expansion of irrigated agriculture, the promotion of water-intensive crops like rice, inefficient irrigation practices, and lack of regulation and enforcement of groundwater use.

Methodology:

Calculation of groundwater depletion:

1)The main idea behind the calculation of groundwater depletion in Punjab is that it is the difference between the amount of extracted groundwater and the amount of recharge, as groundwater depletion is excess in the rate of extracted water compared to the recharged water.

2)Parameters required for the calculation of groundwater depletion

1)effective rainfall
2)crop area
3)evapotranspiration
4)canal irrigation
5)extracted groundwater
6)recharge

Groundwater depletion=groundwater extraction-groundwater recharge

$$GW_d = GW_E - GW_R$$

Where

Groundwater recharge= Irrigation + seepage + effective precipitation - Evapotranspiration

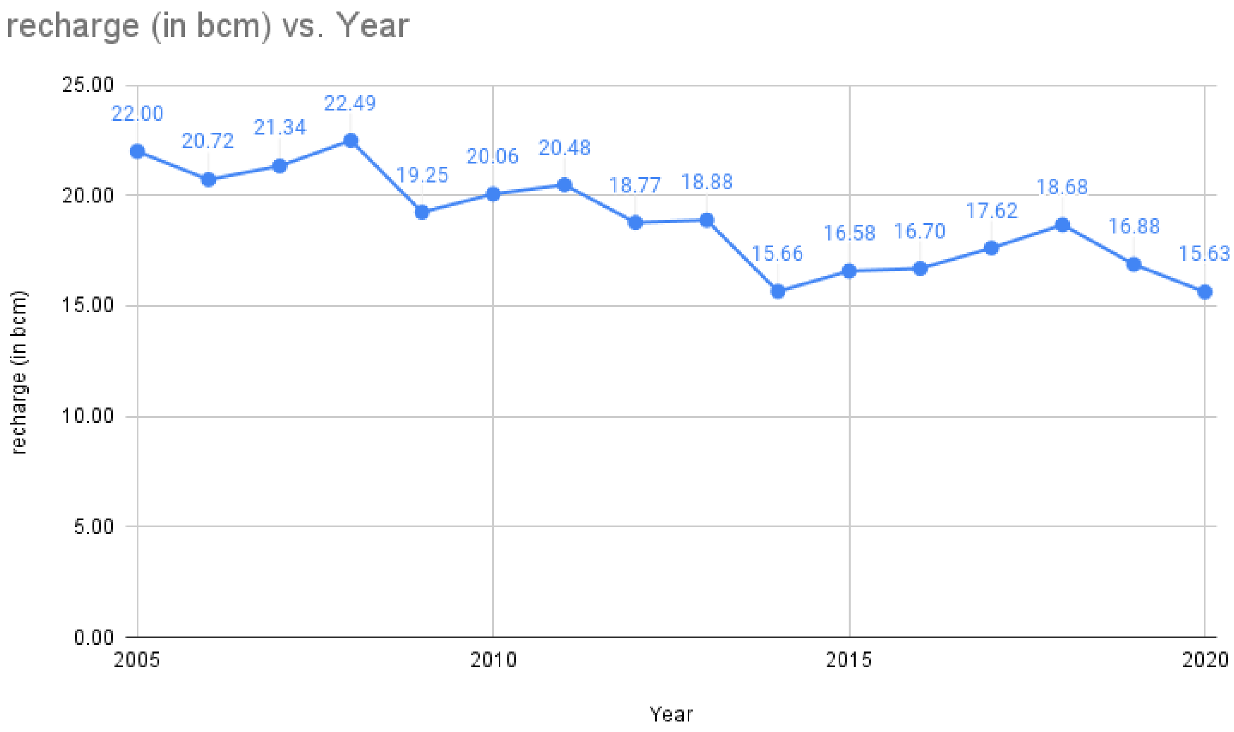
$$GW_R = I + S + PE - ET_0$$

Irrigation=irrigation through canal + irrigation through groundwater extraction

$$I = I_C + I_W$$

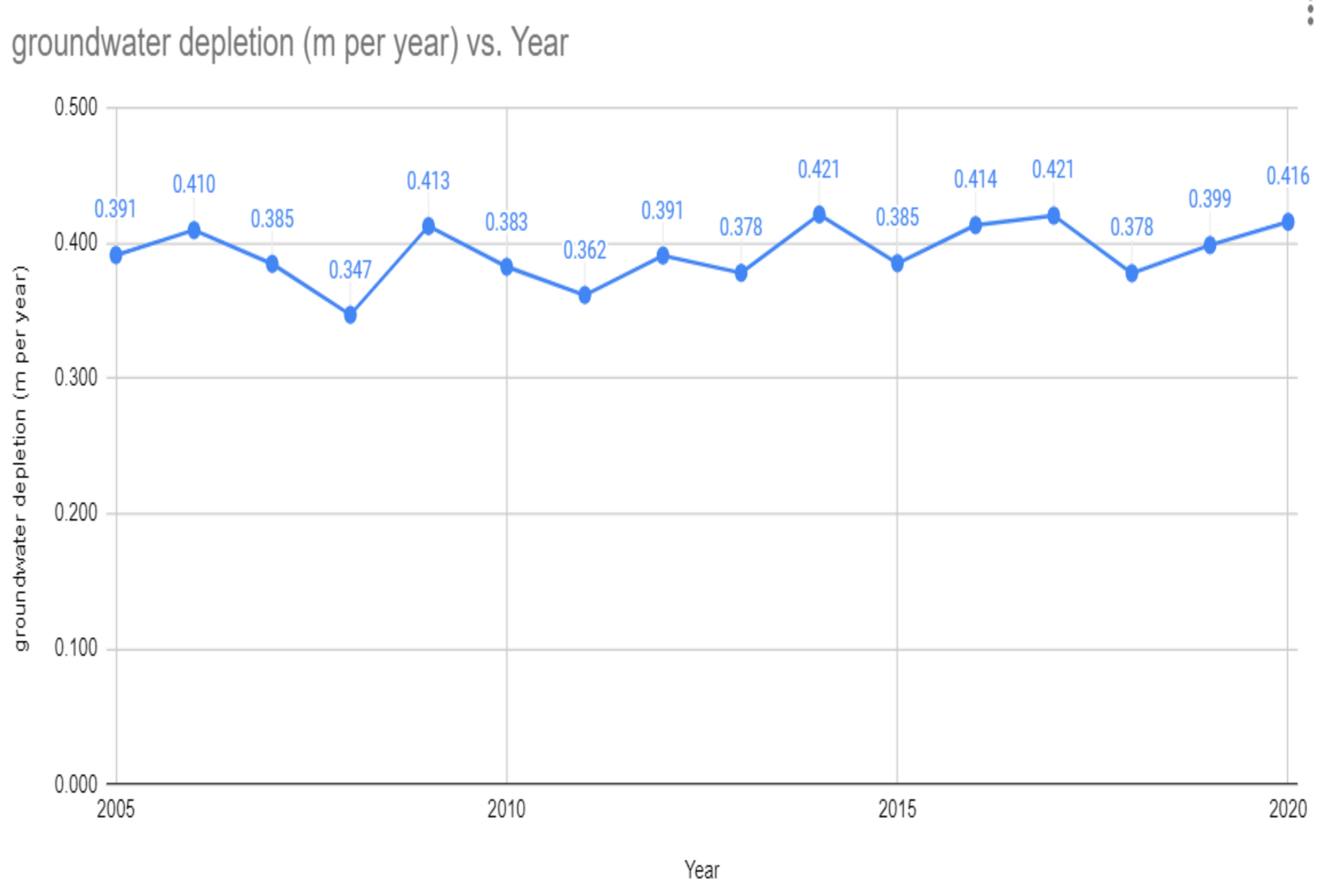
$$\Rightarrow GW_d = GW_E - (I_C + I_W + S + PE - ET_0)$$

On the basis of the above calculations graphs obtained are:



Year	ACTUAL (mm)	Effective rainfall (mm) (USDA)	Crop area(sq. km)	Evapotranspiration ET0(mm per day)	canal irrigation(mm per year)	Extracted groundwater (in bcm)	Irrigation (bcm) per year through groundwater extraction	irrigation(mm per year) through ground water extraction	recharge =(effective rainfall+irrigation +canal irrgation +seepage-evapotranspiration)	recharge (in bcm)	ground water depletion (bcm per year)	groundwater depletion (m per year)
2005	582.7	183.3	42722.3	1826.4	1296.8	38.72	36.78	861.00	514.9	22.00	16.72	0.391
2006	623.7	187.4	42813.4	1905.2	1352.7	38.26	36.35	849.05	483.9	20.72	17.55	0.410
2007	746.4	199.6	42786.4	1863.4	1323.0	37.81	35.92	839.46	498.7	21.34	16.47	0.385
2008	953.1	220.3	42793.4	1806.5	1282.6	37.35	35.48	829.20	525.6	22.49	14.86	0.347
2009	496.1	174.6	42756.2	1876.9	1332.6	36.90	35.05	819.79	450.1	19.25	17.65	0.413
2010	581.8	183.2	42783.6	1804.6	1281.3	36.44	34.62	809.14	469.0	20.06	16.38	0.383
2011	925.7	217.6	42830.7	1853.3	1315.8	35.98	34.18	798.14	478.3	20.48	15.50	0.362
2012	785.6	203.6	42843.1	1907.4	1354.2	35.53	33.75	787.80	438.2	18.77	16.75	0.391
2013	684.5	193.4	42797.3	1830.1	1299.4	35.07	33.32	778.52	441.2	18.88	16.19	0.378
2014	494.1	174.4	42928.4	1919.0	1362.5	33.75	32.06	746.88	364.8	15.66	18.09	0.421
2015	616.8	186.7	43201.0	1840.1	1306.5	33.23	31.57	730.74	383.8	16.58	16.65	0.385
2016	495.3	174.5	43202.4	1889.8	1341.8	34.56	32.83	759.96	386.4	16.70	17.86	0.414
2017	570.4	182.0	43201.3	1935.1	1373.9	35.79	34.00	787.02	407.9	17.62	18.17	0.421
2018	690.3	194.0	43716.8	1833.6	1301.9	35.20	33.44	764.92	427.2	18.68	16.52	0.378
2019	708.6	195.9	43755.4	1915.1	1359.7	34.33	32.61	745.36	385.8	16.88	17.45	0.399
2020	562.7	181.3	43794.0	1926.1	1367.6	33.85	32.16	734.29	357.0	15.63	18.22	0.416
Average						35.80			438.3	18.86	16.94	0.393

Observations and calculations



Results and observations:

➤ The average groundwater depletion is obtained to be 0.393 m per year or 16.94 bcm per year.
➤The average groundwater recharge per year is obtained as 438.3 mm per year or 18.86 bcm.
➤ Recharge vs time curve clearly shows that groundwater recharge is decreasing as time passes.
➤Total groundwater depleted in the last 16 years: 6.288 meters.
➤Average groundwater extraction per year is 35.80 bcm and for this extraction, recharge is only 18.86 bcm.

Post midsem approach

We pivoted our approach from the previous method to a new method named the 'Groundwater level fluctuation method'. (Reference: Ground Water Resource Estimation Committee Methodology).

The water level fluctuation method is applied to estimate the recharge using the Groundwater balance equation. The groundwater balance equation is expressed as,

The groundwater balance equation is expressed as,

$$h \times S_y = R_{rf} - D_G + R_c + R_{SW}$$

where h = rise in water level

S_y = specific yield

R_{rf} = rainfall recharge

D_G = gross ground water draft

R_C = recharge due to seepage from canals

R_{sw} = recharge from surface water irrigation

(In all variables above units are in mm)

Methodology

Irrigation demand:

●Irrigation demand is the quantity of water that is required by crop additional to the rainfall.

●Irrigation demand = crop water requirement - effective rainfall for crops

Here crop water requirement is same as actual evapotranspiration by crops

Effective rainfall (in mm/year) calculation:

●Collected rainfall data of 16 years annually.**(*<u>Reference</u>)**

●Using USDA's soil conservation service method calculate effective rainfall.

Collection of crop area data(in sq. km):

Same as the pre midsem approach.

Calculation of evapotranspiration :

We used the Hargreaves-Samani equation which is a widely used empirical equation for estimating reference evapotranspiration (ETo).

$$ET_0 = 0.0023 \times R_a \times (T_{mean} + 17.8)\sqrt{(T_{max} - T_{min})}$$

ETc is determined by the crop coefficient, which includes the effects of various weather conditions on ETo and the effects of crop characteristics on the Kc coefficient:

ETc = Kc * ETo

Calculation of recharge from surface water irrigation:

●It is part of water applied as surface irrigation that is contributing to groundwater recharge. It is calculated as:-

$$R_{SW} = 0.27 \times Q_{SW}$$

Where Qsw is the irrigation through the canal and can be calculated as,

●The total arable land in Punjab is 42.90 hectares, of which 30.88 hectares are managed by the canal network**.** (*Reference)

$$Q_{SW} = 0.71 \times Irrigation\ demand$$

Calculation of recharge from rainfall:

●Rrf = recharge from rainfall = fraction of actual rainfall which is contributing in deep percolation

$$R_{rf} = 0.1 \times Actual\ rainfall$$

Calculation of gross groundwater draft:

●**Groundwater draft:** Total groundwater withdrawal is the amount of groundwater taken from groundwater in a year and the calculation formula is as follows:

$$GROUNDWATER\ DRAFT(D_G) = D_f - D_d$$

Where D_f is the amount of extracted groundwater used for irrigation. It is calculated from the formula,

$$D_f = 0.29 \times Irrigation\ demand$$

(Here, 29% of irrigation demand comes from groundwater draft as given by the Department of water sources of punjab.(*Reference)

D_d is the amount of groundwater that is going through deep percolation. It is calculated using the formula,

$$D_d = 0.1 \times D_f$$

Year	Effective rainfall (mm) (USDA) (r1)	crop irrigation demand(cubic meter per year)(c1)	irrigation demand(m^3 per year)(m1)	Df=0.29*m1	Dd = 0.1*Df	Groundwater draft(Dg)= Df-Dd
2005	183.3	1826.432789	1643.162789	476.5172088	47.65172088	428.8654879
2006	187.4	1905.195689	1717.825689	498.1694497	49.81694497	448.3525047
2007	199.6	1863.366888	1663.727888	482.4810875	48.24810875	434.2329787
2008	220.3	1806.536318	1586.227318	460.0059222	46.00059222	414.00533
2009	174.6	1876.858092	1702.244092	493.6507866	49.36507866	444.2857079
2010	183.2	1804.634965	1621.452965	470.2213598	47.02213598	423.1992238
2011	217.6	1853.282622	1635.708622	474.3555003	47.43555003	426.9199503
2012	203.6	1907.384829	1703.825829	494.1094904	49.41094904	444.6985413
2013	193.4	1830.111342	1636.664342	474.6326593	47.46326593	427.1693934
2014	174.4	1919.019144	1744.607144	505.9360718	50.59360718	455.3424646
2015	186.7	1840.074478	1653.391478	479.4835286	47.94835286	431.5351758
2016	174.5	1889.796437	1715.268437	497.4278466	49.74278466	447.6850619
2017	182.0	1935.139642	1753.103642	508.4000562	50.84000562	457.5600505
2018	194.0	1833.61554	1639.58154	475.4786466	47.54786466	427.9307819
2019	195.9	1915.128109	1719.270109	498.5883315	49.85883315	448.7294984
2020	181.3	1926.145607	1744.876607	506.0142161	50.60142161	455.4127945

Specific yield(S_y):- The average volume of water that can be drained, per unit surface of aquifer per unit drop of head.

Here, we took S_y = 0.12 (*Reference)

Calculation of recharge by seepage(R_c):

● By Bureau of Indian standard code IS 7112: 1973 “criteria for the design of cross section for an unlined canal”

❖ $Wetted\ perimeter = P = 4.75 \times \sqrt{Q}$

❖ $Wetted\ Area = P \times Length\ of\ canal$

●**As per GEC 1997:**

Table 5. NORMS FOR RECHARGE DUE TO SEEPAGE FROM CANALS AS RECOMMENDED BY GEC 1997

(a) Unlined canals in normal soils with some clay content along with sand	1.8 to 2.5 cumecs per million sq m of wetted area (or) 15 to 20 ham/day/million sq m of wetted area
(b) Unlined canals in sandy soil with some silt content	3.0 to 3.5 cumecs per million sq m of wetted area (or) 25 to 30 ham/day/million sq m of wetted area
(c) Lined canals and canals in hard rock area	20% of above values for unlined canals

●Here we have taken the recharge factor as 20 ham/day/million sq m of wetted area.

Seepage= (seepage factor)/Wetted area

●**Calculations:**

CANAL	discharge	wetted perimeter	distance(KM)	area(10^3 m^2)	Seepage(Rc)(mm)
Sirhind Canal	12620	89.783	59.440	5336.691	0.813
Bist Doab Canal	1408	29.989	43.000	1289.536	2.434
Upper Bari Doab	9000	75.820	42.350	3210.985	0.963
Sirhind Feeder	5264	57.986	136.530	7916.798	1.259
Eastern Canal	3197	45.189	8.020	362.418	1.615
Bhakra Main line	12455	89.194	161.360	14392.336	0.818
Shahnehar Cana	875	23.641	24.230	572.824	3.088
Total					10.991

Recharge:

The process of water entering an aquifer from the surface, through deep percolation from precipitation, irrigation, and seepage.

$$Recharge = (R_{rf} + R_{SW} + R_C - D_G)/S_y$$

R_C= recharge due to seepage from canals

R_{sw}= recharge from surface water irrigation

R_{rf}= rainfall recharge

D_G = gross ground water draft

S_y= specific yield(0.12)

●Ground water level at the end of 2004 is **10.937 meter**(*Reference)

Final calculations:

Year	ACTUAL (mm)	Effective rainfall (mm) (USDA)	Crop area(sq.km)	crop water demand(cubic meter per year)	irrigation demand(m^3 per year)	Qsw (mm)	Df (mm)	Rrf (mm)	Dd (mm)	Rc (mm)	Rsw (mm)	RECHARGE (mm)	groundwater level (m)
2005	582.7	183.3	42722.3	1826.4	1643.2	1166.65	476.52	58.27	47.6517	0.4362	314.99	-459.71	11.3967
2006	623.7	187.4	42813.4	1905.2	1717.8	1219.66	498.17	62.37	49.8169	0.4362	329.31	-468.66	11.8654
2007	746.4	199.6	42786.4	1863.4	1663.7	1181.25	482.48	74.64	48.2481	0.4362	318.94	-335.18	12.2005
2008	953.1	220.3	42793.4	1806.5	1586.2	1126.22	460.01	95.31	46.0006	0.4362	304.08	-118.17	12.3187
2009	496.1	174.6	42756.2	1876.9	1702.2	1208.59	493.65	49.61	49.3651	0.4362	326.32	-565.96	12.8847
2010	581.8	183.2	42783.6	1804.6	1621.5	1151.23	470.22	58.18	47.0221	0.4362	310.83	-447.90	13.3326
2011	925.7	217.6	42830.7	1853.3	1635.7	1161.35	474.36	92.57	47.4356	0.4362	313.57	-169.54	13.5021
2012	785.6	203.6	42843.1	1907.4	1703.8	1209.72	494.11	78.56	49.4109	0.4362	326.62	-325.67	13.8278
2013	684.5	193.4	42797.3	1830.1	1636.7	1162.03	474.63	68.45	47.4633	0.4362	313.75	-371.15	14.1989
2014	494.1	174.4	42928.4	1919.0	1744.6	1238.67	505.94	49.41	50.5936	0.4362	334.44	-592.11	14.7910
2015	616.8	186.7	43201.0	1840.1	1653.4	1173.91	479.48	61.68	47.9484	0.4362	316.96	-437.17	15.2282
2016	495.3	174.5	43202.4	1889.8	1715.3	1217.84	497.43	49.53	49.7428	0.4362	328.82	-574.20	15.8024
2017	570.4	182.0	43201.3	1935.1	1753.1	1244.70	508.40	57.04	50.8400	0.4362	336.07	-533.48	16.3359
2018	690.3	194.0	43716.8	1833.6	1639.6	1164.10	475.48	69.03	47.5479	0.4362	314.31	-367.94	16.7038
2019	708.6	195.9	43755.4	1915.1	1719.3	1220.68	498.59	70.86	49.8588	0.4362	329.58	-398.76	17.1026
2020	562.7	181.3	43794.0	1926.1	1744.9	1238.86	506.01	56.27	50.6014	0.4362	334.49	-535.12	17.6377
Average												-418.79	

Here the negative value of recharge signifies depletion of groundwater level.

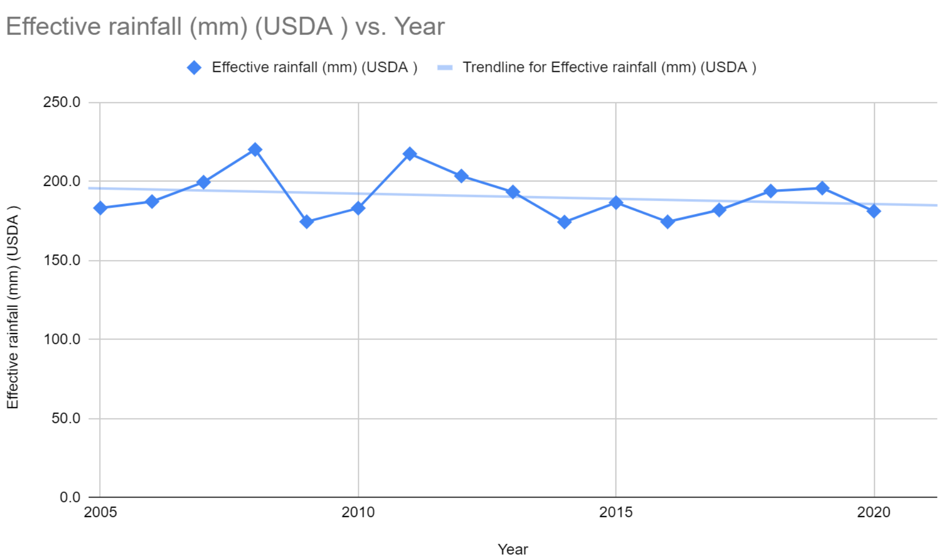
Results

From the above data, we can deduce that average groundwater depletion is coming out to be **0.419 meters** per year.

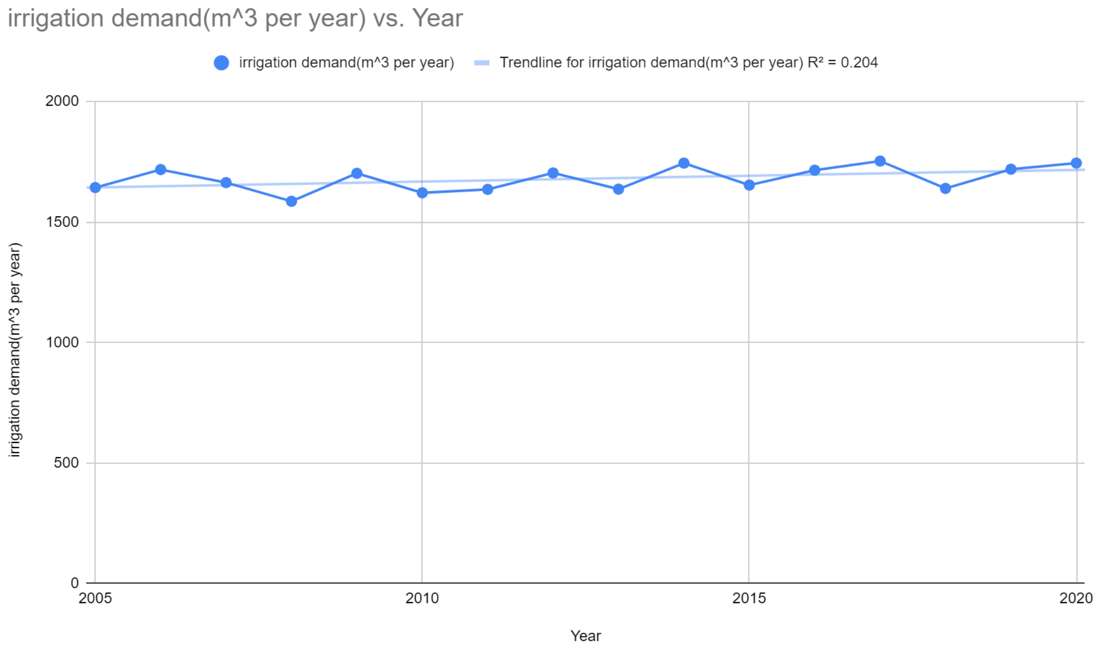
The groundwater level decreased to **17.6377 meters** (calculated from surface level) which was **11.3967 meters** (calculated from surface level) at the end of 2005.

Graphs:

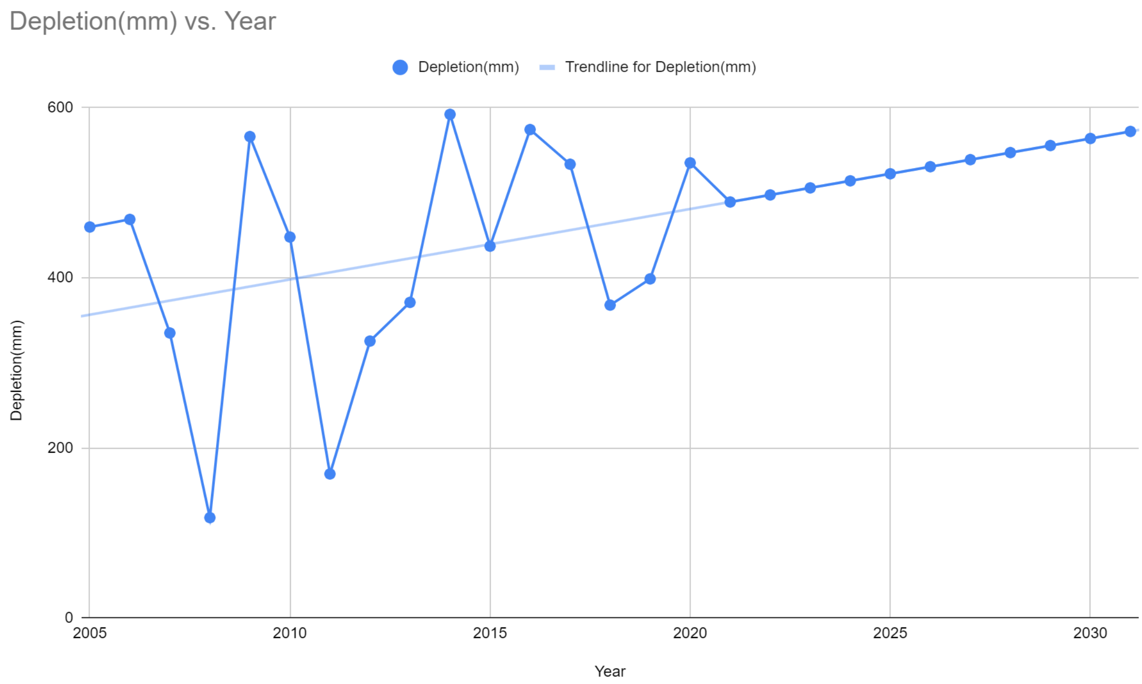
1. Effective rainfall vs Year



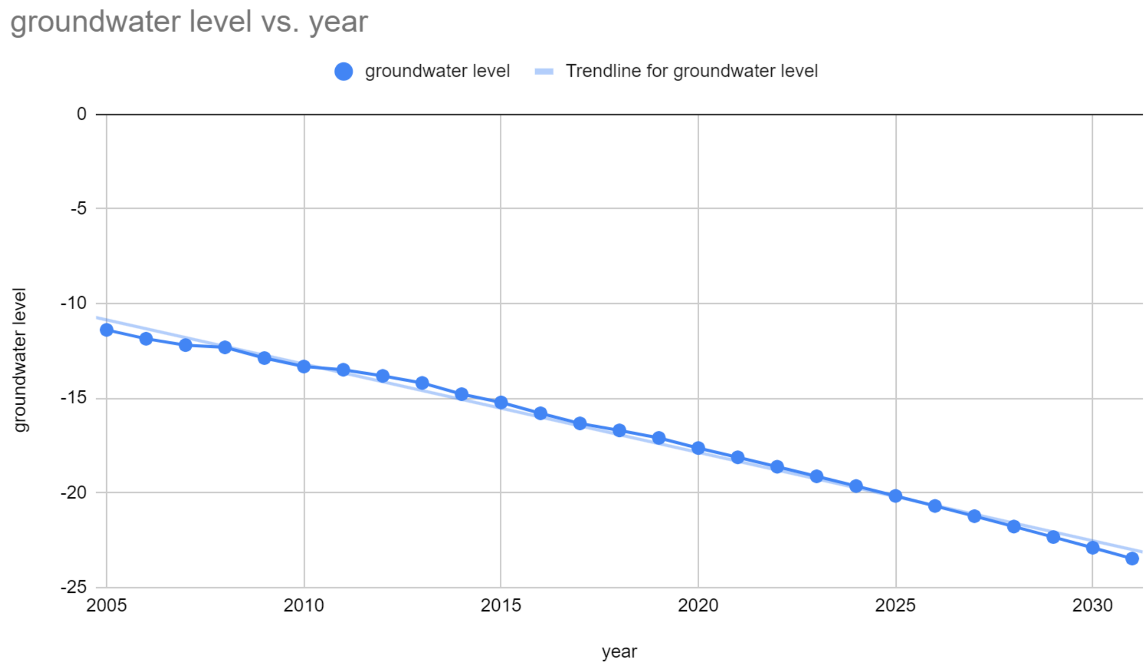
2. Irrigation demand vs Year



3. Depletion vs Year



4. Groundwater level vs Year



Assuming ground surface as the reference point that takes ground surface level as zero.

Inference

●As per the results obtained, the average groundwater level of Punjab has decreased by 7.228 meters in the last 17 years. From the trend obtained, we can deduce that the average groundwater table of Punjab will fall to 25 meters by 2030.
●From the graph, groundwater depletion is increasing.
●From the result obtained, we see that effective rainfall decreases with time. So in conclusion the crop water demand fulfilled by rainfall is decreasing which says that irrigation demand is increasing which is justified by the graph of irrigation demand.

Solutions

1. Recharge of the confined aquifer from water-carrying structures:

- Here we insert pipes from a river bed, pond, and other water structures. These pipes will connect these water sources to the deep unconfined aquifer underground.
- We will insert mechanical valves at the opening of pipes to the water source. During the monsoon season or whenever the water level is high in our structures we will open the valves which will allow the water to deep percolate into the unconfined aquifer without any resistance recharging the groundwater level.
- This will compensate for some fraction of groundwater extraction through tube wells and wells. This method will be more beneficial where the permeability of soil is lesser. Since Punjab consists of 5 rivers and 7 main canals so this method will be very efficient.

2. Construction of recharge tubes:

- These we can construct at the area of higher runoff, especially with lesser permeability. We can dig a hole in a significant area and fill it with coarser aggregates.
- These aggregates will provide high permeability, which ultimately will allow higher discharge to deep percolate. These tubes can be installed near paddy fields where high amounts of irrigation water flow away as runoff or water remains stagnant.

$$\text{No. of Structures} = \frac{\text{Total Surface Water runoff Considered}}{\text{AverageGross Capacity of Single tube (Considering Multiple tubes)}}$$

3. Others:

- These are the solutions currently existing in different parts of the world.
- Rooftop rainwater harvesting,
- Artificial Recharge using Injection Well Technique in which pressure is applied to pump water into the land.
- Cooperative use of water by farmers: farmers will be suggested to use water in cooperative use, which leads to less depletion than uncooperative use.
- Crop rotation