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Research Article

Characterizing the Climate of *Tarai* Region of Uttarakhand Based On Water Balance Studies

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Abstract

This research had been conducted for calculation of water balance components by Thornthwaite Mather method and simulation model WATBAL model had been used to calculate different water balance components like soil moisture, actual evapotranspiration, surplus, deficit, moisture adequacy index and soil moisture index by using average weekly precipitation and potential evapotranspiration from 1981-2020 for *Tarai* region of Uttarakhand. In this study, different weather-based indices like, Humidity Index, Aridity Index and Moisture Index also been calculated on the seasonal and annual basis. Based on which climatic classification had been done for *Tarai* region of Uttarakhand as well as it is of International significance as based on this study water stress condition for the crops and advisories could be done to the farmers for the *Tarai* region of the world. From, this study it has been concluded that humid climate exists in this region. The results also revealed that there is an increase in the water surplus during 1981-2020 when compared with IMD data for Pantnagar during 1971-2005. Water Surplus was found to be 670.0 mm and water deficit was found to be 440.2 mm. Total potential evapotranspiration was found to be 1339.4 mm, which was calculated by Penman Monteith's equation during 1981-2020 and was found to be decreased when compared with the PET calculated by IMD for the year 1971-2005 of about 1463.9 mm. When compared with the IMD data over the periods from 1971-2005 with current data from 1981-2020 for Pantnagar region then humidity index had been decreased from 149.0% to 144.7% respectively. Aridity index had been decreased from 73.0% to 50.2%, as water deficit had been decreased from 566.7 mm to 440.2 mm. Moisture index had been increased from 76% to 94.5% as water surplus was increased from 447.7 mm to 670.0 mm respectively on annual basis.

Keywords: WATBAL, PET; Thornthwaite Mather; Penman Monteith; Water surplus

Introduction

Evapotranspiration information is useful to determine how much water has evaporated from the cropped field. In most situations, daily evapotranspiration by crop equals the depletion of water from the soil that day. Therefore, the records of accumulated evapotranspiration in between two waterings can be used to determine when and how much irrigation water is needed to the crop [1]. In general, the variables that effect the evapotranspiration phenomenon are wind velocity, solar radiation, humidity, temperature, cloud cover, advection, ground cover, soil and plant characteristics and the soil moisture status water etc. Knowledge of relative effects of these inter correlated variables

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and factors on ET is very important within the context of irrigation of wheat crop and all other crop especially in the tropical countries like India.

In today's world, striking a balance between incoming precipitation and stream or spring discharge is a difficult task in many scientific fields concerned with water management. Although breakthroughs in the approaches for water balance calculation for each component have been made in this area, despite the fact that most of the goals for the water cycle have been realized, the Thornthwaite–Mather approach remains one of the most popular [2]. Different indices like Aridity index (Ia), Humidity index (Ih), Moisture index (Im) can be easily computed by using water balance analysis. The above-mentioned indices can be used in classification of climate and to assess type of climate that prevails in the particular region. Moisture Adequacy index (MAI) indicates the good moisture status in the soil in relation to the need of the water by the plants. And if MAI is higher it indicates good moisture availability. There are different components of water balance analysis like Water surplus (WS), Water deficit (WD), Actual Evapotranspiration (AET) etc. Water Deficit (WD) and Water Surplus (WS) could be observed in different locations plays a significant role in water balance studies. If we assess the period of water surplus and water deficit that occurs in the particular season or year is very much useful to find ideal period for initiation of crop season and its different growth stages, and which may fall during deficit period for that crop [3]. It also helps to assess flood and drought areas. Water balance actually refers to climatic equibrilium which can be obtained, by distinguishing the rainfall as income with the evapotranspiration as loss or expenditure, soil acts as the source or acts as reservoir of water during excessive rainfall and acts as lifesaving irrigation during drought period or when there is deficit of water. Water surplus is actually defined as the excess amount of water that is left after the evaporative requirements of the soil and plants and when the soil water storage tends to return back to maximum water holding capacity or field capacity of soil (0.33 bars).Water deficit is defined as amount of water which is available for the crops is not enough to meet the water demand and is assessed by subtracting potential evapotranspiration from the actual evapotranspiration for the particular period of time.

Materials and Methods

Estimation of Potential Evapotranspiration (PET) by Penman Monteith equation on weekly basis

Penman integrated the energy balance with the mass transfer method in 1948, resulting in an equation that could be used to calculate evaporation from an open water surface using conventional climatological measurements of daylight, temperature, humidity, and wind speed. Many studies refined this so-called combination approach and applied it to cropped surfaces by incorporating resistance elements. Aerodynamic and surface resistance factors are distinguished in the resistance nomenclature [4]. The surface resistance parameters are frequently combined into a single parameter, the 'bulk' surface resistance parameter, which works in conjunction with the aerodynamic resistance. The resistance of vapour movement through stomata openings, total leaf area and soil surface. The aerodynamic resistance, ra, is a measure of resistance from the vegetation upward, which includes friction from air passing over vegetative surfaces. Although the exchange mechanism in a vegetation layer is too complex to be adequately characterized by the two resistance factors, good correlations between measured and computed evapotranspiration rates can be established, particularly for a uniform grass reference surface. Penman (1948) established an equation for calculating evaporation from a free water surface, which he subsequently used empirical coefficients to translate to reference evapotranspiration from vegetated surfaces. Penman presumptively believed that the heat flux entering the and out of the soil is insignificant enough to be overlooked. By combination method, the reference evapotranspiration rate from a short green crop completely shading the ground and never short of water is expressed in generalized form as follows Doorenboss and Pruitt 1977.

$$ET = \frac{0.408\Delta\,(Rn - G) + \gamma\,\frac{900\,u2\,(es - ea)}{T + 273}}{\Delta + \gamma\,(1 + 1.34\,u2)}$$

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 of daily air temperature [°C]

u2 = Wind speed at 2 m height [m s^{-1}]

es = Saturation vapour pressure [kPa]

ea = Actual vapour pressure [kPa]

Δ = Slope vapour pressure curve [kPa $^{\circ}C^{-1}$]

γ = Psychometric constant [kPa $^{\circ}C^{-1}$].

The net radiation from bright sunshine hours is calculated as follows:

Rn = Rsw-Rlw

Rsw = 0.77 * R

Rlw = (0.000000004903 * ((Tx + Tn)/2)) *

(0.34 – (0.14*√ea)) * ((1.35* Rs / 0.75*Ra) - 0.35)

Rs= (0.25+0.5 * BSSH_a / BSSH_N)

Where,

Tx= Maximum Temperature

Tn= Minimum Temperature

Rsw= Short wave radiation

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Rlw= Long wave radiation

Rs= Solar Radiation

Ra= Extra Terrestrial Radiation

BSSH_a= Actual Sunshine hours

BSSH_N= Maximum possible Sunshine hours

For the calculation of PET by Penman-Monteith's equation firstly we will calculate average of 52 weeks for 40 years of different parameters like Tmax, Tmin, RH1, RH2, Wind Speed and Sunshine hours and then we use WATERBAL Software and in that we use PENMAN application to calculate PET using these data in the notepad. The program will ask for the different information namely:

a. Name of the station
b. Latitude in decimals
c. Altitude
d. Height of Altitude in Meters
e. No of weeks/ months
f. A, B values (Angstrom's formula)
g. Albedo
h. Sunshine / Cloudiness Flag
i. No of years
j. Name of the file

After computing these values program is run and file is saved as OUT.PET and PET value is calculated.

Computation of Weekly Water Balance Components and Different Agroclimatic Indices on seasonal and annual basis

To compute weekly water balance, Thornthwaite and Mather's method [5] has been used. For its computation following data are required:

a. Weekly Rainfall (mm)
b. Weekly Potential Evapotranspiration (mm)
c. Available water holding capacity of soil (mm)

Water Balance components are calculated using WATBAL software obtained from CRIDA, Hyderabad. The Thornthwaite approach was used to assess water availability in *Tarai* region of Uttarakhand. Because temperature is considerably easier to measure than other meteorological variables, this method can be used to estimate potential evapotranspiration (PET) [6]. Water storage, storage changes and normal evapotranspiration, according to the PET results from Thornthwaite and Mather's model, water storage, storage changes, actual evapotranspiration, surplus and deficit can be calculated. The inputs are temperature, precipitation, bright sunshine hours as a function of latitude and available water capacity of the soil.

Thornthwaite-Mather water balance equation uses the soil moisture capacity to estimate water budgets. The parameters needed for using this method include:

1. Difference between precipitation and potential evapotranspiration (P-PE)
2. Accumulated potential water loss (APWL)
3. Available water capacity (AWC)
4. Difference between soil moisture storage (ΔST)
5. Actual evapotranspiration (AE)
6. Deficit and surplus of the water budget
7. Runoff estimation

A. Precipitation (P)

Precipitation data on a monthly basis is required. Missing rainfall data can be estimated first by the arithmetic method or the normal ratio method. If a study area has many rain gauges stations, the mean areal precipitation value shall be determined first. Mean areal precipitation in this study determined by averaging the rainfall data from Pantnagar region representative rain gauge.

B. Potential Evapotranspiration (PE)

Potential evapotranspiration means the atmosphere potential that can take out water from the land surfaces. In the Thornthwaite method, the potential evapotranspiration (PE) is computed according to:

1. Calculate the annual value of the heat index (I) based on the monthly heat index (i) and summing all the 52 weeks heat indices.

   $i = (Ta/5)^{1.5}$

   $I = i1 + i2 + \dots + i12$

   Ta is the mean monthly temperature.

2. With $I = (67.5*10)^{-8} {}_{*} I^{3} - 77.1 {}_{*} 10^{-6} * I^{2} + 0.0179I + 0.492$ calculate the unadjusted PE' (mm) using the following equation

   PE' = $16(10.\frac{Ta}{I})^{a}$

3. Adjusting the unadjusted PE' by using the average weekly daylight duration (in hour) which is a function of season and latitude. If the daylight duration data is known, the following equation can be used to calculate the adjusted PE.

Difference between precipitation and potential evapotranspiration (P-PE)

The difference value of potential evapotranspiration and

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precipitation (P-PE) is negative when there is a potential water deficit, while positive P-PE value represents a potential water surplus. If the P-PE value is less than zero, the month called as "dry week" and it is subjected to APWL value [7]. While the P-PE value is more than zero, the month called as "wet week" and it is subjected to surplus value.

Accumulated Potential Water Loss (APWL)

The accumulated potential water loss is calculated as the cumulative sum of P-PE values during months when P-PE is negative. Accumulated potential water loss increases during dry seasons. It is reduced during wet seasons because of soil moisture recharge. The value would be zero when soil moisture equals the soil's available water holding capacity.

Available Water Capacity (AWC)

Thornthwaite and Mather have suggested the determination method of AWC values by considering land use, soil texture types and rooting depth by providing a water holding capacity (WHC). In this study, the AWC typical value of each land use assumed to be 140 mm/m. It can be also said as Field Capacity

Soil Moisture Storage Difference (ΔST)

The soil-moisture term represents the amount of water held in soil storage. If the value of P-PE is positive, then soil moisture storage value is the same as the AWC. On the other hand, if the value of P-PE is negative, then soil moisture storage is calculated by equation given below [8]. The difference in soil moisture between months (ΔST) then can be calculated by equation given below. A positive value of ΔST means there is enough water to add to the soil moisture storage, while negative value implies that water is removed from the storage because of evapotranspiration.

$$ST = AWC * e^{(APWL/AWC)}$$

$$\Delta ST_i = ST_i - ST_{i-1}$$

Actual Evapotranspiration (AE)

The difference between actual evapotranspiration (AE) and potential evapotranspiration (PE) is in their relationship with soil moisture storage. The PE accounts water removal from land surfaces only by atmospheric potential (heat), while the AE accounts changes on soil moisture storage in land surfaces. When the precipitation (P) is higher than the PE, it means that soil moisture storage still saturated from the excess precipitation. Hence, the AE equals the PE because there are no changes to the soil moisture storage. When the P is lower than the PE, it means there are changes in the soil moisture storage. Thus, the AE equals the P subtracted by the changes in soil moisture storage.

$$P > PE,\ AE = PE$$

$$P < PE,\ AE = P - \Delta ST$$

Deficit (D) and Surplus (S)

Soil moisture deficit expressed as the difference between actual evapotranspiration and potential evapotranspiration. When soil moisture reaches the maximum soil-moisture capacity, which is AWC, any excess precipitation become the surplus value, thus makes surplus value equals to P-PE.

$$D = PE - AE$$

$$S = P - PE$$

Surplus exists when soil moisture storage (ST) > 300 and P>PE

When storage values are moving towards 300, first Surplus (S) = P-PE-ΔST

For computation of weekly water balance components application named WATBAL has been obtained from CRIDA, Hyderabad. Water balance indices have been computed by Thornthwaite and Mather model [5].

Moisture Index

It is the difference between Humidity Index (HI) and Aridity Index (AI). Used to monitor droughts in which agricultural impacts are a primary concern. The output is weighted, so it is possible to compare different climate regimes. It responds quickly to rapidly changing conditions. The Table 1 below shows the type of climate classification based on moisture index.

Moisture index = Ih –Ia (Im %)

MI = 100 (S – D / PET)

Humidity Index

It is an index of degree of Water Surplus (s) over water need (n) at any given location. Humidity index was also proposed by Thornthwaite . This index is just reverse of the Aridity index and depicts the annual availability of moisture. It is ratio of annual moisture surplus to the annual potential evapotranspiration. It is expressed in terms of percentage.

Humidity index = When P>PE

Table 1: Moisture Index vs. climatic types [5].

Symbol	Climatic type	Moisture index (Im)%
A	Perhumid	100 and above
B_4	Humid	80 to 100
B_3	Humid	60 to 80
B_2	Humid	40 to 60
B_1	Humid	20 to 40
C_2	Dry Sub-humid	0 to 20
C_1	Moist Sub-humid	-33.3 to 0
D	Semi-arid	-66.7 to -33.3
E	Arid	-100 to -66.7

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The Table 2 shows the seasonal dry climate classification based on the humidity index as given by Thornthwaite [5].

Table 2: Seasonal climate vs. humidity index [5].

Seasonal dry climate (C1, D and E)	Humidity Index (%)
d- little or no water surplus	0-16.7
s1- moderate summer surplus	16.7-33.3
w1- moderate winter surplus	16.7-33.3
s2- large summer surplus	Above 33.3
w2- large winter surplus	Above 33.3

Table 3: Seasonal moist climate versus aridity index [5].

Seasonal moist climate (A, B and C2)	Aridity Index (%)
r- little or no water deficit	0-16.7
s1- moderate summer deficit	16.7-33.3
w1- moderate winter deficit	16.7-33.3
s2- large summer deficit	Above 33.3
w2- large winter deficit	Above 33.3

Aridity Index

It is an index of the degree of water deficit (D) at any given location. Aridity index was proposed by Thornthwaite [5]. It explains the annual deficiency of water in the particular year of particular region. It is ratio of annual moisture deficit to the annual water need (potential evapotranspiration). It is expressed in terms of percentage. The Table 3 below shows the seasonal moist climate classification based on the aridity index as per Thornthwaite.

Moisture Adequacy Index

It is defined as the ratio of actual evapotranspiration (AET) to the potential evapotranspiration (PET). The moisture, that is necessary for the sustenance of a crop or a vegetation species, can be best derived from knowledge of the moisture adequacy index [9]. The moisture adequacy index is a true representative of moisture effectivity, thus, can be used in correlative studies of vegetation in relation to climate. The Table 4 below shows the classification of Agricultural drought classes based on moisture adequacy index given by Subramanyam [10] in 1982.

Moisture adequacy index = AET / PET

Table 4: Moisture Adequacy Index versus agricultural drought classes [10].

MAI (%)	Agricultural Drought class
76-100	No Drought
51-75	Mild Drought
26-50	Moderate Drought
0-25	Severe Drought
† MAI: Moisture Adequacy Index	

Climatic classification based on rainfall criteria

The National Agricultural Commission (1976) delineated the country into different rainfall groups and they have chosen the limits that have a closer relation with crop development. Since, the time-span of most of the crops usually > 90 days, following limits were chosen by them.

a. Rainfall > 30 cm/month for at least three consecutive months would be suitable for high requirement crops.

b. Rainfall of 20-30 cm/month consecutively for at least 3 months will be suitable for medium water requirement crops.

c. Rainfall of 10-20 cm/month consecutively for at least 3 months is suitable for low water requirement crops.

d. Rainfall of 5-10 cm/month for at least 3 consecutive months is suitable for drought resistant, short duration, low water requirement crops.

e. Rainfall < 5 cm/ month is not of much significance for crop production unless irrigation is assured.

Result and Discussion

PET is calculated by using these data in notepad with one spacing and saved as ran81.dat file and then PET model has been run using different average weekly weather parameters like Tmax, Tmin, RH1, RH2, SSH and Wind speed over the periods for Pantnagar region of Uttarakhand [11]. And output file appears in the notepad as PET.OUT and final PET comes out to be like this in notepad as described in Table 5.

Table 5: Average Weekly Potential Evapotranspiration (mm)-Penman method for *Tarai* region of Uttarakhand.

Standard Meteorological Weeks	Potential Evapotranspiration
1	8.7
2	8.9
3	9.3
4	10.6
5	11.6
6	13.2
7	14.7
8	16.7
9	18.1
10	20.9
11	23.4
12	25.7
13	28.6
14	32.3
15	35.2
16	38.3
17	41.1

18	42.6
19	42.6
20	45.5
21	46.1
22	46.1
23	45.7
24	43.5
25	39.9
26	34.8
27	33.5
28	32.4
29	31.3
30	30.2
31	30.2
32	33.9
33	28.2
34	28.6
35	28.5
36	29
37	27.6
38	27.8
39	27.1
40	26.3
41	26.9
42	22.3
43	19.8
44	18
45	16.2
46	14.6
47	13.1
48	11.7
49	10.7
50	9.9
51	9
52	8.8
	1339.4

From the Table 5 we can conclude that more PET can be seen during summer and monsoon in comparison to other seasons. And if we plot the graph also, we can observe that maximum PET can be observed during SMW 14 to 24 which is between April to mid of June i.e., in the Summer season and minimum PET can be observed during winter season i.e., SMW 45-52 and SMW 1-9 as shown in Figure 1.

Computation of Weekly Water Balance Components.

Water balance components are calculated by Thornthwaite Mather's method and simulation model WATBAL model has been to i.e., calculate different components as stated below in Table 6 and output comes out to be like this. For running WATBAL model pet file as calculated above and rainfall file is needed in .dat file extension. For checking the model whether it is correct or not if rainfall sum comes out to be same as calculated before then the model is correct [12].

According to the results it can be concluded that maximum PET can be observed during summer season due to high temperature and maximum rainfall is observed during monsoon season as usual. Total of the water deficit over the periods from 1981-2020 comes out to be 440.2 mm and water surplus is 670.4 mm. In Table 6 total annual average rainfall for *Tarai* region of Uttarakhand comes out to be 1567.4 mm and Total PET comes out to be 1339.7 mm. If we calculate the actual water balance which is difference of ∑PPT - ∑PET comes out to be 227.7 mm.

If we observe the patterns of the rainfall then maximum rainfall is observed during SMW 33 which is about mid of August and except monsoon season all other seasons have PET> PPT. If we observe the value of MAI, its value is 1.00 for SMW 25 to 39 i.e., during monsoon season AET = PET and we know that AET can never be more than PET and total AET comes out to be 899.5 mm. There is sufficient rainfall during SMW 28- 39 during mid of July to September as soil moisture becomes equal to field capacity ie, 140.0 mm. Afterwards, we can observe that AET becomes less than PET as the soil dries up, it becomes more difficult to get additional water for evapotranspiration. As a result, the rate of evapotranspiration decreased as the soil moisture content decreased. The moisture deficiency suggests that the plants will be stressed at that time, necessitating irrigation. Water deficit is the difference between the potential evapotranspiration (PE) and actual evapotranspiration. During the period of water deficit, rainfall and available soil moisture together will be less than potential evapotranspiration. Table 6 shows that the area was relatively dry during the period of January to mid of June. Maximum water deficit occurred in the month of May which was 34.9 mm. Further, it can be seen that there was again a water deficit in the months of October to December. Soil moisture recharge took place from SMW 25-28 mid of June to mid-July [13]. Afterwards, the soil moisture storage reached to the water holding capacity, then any excess precipitation was counted as water surplus. From mid-July to September was the period of water surplus (670.0 mm).

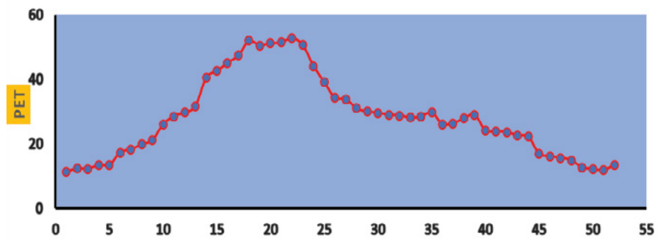

Figure 1: Average Weekly PET over the periods from 1981- 2020 for *Tarai* region of Uttarakhand.

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Where,

PPT= precipitation (mm)

PET= potential evapotranspiration (mm)

AET= actual evapotranspiration (mm)

SPL= water surplus (mm)

DEF=water deficit (mm)

SM =soil moisture storage (mm)

SMI= soil moisture index (Available soil moisture/Water holding capacity)

MAI=moisture adequacy index

DIV = (1-MAI)

Computation of different indices on seasonal as well as annual basis

According to the Table 7, it can be concluded that Humid type of climate exists over *Tarai* region of Uttarakhand as on the annual basis moisture index is found to be 94.5% which lies between 80-100% and comes under B4-Humid with large summer deficit – s2 type climatic type according to Thornthwaite's Climatic classification. And if we compare on the seasonal basis then for summer season Moisture Index values lies in between -100 to -66.7 so comes under E-Arid climatic type, but for winter season values are in between 0 to -33.3 so lies in C1-Dry sub humid climatic type. The overall humidity index for *Tarai* region of Uttarakhand comes out to be 144.7% as most of the precipitation is concentrated during monsoon season and in rest of the year water deficit can be

Table 6: Average Weekly Water Balance Using Thornthwaite Method for *Tarai* region of Uttarakhand AWHC= 140.0 mm.

WEEK	PPT	PET	SM	AET	SPL	DEF	MAI	DIV	SMI
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)			
1	6.7	8.7	48.3	7.4	0	1.3	0.85	0.15	0.35
2	5.7	8.9	47.2	6.8	0	2.1	0.76	0.24	0.34
3	9.1	9.3	47.1	9.2	0	0.1	0.99	0.01	0.34
4	4.1	10.6	45	6.2	0	4.4	0.59	0.41	0.32
5	4.9	11.6	42.9	7	0	4.6	0.6	0.4	0.31
6	12.3	13.2	42.6	12.6	0	0.6	0.95	0.05	0.3
7	12.2	14.7	41.9	13	0	1.7	0.88	0.12	0.3
8	8.3	16.7	39.4	10.7	0	6	0.64	0.36	0.28
9	9.7	18.1	37.1	12	0	6.1	0.66	0.34	0.27
10	4	20.9	32.9	8.2	0	12.7	0.39	0.61	0.24
11	4.9	23.4	28.8	9	0	14.4	0.38	0.62	0.21
12	2.4	25.7	24.4	6.8	0	18.9	0.27	0.73	0.17
13	3.7	28.6	20.4	7.7	0	20.9	0.27	0.73	0.15
14	4.1	32.3	16.7	7.8	0	24.5	0.24	0.76	0.12
15	2.3	35.2	13.2	5.8	0	29.4	0.16	0.84	0.09
16	4.6	38.3	10.3	7.4	0	30.9	0.19	0.81	0.07
17	8.6	41.1	8.2	10.8	0	30.3	0.26	0.74	0.06
18	8.1	42.6	6.4	9.9	0	32.7	0.23	0.77	0.05
19	14.4	42.6	5.2	15.6	0	27	0.37	0.63	0.04
20	11.3	45.5	4.1	12.4	0	33.1	0.27	0.73	0.03
21	10.3	46.1	3.2	11.2	0	34.9	0.24	0.76	0.02
22	18.7	46.1	2.6	19.3	0	26.8	0.42	0.58	0.02
23	35	45.7	2.4	35.2	0	10.5	0.77	0.23	0.02
24	37	43.5	2.3	37.1	0	6.4	0.85	0.15	0.02
25	48.6	39.9	11	39.9	0	0	1	0	0.08
26	73	34.8	49.2	34.8	0	0	1	0	0.35
27	88.3	33.5	104	33.5	0	0	1	0	0.74
28	105.6	32.4	140	32.4	37.2	0	1	0	1
29	101.7	31.3	140	31.3	70.4	0	1	0	1
30	108	30.2	140	30.2	77.8	0	1	0	1

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31	107.5	30.2	140	30.2	77.3	0	1	0	1
32	88.5	33.9	140	33.9	54.6	0	1	0	1
33	125.9	28.2	140	28.2	97.7	0	1	0	1
34	102.3	28.6	140	28.6	73.7	0	1	0	1
35	75.8	28.5	140	28.5	47.3	0	1	0	1
36	81.9	29	140	29	52.9	0	1	0	1
37	52.3	27.6	140	27.6	24.7	0	1	0	1
38	73.2	27.8	140	27.8	45.4	0	1	0	1
39	38.1	27.1	140	27.1	11	0	1	0	1
40	10.1	26.3	124.7	25.4	0	0.9	0.97	0.03	0.89
41	10.8	26.9	111.1	24.4	0	2.5	0.91	0.09	0.79
42	11	22.3	102.5	19.6	0	2.7	0.88	0.12	0.73
43	0.6	19.8	89.3	13.8	0	6	0.69	0.31	0.64
44	1.7	18	79.5	11.5	0	6.5	0.64	0.36	0.57
45	1.1	16.2	71.4	9.2	0	7	0.57	0.43	0.51
46	0.6	14.6	64.6	7.4	0	7.2	0.51	0.49	0.46
47	0.5	13.1	59	6.1	0	7	0.46	0.54	0.42
48	1.9	11.7	55	5.9	0	5.8	0.5	0.5	0.39
49	1.5	10.7	51.5	5	0	5.7	0.47	0.53	0.37
50	7	9.9	50.5	8.1	0	1.8	0.81	0.19	0.36
51	0.7	9	47.6	3.6	0	5.4	0.4	0.6	0.34
52	6.8	8.8	46.9	7.5	0	1.3	0.85	0.15	0.33
	1567.4	**1339.7**		**899.5**	**670**	**440.2**			

†PPT: Precipitation, PET: Potential Evapotranspiration, SM: Soil Moisture, AET: Actual Evapotranspiration, SPL: Surplus, DEF: Water Deficit, SMI: Soil Moisture Index, MAI: Moisture Adequacy Index.

observed so humidity index is zero for other seasons. The overall Aridity Index comes out to be 50.2% and maximum during summer season which means crops during summer season can only be grown by supplemental irrigation whose water requirement is more. If we compare with the IMD data i.e., from 1971-2005 with current data i.e., from 1981-2020 for Pantnagar region then Ih% had been decreased from 149.0% to 144.7% respectively. The Ia% had been decreased from 73.0% to 50.2%, as WD has been decreased from 566.7 mm to 440.2 mm as observed below in Figure 2. Im% had been increased from 76% to 94.5% as WS has been increased from 447.7mm to 670.0 mm respectively on annual basis.

Water surplus= PPT-PET=670.0 mm (observed during week no. 29-39)

Water deficit= PET-AET=440.2 mm (observed during week no. 1-24 and 40-52)

Soil moisture Recharge = PPT-AET= 101.7 mm (observed during week no. 25-27)

Soil moisture utilization= AET-PPT=139.9 mm (observed during week no. 1-24 and 40-52)

According to the results from Table 8 it can be concluded that Moderate Drought can be found in summer season. In winter due to good rainfall observed in this region due to western disturbances so there almost no drought condition as MAI is 72.7% which is very close to 75% that comes under no drought condition. Even good Rainfall can be observed during Post Monsoon season so MAI comes out to be 68.1%. And due to excessive rainfall during Monsoon season and almost reaches to Field Capacity so there is a need of proper drainage to prevent the crop yield loss due to excessive rainfall. As per Table 9 maximum variation in mean monthly rainfall for *Tarai* region from 1981-2020 could be observed in the October month followed by November and December due to western disturbances, which was observed since last 10 years. If we observe mean monthly rainfall during last 5 years i.e., from 2017-21 as depicted in Table 10 same had been observed, but more amount of rainfall post monsoon months during last 5 years as compared to 40 years as described below [14]. To denote the monthly distribution of rainfall over the year as described above in M, the monsoon months (June- September) were placed at centre in brackets. The four post-monsoon months (October –January) were placed at the right and the four pre-monsoon months (February-May) at the left without brackets. As described above in M, classification of climate for the region has been done based on the mean monthly rainfall. So, as per Table 9, following

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is the climate type and the no. of the months receiving the quality of rainfall as per symbol is given in the subscript with all the numbers totaling 12. The climate type for *Tarai* region of Uttarakhand from 1981-2020 is - E3 D1 (C1 A2 B1) E4 type. The four monsoon months (June to September) were placed in bracket at the centre. First month of monsoon, viz., June is C type as monthly rainfall is 19.4 cm. The next two months (July and August) are A type as mean monthly rainfall is about 44 and 45 cm respectively as per Table 9, which is more than 30 cm as described above in M. The last month of monsoon, viz., September is B1 type. Similarly, first three pre monsoon months i.e., from February to April has E type of climate due to rainfall less than 5 cm and last month of pre monsoon season, i.e., may has D type of climate and all the post monsoon months, viz., from October to January has E type of climate.

Table 7: Calculated seasonal and annual basis indices for *Tarai* region of Uttarakhand.

Seasons	HI (Ih%)	AI (Ia%)	MI (Im%)
Summer	0	71.8	-71.8
Monsoon	144.7	18.9	125.8
Post Monsoon	0	27	-27
Winter	0	27.4	-27.4
Annual	**144.7**	**50.2**	**94.5**
† HI: Humidity Index, AI: Aridity Index, MI: Moisture Index			

Table 8: Seasonal classification of Agricultural Drought classes based on calculated MAI.

Seasons	MAI%	Drought Classes
Summer	28.4	Moderate Drought
Monson	97.8	No Drought
Post Monsoon	68.1	Mild Drought
Winter	72.7	Mild Drought
† MAI: Moisture Adequacy Index		

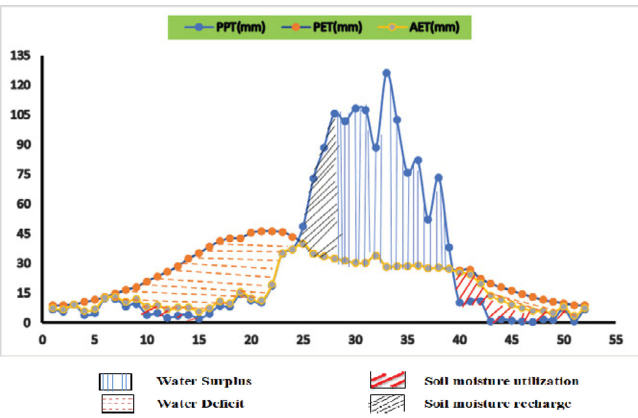

Figure 2: Weekly water balance components though graphical method.

Table 9: Monthly average rainfall and CV% from 1981-2020 for *Tarai* region of Uttarakhand.

Month	Monthly Average Rainfall (mm)	CV (%)
January	31.6	103.2
February	38.1	121.5
March	20.5	125.4
April	19.2	118.2
May	51.6	113.2
June	193.8	72.3
July	440.3	38.4
August	451.7	44
September	259.2	71.5
October	38.2	210.2
November	4.4	186.3
December	16.1	153.4

Table 10: Monthly average rainfall and CV% from 2017-21 for *Tarai* region of Uttarakhand.

Month	Monthly Average Rainfall (mm)	CV (%)
January	43.6	106.8
February	13	111.2
March	11.2	176.2
April	27.1	107
May	62.7	119.5
June	171.4	42.4
July	407.2	43.3
August	387.7	37.6
September	189.5	71.6
October	86	221.9
November	6.7	190.4
December	18.2	189.7

Conclusion

It can be concluded that total of the water deficit over the periods from 1981-2020 comes out to be 440.2 mm and water surplus is 670.4 mm. It means WS exceeds WD so this region could have good green cover and comes under humid region. The total annual average rainfall and total PET for *Tarai* region of Uttarakhand comes out to be 1567.4 mm 1339.7 mm respectively. If we calculate the actual water balance which is difference of ∑PPT - ∑PET comes out to be 227.7 mm. If we observe the value of MAI, it is more in monsoon and winter as compared to other seasons as its value was calculated as 97.8% and 72.7% respectively [15]. The reason behind more MAI value during winter season is good rainfall during this season due to western disturbances. While in other seasons we can observe that AET becomes less than PET as the soil dries up, it becomes more difficult

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to get additional water for evapotranspiration. As a result, the rate of evapotranspiration decreased as the soil moisture content decreased. The moisture deficiency suggests that the plants will be stressed at that time, necessitating irrigation. The results revealed that the area was relatively dry during January to mid of June. Maximum water deficit occurred in the month of May. Further, it could be observed that there was again a water deficit in the months of October to December. Soil moisture recharge took place during mid of June to mid-July. Overall, these components can be used in irrigation scheduling and recommendation of the types of crop could be done based on soil moisture reserve and type of soil.The different agroclimatic indices had been calculated for this area. According to the results, it can be concluded that *Tarai* region of Uttarakhand comes under **B4-Humid with large summer deficit – s2 type of climate** according to Thornthwaite's climatic classification and as shown in Table 11, classification of climate has been done based on MI% found from the study for different seasons. It can be concluded from the study that much irrigation is required for the crops growing in the summer and post monsoon season or short duration crops can be grown for this region.

References

1. Appa H, Bhide BA. Water availability periods and soil moisture during extreme years of crop production at Solapur. Mausam 31 (1980): 545-550.
2. Bhakar SR, Singh RV. Estimation of reference evapotranspiration under subhumid climatic conditions of Rajasthan. In: 37th ISAE Convention, at CTAE, Udaipur (2003): 91-93.
3. Kumar CK. Comparison of Reference Evapotranspiration Estimated by Different Methods and Determination of Crop Water Requirement of Wheat and Chickpea for Varanasi. Thesis, Masters of Technology, Banaras Hindu University, Varanasi, India 2017): 22.
4. Desta F, Bissa M, Korbu L. Crop water requirement determination of chickpea in the central vertisol areas of Ethiopia using FAO CROPWAT model. African J of Agri Res 1 (2015): 685-689.
5. Thornthwaite CW, Mather JR. Water Balance: Publications in Climatology 8 (1955).
6. Gautam S, Roy S, Murty N, et al. Climatic water balance and moisture adequacy index in Tarai region of Uttarakhand. J of Agromet 11 (2013): 12-60.
7. Ghadekar SR, Miskin RB, Korde PO, et al. Water requirement of crops in kharif, rabi and summer in sub-humid region of Chandrapur. J of Soils and Crops 4 (1984): 41-43.
8. Hargreaves GH, Samani ZA. Reference crop evapotranspiration from temperature. Applied Eng in Agri 1 (1985): 96-99.
9. Kashyap PS, Panda RK. Evaluation of crop evapotranspiration estimation methods and development of crop-coefficient for potato crop in sub humid region. Agri Water Management 50 (2001): 9-25.
10. Subrahmanyam VP. Water balance approach to the study of aridity and droughts with special reference to India J of Agromet 11 (1982): 20-25.
11. Killingtveit A. Water balance studies in two catchments on Spitsbergen, Svalbard. IAHS Publications, Series of Proceedings and Reports 290 (2004): 120-138.
12. Kumari P, Balmuchu S, Tirkey A, et al. Climatic water balance and length of growing period for efficient crop planning under different agrotype-climate in Ranchi, Jharkhand. J of Soil and Water Conservation 18 (2019): 59-64.
13. Rehman NU. Comparative studies on evapotranspiration, water requirements and crop coefficient, at different growth stages of wheat under Raipur conditions. Thesis, Masters of Science, Indira Gandhi Agricultural University, Raipur, Chhattisgarh (2002): 10-12.
14. Ramakrishna YS, Rao R, Rao G. Water balance and crop planning - A case study of western Rajasthan. Ann. Arid Zone 24 (1985): 114-119.
15. Singh R, Singh K, Bhandarkar DM. Estimation of water requirement for soybean (Glycine max) and wheat (Triticum aestivum) under vertisols of Madhya Pradesh. Indian J of Agri Sci 84 (2014): 190-197.