CP 302: Capstone-I

Crop Water Requirement for Punjab Considering Climate Change

Under the supervision of Dr. Sagar Rohidas Chavan, Dr. Ickkshanshu Sonkar, Dr. Sayantan Ganguly, Dr. Ratan Sarmah

Group Members:

Aman Kumar	2020CEB1005
Harshdeep Singh	2020CEB1010
Lakshay Bansal	2020CEB1017
L. Krushna S.	2020CEB1018
Vinay Jain	2020CEB1034

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Introduction :

Agriculture is the primary source of livelihood in Punjab. In Punjab, irrigation is essential for crop growth and yield production, as the region receives low rainfall, especially during the growing season. The water requirement of crops is mainly fulfilled through irrigation, either by canals or tube wells.

In accordance with the above factors, this project is based on predicting the water requirements of the sample crop “Wheat” for different soil types and climatic conditions in Punjab.

Motivation :

Too much water can increase weed pressure and create a disease-conducive environment. Plant growth and yield can also be affected by overwatering. If the plant does not get enough water, it will shrink and become stressed.

Due to some changes in environmental factors, the trend of climatic conditions may vary. This may affect the precipitation or wind speed factors unknown to the farmers. Therefore, by using their traditional farming practices, farmers might not be able to achieve the crop productivity they could have achieved.

Suppose a farmer knows in advance about the desirable range of irrigation water that needs to be provided to the crop in the coming years or months, considering the above factors. In that case, the farmer can pre-plan and provide the proper amount of irrigation water to crops timely.

Goals :

This project focuses on predicting the water requirements of the sample crop “Wheat” for different soil types and climatic conditions in Punjab.

Its process is governed by understanding and analysing the trend of water requirements and crop yield for the past years.

Literature Review:

Before our mid-semesters, we were using the NASA Laarc website for the collection of required parameters (min-max temperature, relative Humidity, Precipitation, and Wind speed). But our results showed some deviations from the literature/research paper that was found online.

So, upon discussion with the professors, they suggested us to use NCEP Reanalysis 2 product data in place of NASA .It is because NCEP data is the most dependable and accurate source for climate and environmental parameters. We implemented this suggestion and observed that the results we obtained were significantly improved, aligning more closely with real-world values.

Softwares Used :

1. **CropWat:** Cropwat is a computer program developed by the Food and Agriculture Organization of the United Nations (FAO) to calculate the water requirements and irrigation of crops. The name Cropwat is short for “Crop Water Requirements”. Cropwat takes into account factors such as plant type, soil type, climate and watering schedule to calculate how much water a plant needs for optimal growth and development. The program can be used to determine the water needs of different crops, design irrigation schedules, and estimate the impact of climate change on crop water needs.

2. **QGIS:** QGIS stands for Quantum Geographic Information System. It is a geographic information system (GIS) software, allowing users to analyse and edit spatial information as well as visualise the data using maps, charts and diagrams. Here, this software is used to make divisions of Punjab as Region 1,2,3. Area distribution of each region of Punjab in their respective grid is also calculated using QGIS. The area is distributed in grids of 2-degree longitude and 2-degree latitude. According to these grids, corresponding data is then weighted with respect to the total area.

3. **MATLAB:** MATLAB is a fourth-generation high-level programming language and interactive environment for numerical computation, visualisation and programming. Here, Matlab software is used to extract the data into a desired format corresponding to particular longitude and

latitude, which is then used in grid-distributed layers to find out weighted data. We have the data of 5 parameters: Min -Max Temperature, Precipitation,Wind Speed, and Relative Humidity. Data collected for these 5 parameters were converted into the desired format using MATLAB.

4. **NCEP/DOE REANALYSIS 2:** The NCEP/NCAR Reanalysis is an atmospheric reanalysis produced by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). It is a continually updated globally gridded data set that represents the state of the Earth's atmosphere. We have collected data for the above-mentioned 5 parameters from this NCEP/NCAR Reanalysis 2 model at Ground Surface or 2 m above ground. Collected Data of input parameters such as wind speed and parameters is run in MATLAB using the code mentioned in the next slide.

Factors Affecting Crop-water Requirement :

1. **Reference Evaporation (ETo)**: ETo is the amount of water lost through evaporation and transpiration from a hypothetical grass crop that has an ample amount of water and used as a reference for estimating the water needs of other crops. Various meteorological parameters, including temperature, humidity, wind speed, and solar radiation, determine ETo. If reference evapotranspiration increases, crop water requirements will increase.

2. **Relative Humidity(RH)**: Relative humidity is a measure of the percentage of water vapour in the air compared to the maximum amount of water vapour the air can hold at a specific temperature. When Relative humidity is low, transpiration increases, causing water deficits in the plant and increasing crop-water requirements.

3. **Extraterrestrial Radiation**: Extraterrestrial radiation (ETR) is the energy received from the Sun outside the Earth's atmosphere. It is also referred to as solar radiation. The amount of ETR received by the Earth varies depending on the position of the Earth in its orbit around the Sun and the angle of the Sun's rays. At the equator, the Sun's rays are more direct, and the amount of ETR received is higher than at the poles, where the Sun's rays are more oblique.

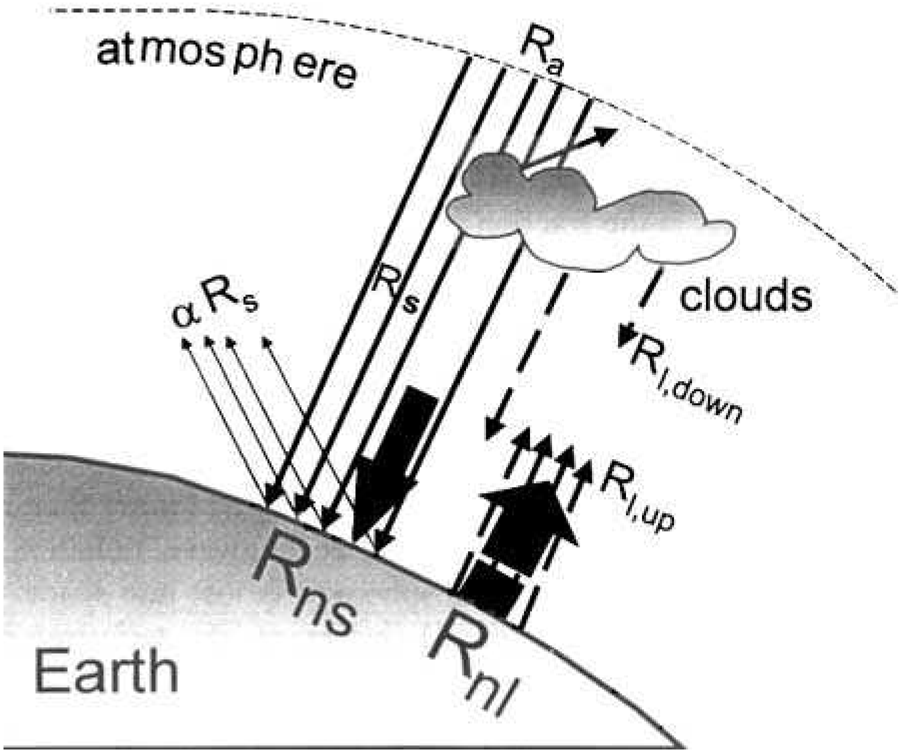


Fig-1: Extraterrestrial Radiation

4. **Effective Rainfall**: Effective rainfall is the portion of the total rainfall available for plant use and contributes to soil moisture recharge. It is the difference between the total rainfall and the amount of water lost due to runoff, deep percolation, evaporation, and interception by the canopy of the plants. If effective rainfall increases then irrigation demand will decrease for crop water requirement.

5. **Crop Coefficient (Kc)**: Crop coefficient (Kc) is a dimensionless factor that is used to estimate a particular crop's water requirements. It represents the ratio of the crop's actual evapotranspiration (ETc) to the reference evapotranspiration (ETo) under standard conditions. The crop coefficient varies with the crop's growth stage and with environmental conditions such as temperature, humidity, solar radiation, and wind speed. Different crops have different Kc values depending on their growth characteristics and water use efficiency. Crop coefficients are used with ETo data to estimate the amount of water a particular crop requires at a specific growth stage. The crop's water requirement can be calculated by multiplying the ETo by the crop coefficient. The Kc for a given crop varies over the crop-growing Stages since ground cover, Crop height, and leaf area change as the crop develops. A plant with a higher crop coefficient needs more water.

    a. **Initial period (Init)**: During this period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the Kc during the initial period is large when the soil is wet from irrigation or rainfall and is low when the soil surface is dry.

b. **Development stage (Deve):** As the crop grows, it shades more and more of the ground. It keeps the ground below it cool, and this, in turn, reduces evaporation and transpiration gradually becomes the major process.

c. **Mid-season stage (Mid):** This is the stage at which the Kc reaches its maximum value.

d. **Late season stage (Late):** the Kc value at the end of the late season stage reflects crop and water management practices. This value is high if the crop is frequently irrigated until harvested. If the crop is allowed to reach the dry conditions in the field before harvest, the Kc value will be small.

Variations in Crop coefficient values during the development of the crop is illustrated in the next page.It also contains the main factors affecting crop coefficient in the four growth stages like soil evaporation, ground cover, crop type and harvesting date etc.

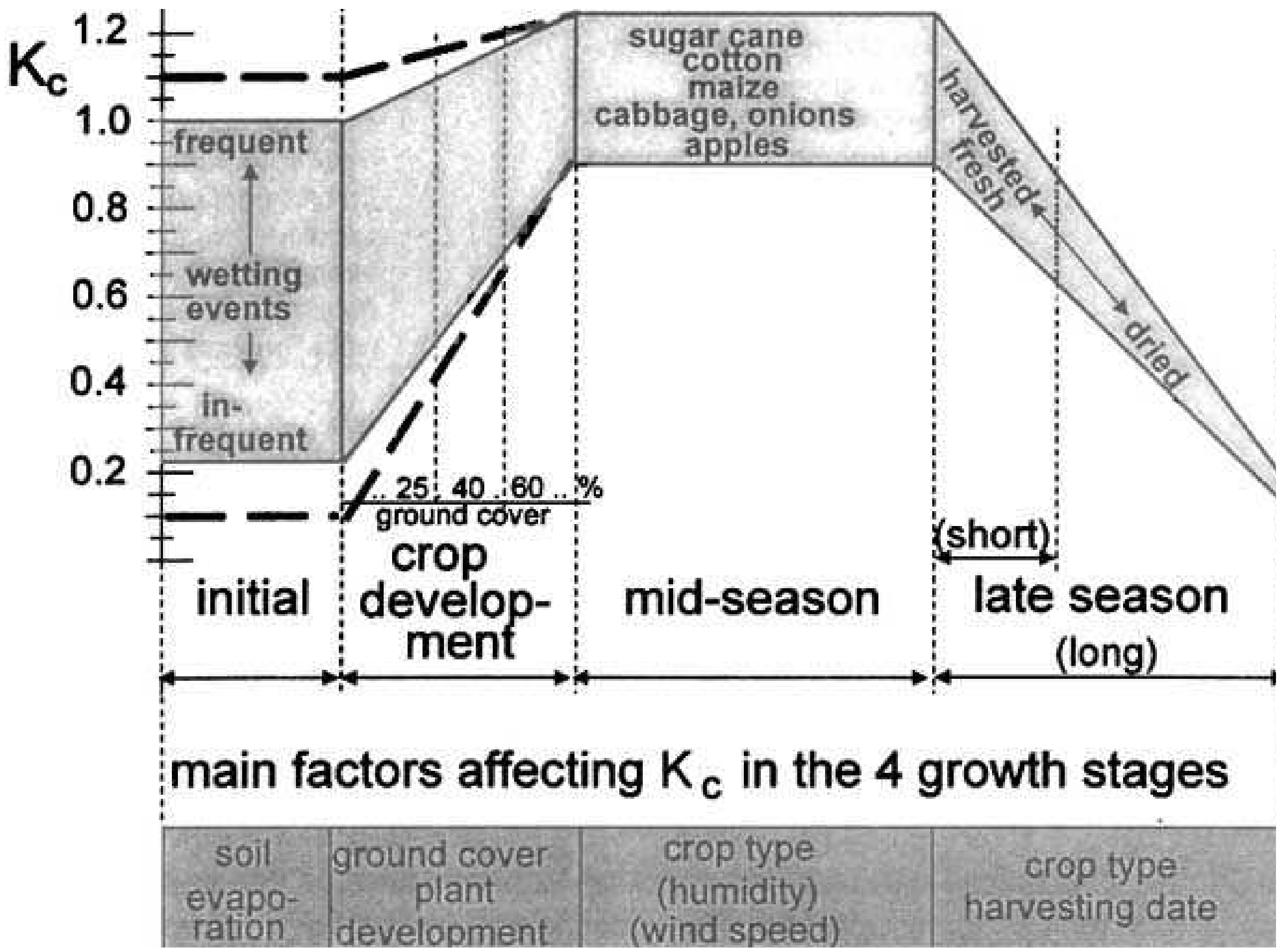


Fig-2: Factors affecting Crop Coefficient (Kc)

6. **Yield Response Factor:** Yield response to the water supply is quantified by yield response factor (Ky), which relates relative yield decline to relative evapotranspiration deficit. Water deficit of a given unit, expressed as the ratio of crop evapotranspiration under non-standard conditions (ETc adj) to crop evapotranspiration at each growth stage.

7. **Critical depletion factor:** The critical depletion fraction (p) represents the critical sensitive crops with limited root systems at high evaporation all soil moisture level at which water stress affecting evapotranspiration and crop yields first occurs. The values are expressed as a fraction of the Total Available Water (TAW) and are generally between 0.4 and 0.6, assuming higher values for deep and densely rooted plants with low evaporation. The crop with a higher critical depletion factor is susceptible to facing water shortages. In addition, the p-part is a function of the atmospheric evapotranspiration capacity. With lower ETc coefficients, the p-partition value is higher than with high ETc coefficients.

8. **Maximum infiltration rate**: It is the maximum amount of water that can penetrate the soil within a day, and is measured in millimetres per day. It varies based on several factors such as the type of soil, slope degree, and the intensity of rain or irrigation. The hydraulic conductivity of the soil at saturation is equivalent to the maximum percolation rate. It is possible to estimate the runoff (RO) that takes place when the precipitation intensity surpasses the soil's infiltration capacity by utilising the maximum infiltration rate.

Punjab Regional Distribution based on soil types

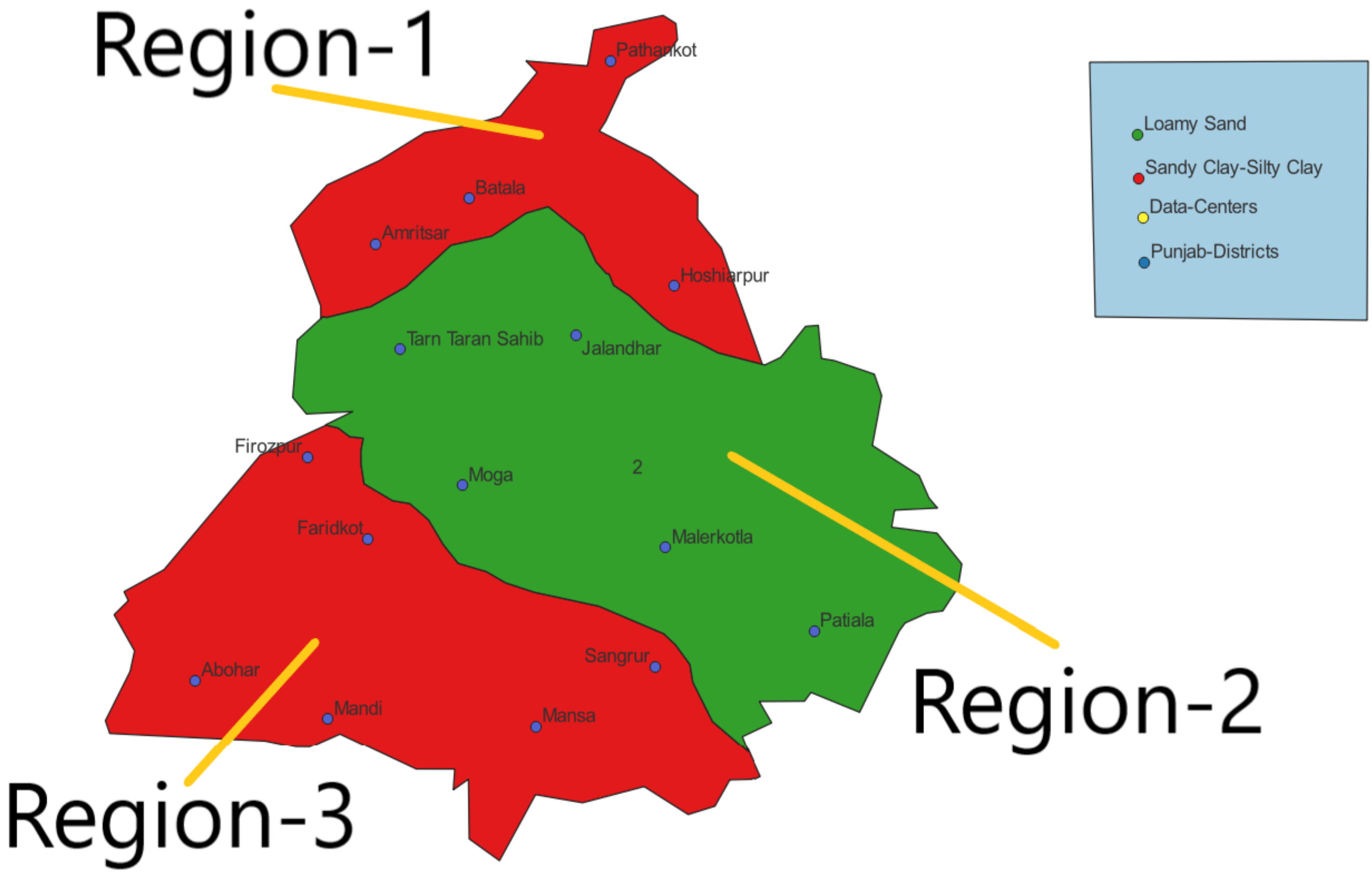


Fig-3: Punjab Division based on Soil Type

Punjab's area is distributed (Using **QGIS**) by the main soil present in the region. The above area is then distributed in grids of 2-degree longitude and 2-degree latitude. According to these grids, corresponding data is then weighted with respect to the area distributed in each grid. The area distributed for each layer is shown below:

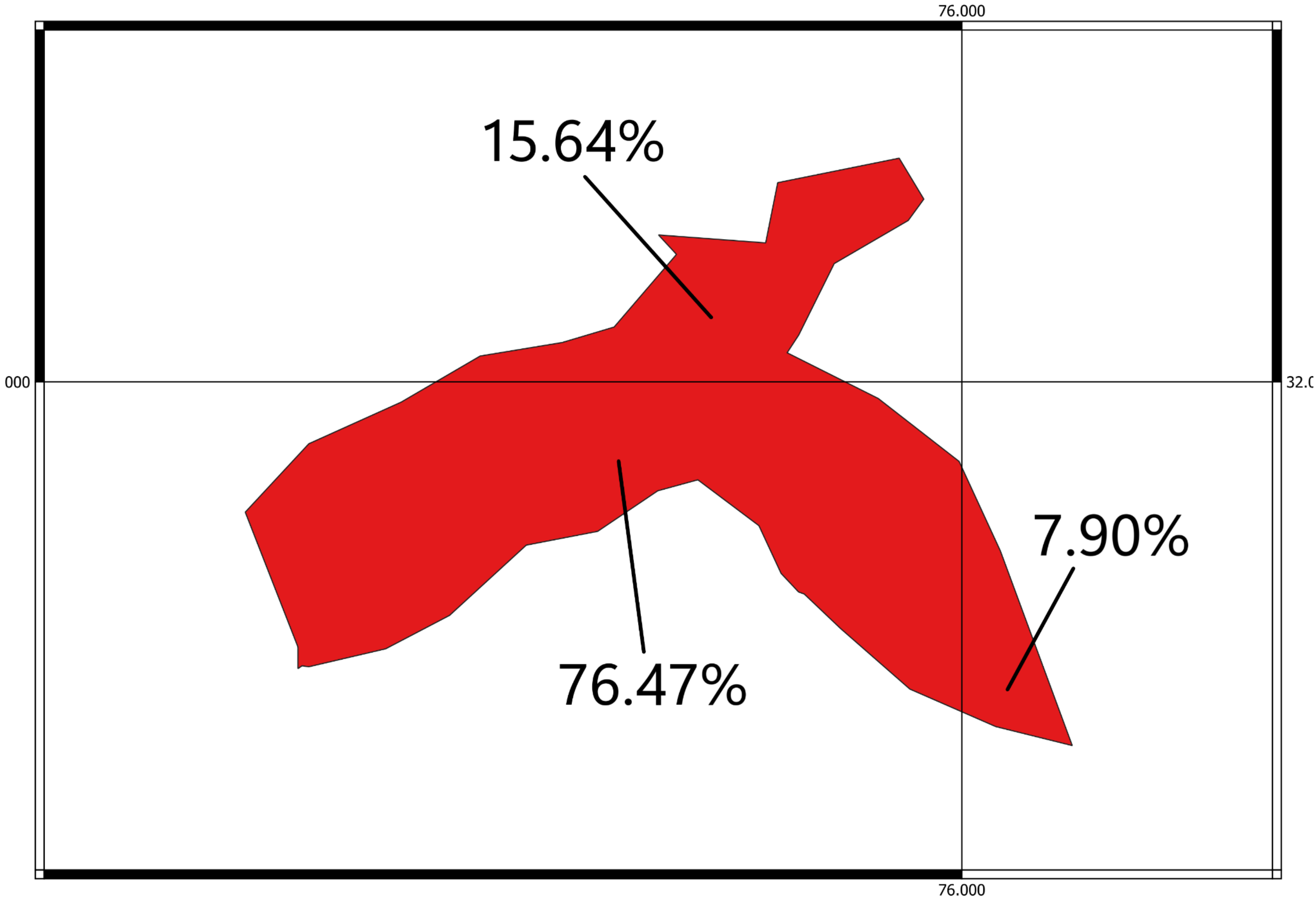


Fig-4: Region-1 Area Distribution

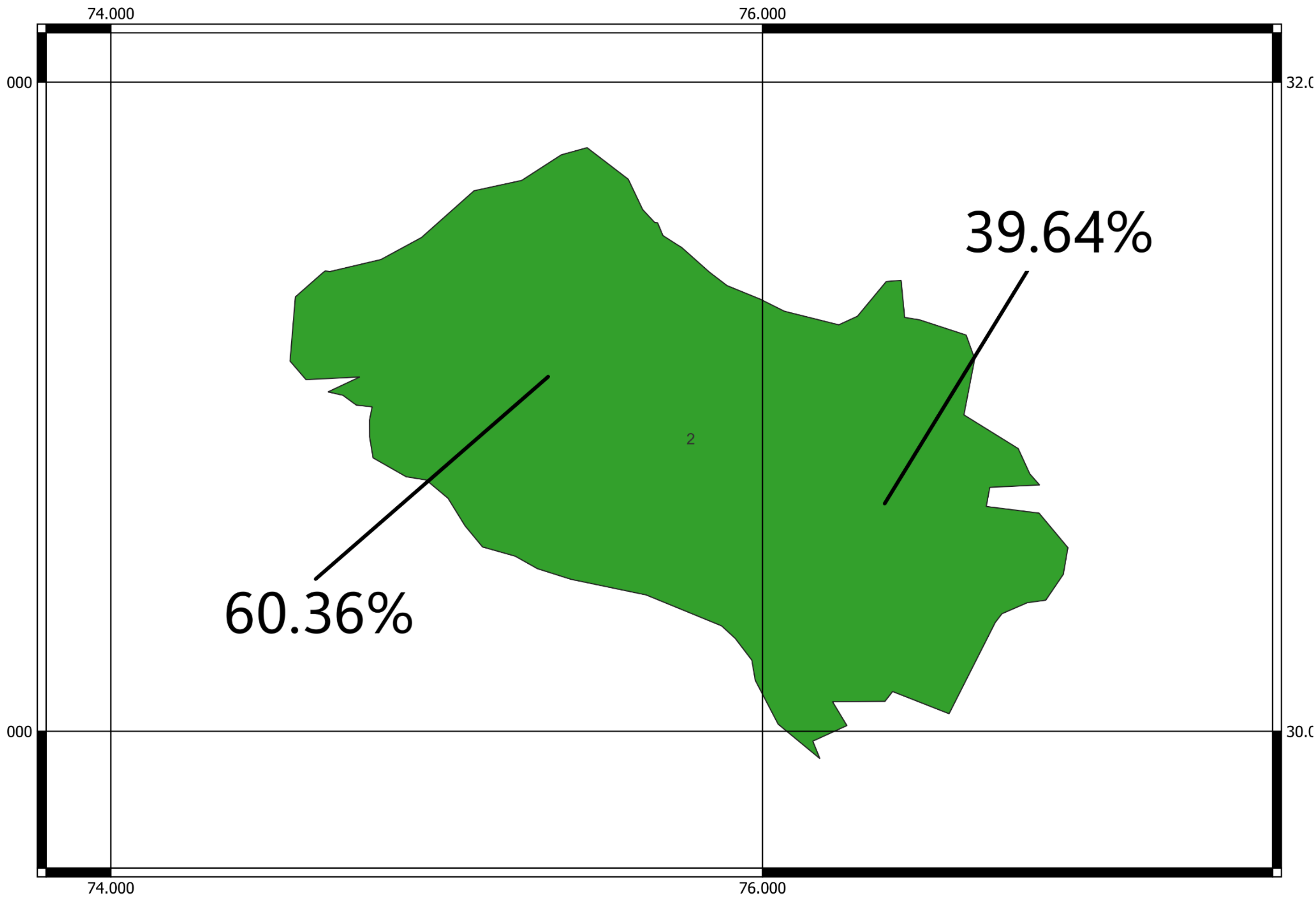


Fig-5 : Region-2 Area Distribution

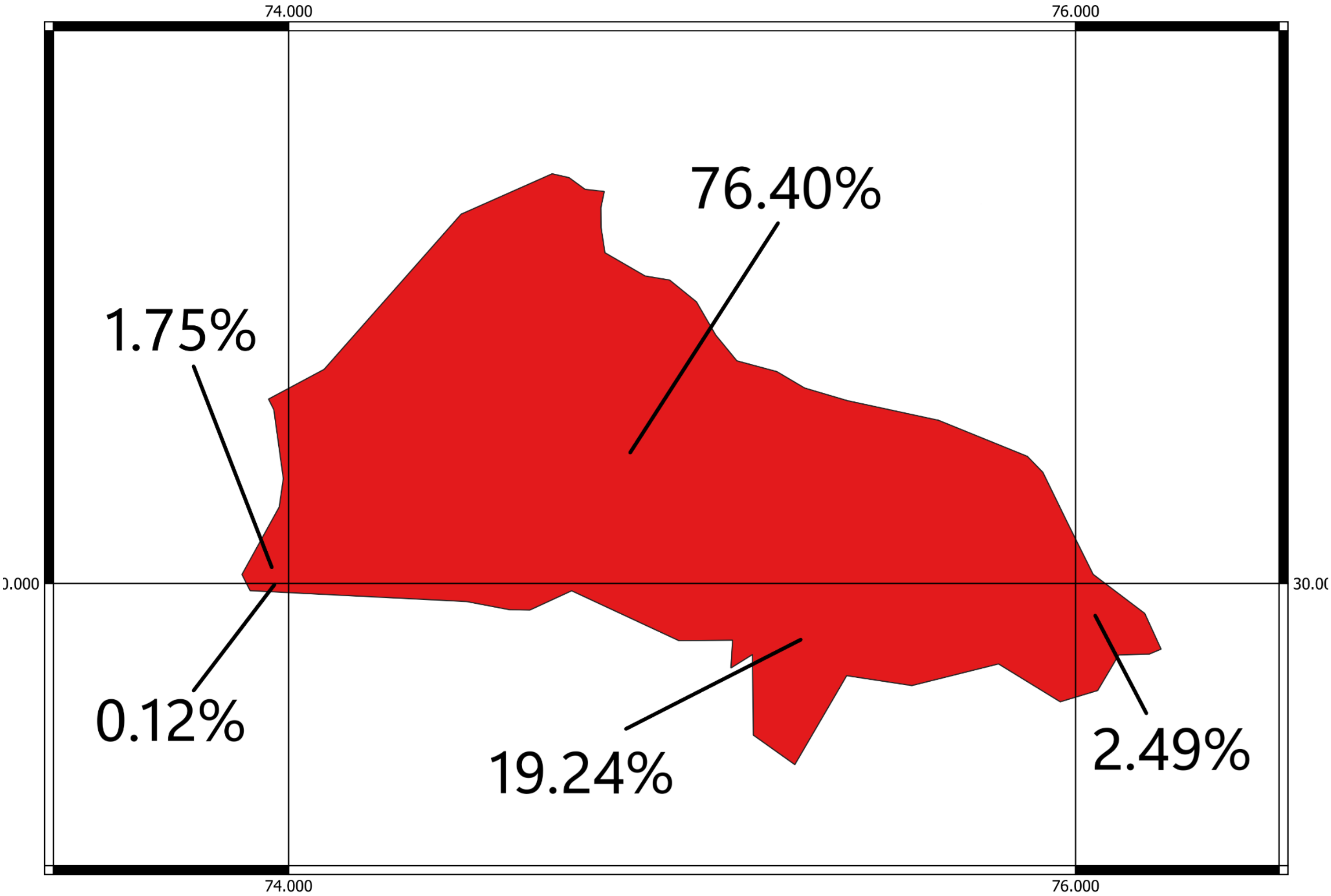
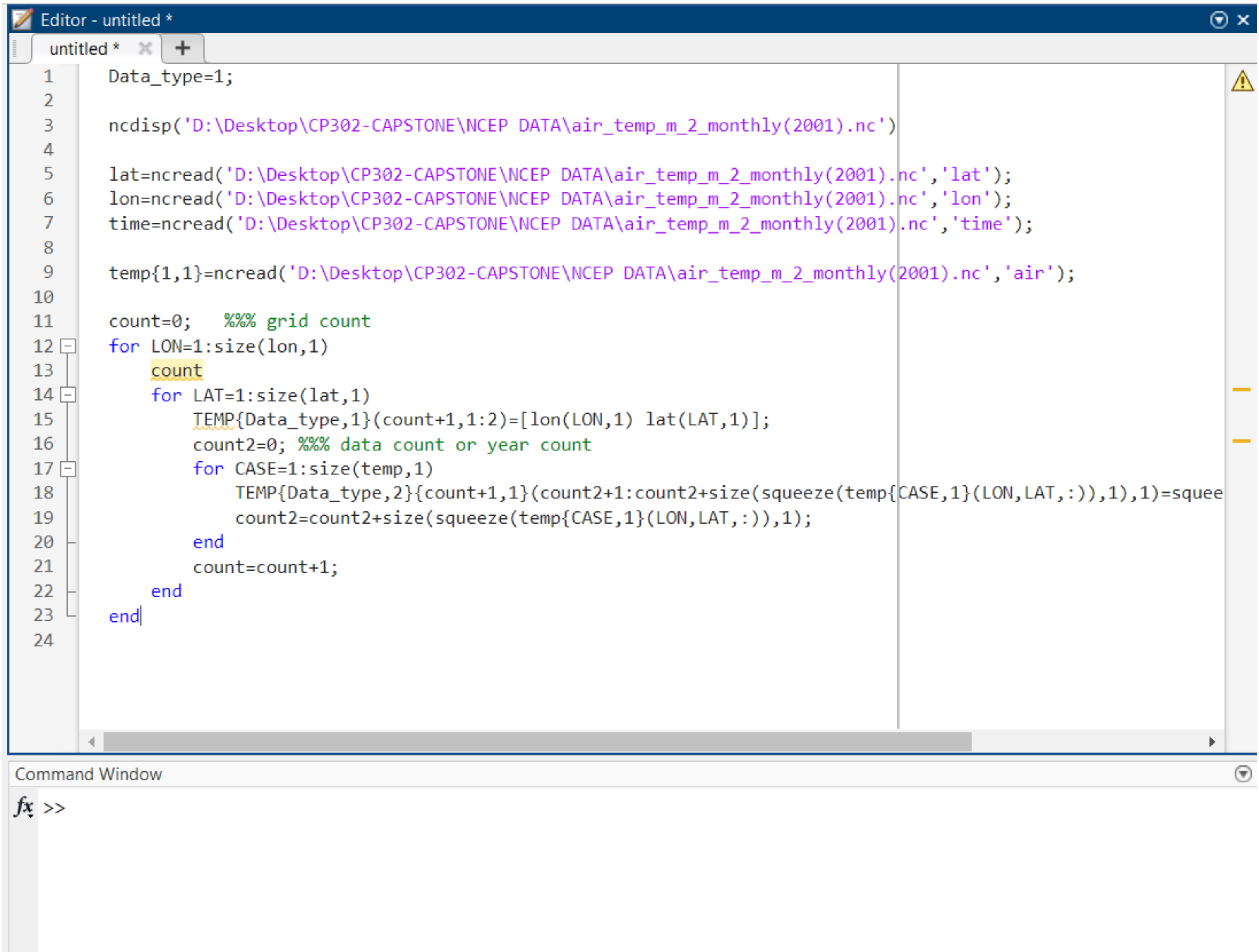


Fig -6 : Region -3 Area Distribution

Use of Matlab :-

Matlab software is used to collect the data corresponding to particular longitude and latitude which is then used in grid-distributed layers to find out weighted data.



```
Data_type=1;

ncdisp('D:\Desktop\CP302-CAPSTONE\NCEP DATA\air_temp_m_2_monthly(2001).nc')

lat=ncread('D:\Desktop\CP302-CAPSTONE\NCEP DATA\air_temp_m_2_monthly(2001).nc','lat');
lon=ncread('D:\Desktop\CP302-CAPSTONE\NCEP DATA\air_temp_m_2_monthly(2001).nc','lon');
time=ncread('D:\Desktop\CP302-CAPSTONE\NCEP DATA\air_temp_m_2_monthly(2001).nc','time');

temp{1,1}=ncread('D:\Desktop\CP302-CAPSTONE\NCEP DATA\air_temp_m_2_monthly(2001).nc','air');

count=0;   %%% grid count
for LON=1:size(lon,1)
    count
    for LAT=1:size(lat,1)
        TEMP{Data_type,1}(count+1,1:2)=[lon(LON,1) lat(LAT,1)];
        count2=0; %%% data count or year count
        for CASE=1:size(temp,1)
            TEMP{Data_type,2}{count+1,1}(count2+1:count2+size(squeeze(temp{CASE,1}(LON,LAT,:)),1),1)=squee
            count2=count2+size(squeeze(temp{CASE,1}(LON,LAT,:)),1);
        end
        count=count+1;
    end
end
```

Fig -7 : Code for decoding .nc files downloaded from ncep site

Note :- This code varies according to the input variables such as wind speed, precipitation etc for which we are calculating corresponding values.

Methodology :-

- For the purpose of studying the current water requirements, we are using CropWat 8.0 software. To calculate water requirements, the software requires information on climate conditions, rainfall, crop, and soil.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ETo	reference evapotranspiration [mm day-1],
Rn	net radiation at the crop surface [MJ m-2 day-1],
G	soil heat flux density [MJ m-2 day-1],
T	mean daily air temperature at 2 m height [^oC],
u2	wind speed at 2 m height [m s-1],
es	saturation vapour pressure [kPa],
ea	actual vapour pressure [kPa],
es-ea	saturation vapour pressure deficit [kPa ^oC-1],
Δ	slope vapour pressure curve [kPa ^oC-1],
γ	psychrometric constant [kPa ^oC-1]

- This software internally utilises the Penman-Monteith equation.

Country: India   Station: bottom
Altitude: 206 m.   Latitude: 30.21 °N   Longitude: 74.94 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m²/day	ETo mm/day
January	4.9	19.2	31	2.4	7.9	13.4	3.26
February	7.2	19.5	41	2.8	9.2	17.2	3.69
March	9.8	24.6	28	2.4	10.5	21.9	4.97
April	16.0	32.8	22	2.3	11.5	25.8	6.85
May	17.9	35.7	16	2.1	12.2	28.0	7.57
June	23.8	40.4	23	2.1	12.2	28.3	8.43
July	22.9	33.7	63	1.4	10.6	25.7	5.99
August	22.2	32.5	64	1.3	10.3	24.3	5.42
September	19.3	32.4	48	1.5	10.2	22.2	5.22
October	13.4	28.5	32	1.8	10.2	19.2	4.64
November	8.0	22.0	27	2.9	9.4	15.5	4.33
December	6.7	18.0	38	3.1	8.6	13.4	3.35
Average	14.3	28.3	36	2.2	10.2	21.2	5.31

Fig - 8 : Monthly Reference Evapotranspiration (ETo) in mm/day

- For calculating reference evapotranspiration and effective rainfall, CropWat requires Tmax, Tmin, Relative humidity, Wind Speed, Latitude, Longitude and Sunshine hours, Monthly rainfall which we got from NCEP website. CropWat calculates the effective rainfall using the following formula:

Peff = Pmonth * (125-0.2*Pmonth)/125   for Pmonth <= 250 mm

Peff = 125 + 0.1 * Pmonth   for Pmonth > 250 mm

	Rain mm	Eff rain mm
January	34.0	32.2
February	80.9	70.4
March	22.3	21.5
April	60.5	54.6
May	30.2	28.7
June	34.4	32.5
July	155.0	116.6
August	162.4	120.2
September	19.0	18.4
October	0.3	0.3
November	3.4	3.4
December	36.0	33.9
Total	638.4	532.8

Fig - 9: Effective Rainfall (mm)

- For the crop, we have provided the Kc values, rooting depth, initial, development, mid and harvest stage duration, critical depletion factor and yield response.

Crop Name: Spring Wheat Planting date: 23/11 Harvest: 01/04

Stage	initial	develop	mid	late	total
Length (days)	30	30	40	30	130
Kc Values	0.30	-->	1.15	0.30	
Rooting depth (m)	0.30	-->	1.20	1.20	
Critical depletion	0.55	-->	0.55	0.80	
Yield response f.	0.40	0.60	0.80	0.40	1.15
Cropheight (m)			1.00		

Fig - 10: Crop parameters in various Growing Stages

- For the soil, CropWat demands total available soil moisture, max infiltration rate, max rooting depth, and Initial soil moisture depletion.

Soil name: Sandy Silty Soil

General soil data:

Total available soil moisture (FC - WP)	200.0	mm/meter
Maximum rain infiltration rate	150	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TA	0	%
Initial available soil moisture	200.0	mm/meter

Fig - 11 : Soil Data

- Considering all the parameters entered, CropWat provides the optimal irrigation schedule. From there, we get the crop water irrigation requirement.

Results are followed as :-

ETo station: bottom
Rain station: india

Crop: Spring Wheat
Planting date: 23/11

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	3	Init	0.30	1.20	9.6	2.8	6.2
Dec	1	Init	0.30	1.10	11.0	8.9	2.1
Dec	2	Init	0.30	1.00	10.0	12.8	0.0
Dec	3	Deve	0.42	1.39	15.3	12.1	3.2
Jan	1	Deve	0.72	2.38	23.8	9.7	14.1
Jan	2	Deve	1.01	3.30	33.0	8.9	24.2
Jan	3	Mid	1.18	4.00	44.0	13.7	30.2
Feb	1	Mid	1.18	4.17	41.7	22.0	19.7
Feb	2	Mid	1.18	4.34	43.4	27.6	15.8
Feb	3	Mid	1.18	4.84	38.7	20.8	17.9
Mar	1	Late	1.07	4.87	48.7	10.0	38.6
Mar	2	Late	0.78	3.89	38.9	3.3	35.5
Mar	3	Late	0.48	2.66	29.3	8.3	21.0
Apr	1	Late	0.30	1.89	1.9	1.6	1.9
					389.2	162.5	230.5

Fig -12 : Crop water requirements in mm/decade

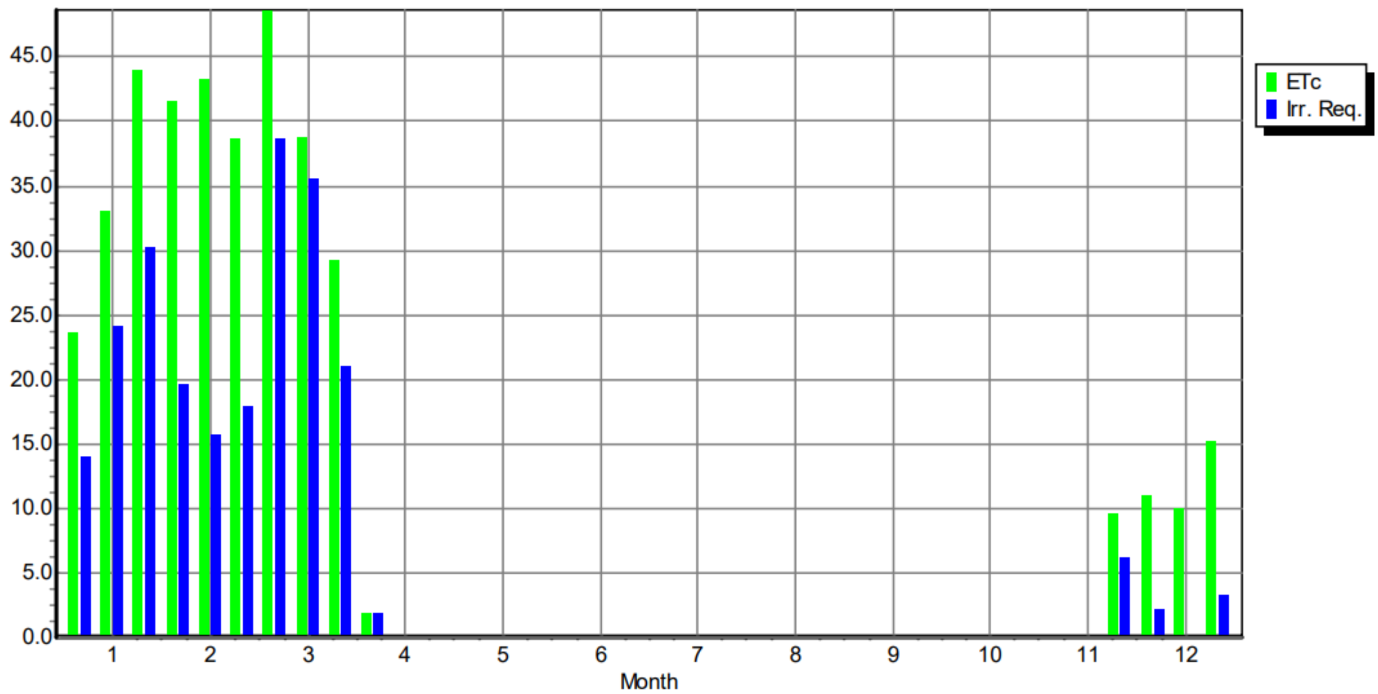


Fig -13 : Crop water requirements and actual evapotranspiration (ETc) in mm/decade

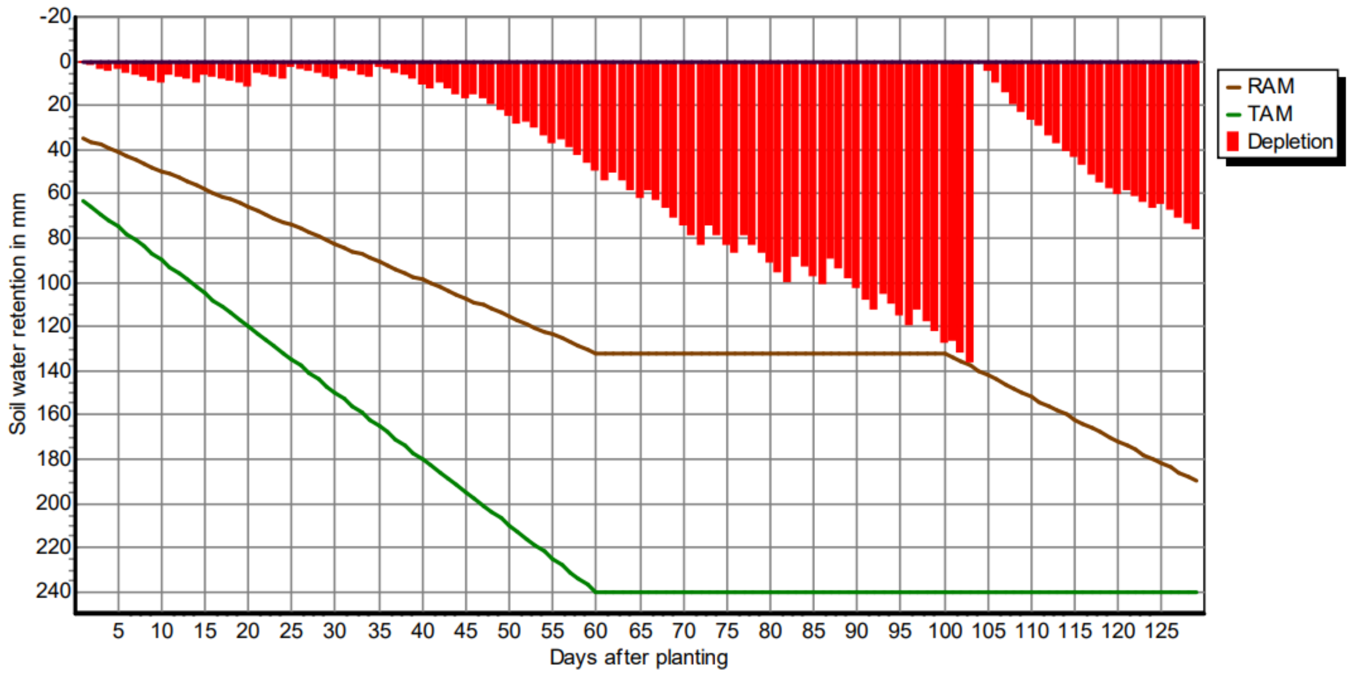


Fig -14 : Soil water retention during Growth Period

Comparison of Results of Three Regions for the last 20 Years (2003-2022) :-

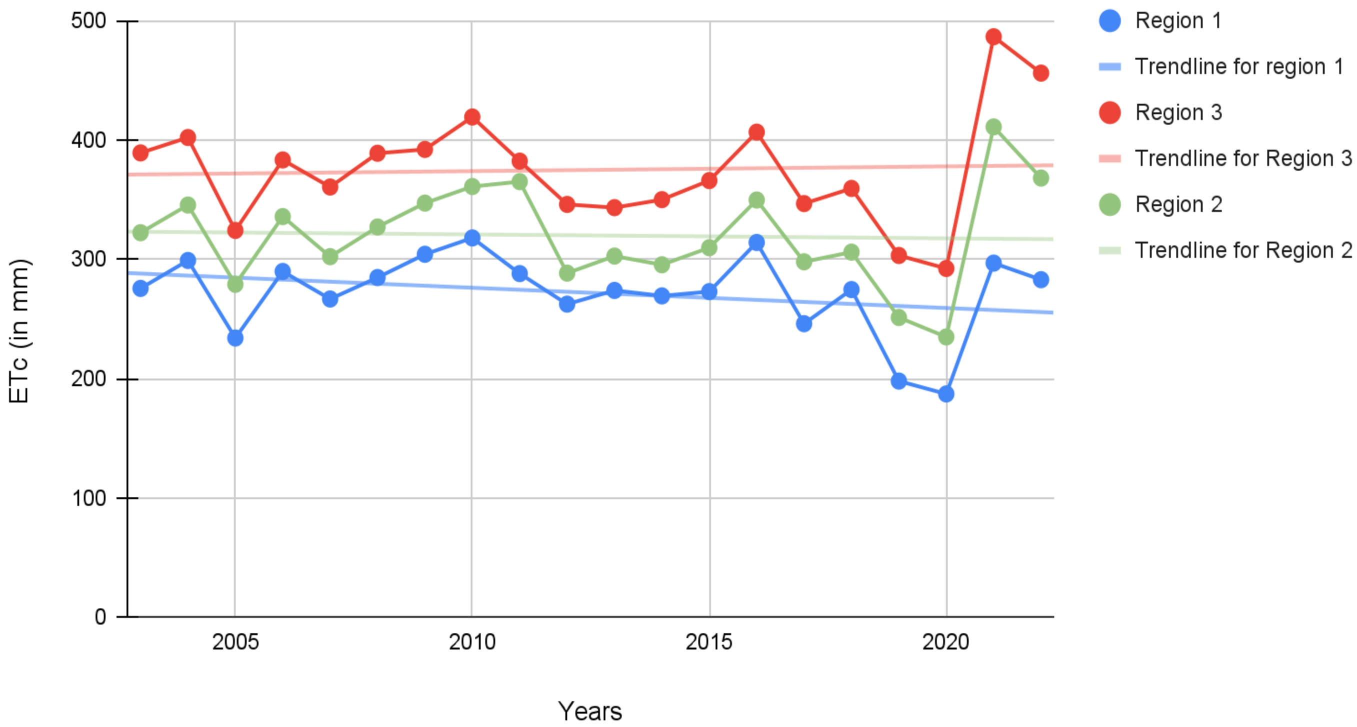


Fig 15 : Potential Evapotranspiration [ETc] (mm)

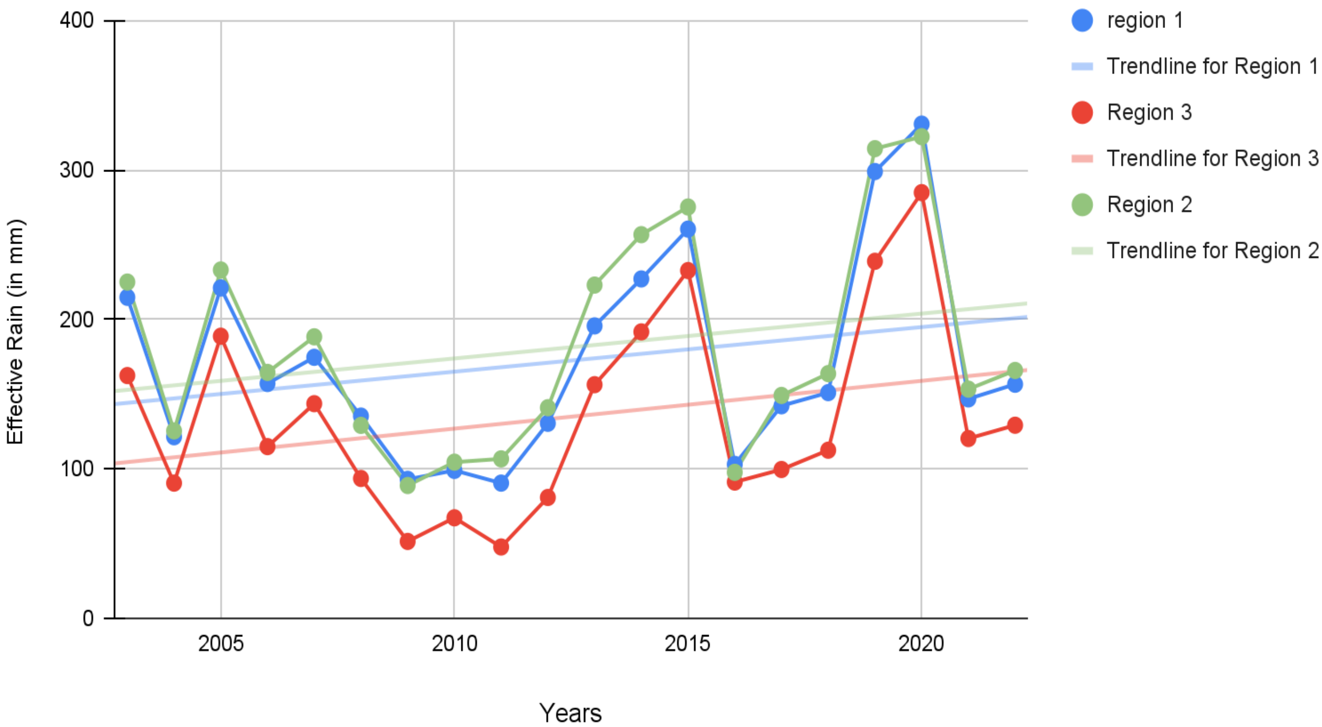


Fig -16 : Effective Rainfall (mm)

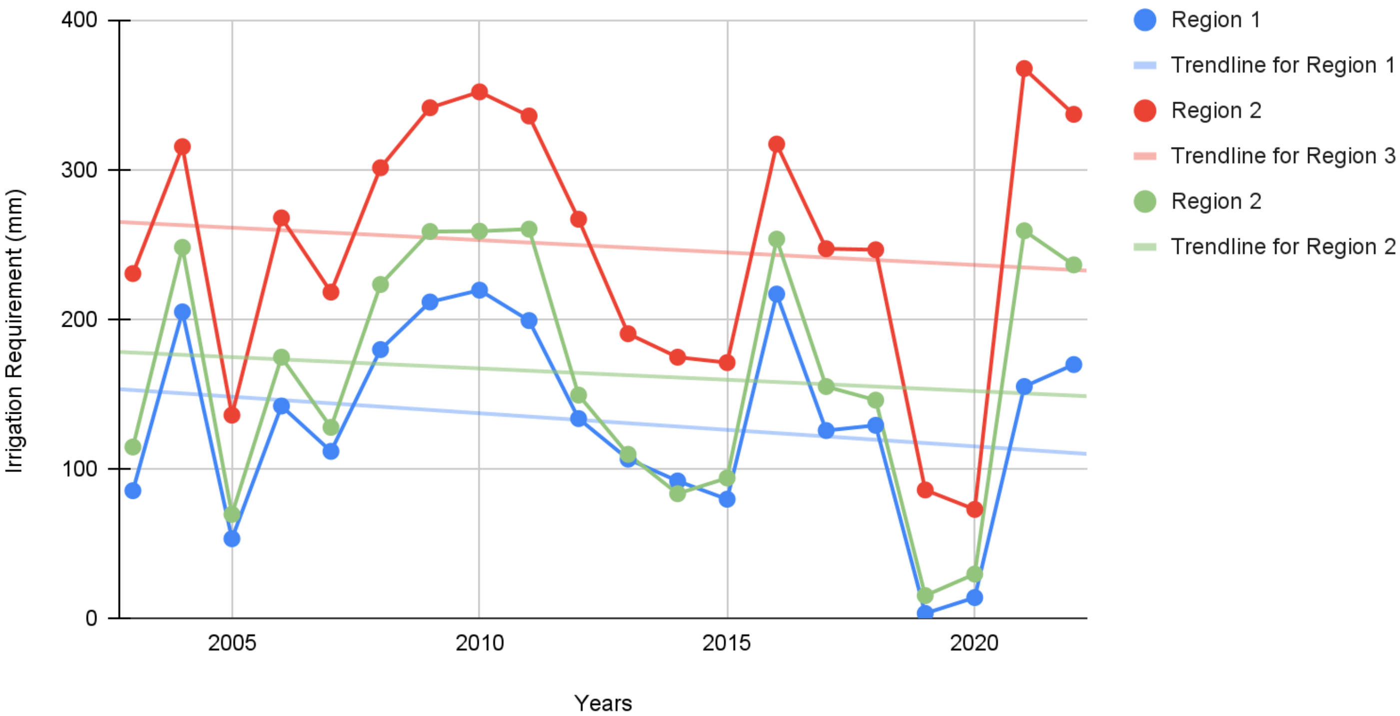


Fig - 17 : Crop Irrigation Requirement (mm)

Inference:

- The Effective rainfall trend is on a rise, which suggests that the crops are getting more water from the rainfall, which in turn reduces the requirement for irrigation, which is in line with the trends that are shown by the crop irrigation requirement graphs. Moreover, the ETc values are constant or somewhat decreasing over the years.

- A decrease in irrigation requirements (as observed from the graph) is found beneficial for Punjab's agricultural sector, as water usage has reduced over the last years. This has helped in conserving water resources and improved the sustainability of agricultural practices in the region. Now, just to check the "irrigation requirement" pattern for the future, we are required to analyse the data for the next 20 years.

Capstone II Goals:

- ❖ Predict the climatic conditions considering the last 20 years of data that we have collected.
- ❖ Calculation of the crop water requirements and yield production taking predicted climatic data into consideration.

References:

- https://en.climate-data.org/asia/india/punjab/ludhiana-889/
- https://en.climate-data.org/asia/india/punjab/bathinda-5994/
- https://en.climate-data.org/asia/india/punjab/gurdaspur-47513/
- https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html
- https://www.fao.org/3/s8684e/s8684e0a.htm
- https://indiawris.gov.in/wris/#/soil