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Determination of Climatic Water Deficit using RS & GIS for Morni Sub-watershed in Panchkula District, Haryana

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Abstract- The development of watershed aims at productive utilization of all the available natural resources in the entire area extending from ridge line to stream outlet. Remote sensing and GIS techniques are being increasingly used for planning, management and development of watersheds. In the present study, an attempt has been made to calculate the Climatic Water Deficit (CWD) of Morni Sub-watershed. To attained this, Crop Evapotranspiration (ETc) was calculated followed by reference evapotranspiration (ETo) by using the Hargreaves formulae. Climatic water deficit (CWD) was determined as the difference between effective rainfall and ETc by assessing all raster data in ARCGIS 10. In this respect monthly and annual temperature (minimum & maximum) for a period of 42 years (1954-1996) and available rainfall data of 102 year (1901-2002) was used. It was found from Digital elevation model that topography of the study area is very undulating.

Key words: Crop evapotranspiration, climatic water deficit, effective rainfall, minimum and maximum temperature

1. INTRODUCTION

Modern strategies for the management of natural resources promote sustainable land and water resource systems, designed and managed to ‘‘fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity’’(ASCE, 1998). Among those systems, the improvement of water management has become a priority due to obvious economic and environmental reasons arising especially in the regions where water is scarce in the months except rain season and should be saved for other uses. Water is the most critical resource for sustainable development that is not only for agriculture, industry and economic growth, but it is also the most important component of the environment, with significant impact on health and nature conservation. Rainfall is the main source of water which is unevenly distributed spatially and temporally. Water scarcity refers to a situation where there is insufficient water to satisfy normal human water needs for food, feed, drinking and other uses, implying an excess of water demand over available supply. It is a relative concept; therefore, difficult to capture in single indices (Falkenmark, 2007).Giving the extension of the area about 6551.40 ha, it was considered that remote sensing would offer several advantages for such a task. Its potential for monitoring water resources are well known and there is a large number of successful applications in operative contexts in the last decades (e.g. FAO 1995; Belmonte et al. 1999; Shultz and Engman 2000; D’Urso 2001; Stehman and Milliken 2007). A review of available remote sensing approaches to water resources estimation was provided by Schmugge et al. (2002). Considering the estimation of crop water use, i.e. evapotranspiration, several methodologies are available. Many are based on the determination, through the use of thermal infrared bands Then monthly crop coefficient (Kc) values are associated to each crop class and a reference evapotranspiration map, e.g. derived from meteorological data, is used in order to estimate crop evapotranspiration in a GIS environment (e.g. Stehman and Milliken 2007) To overcome water shortage for more agricultural produce with economic and social status development, it is essential to store large quantity of water using appropriate strategies. The present paper describes the GIS and RS based water management system in hilly region.

2. DESCRIPTION OF STUDY AREA

The Morni sub watershed situated in North-west direction of Panchkula district covers a surface area of 6551.40 ha as shown in figure 1 and located at latitude 30°40'17"- 30°46'10"N and longitude 77°00'01"-77°09'52"E. Study area consisted of a continuous series of hills with a variation ranging from 448.15m to 1453.43m above MSL with a slope range between 0º -88.80º. The study area has climate having, hot summers, cool winters and good monsoon rainfall, out of which 80% of annual rainfall is received in June to September months. It also receives some rainfall in winter months due to western disturbances. Despite heavy rains in the area, water retention is very low because of steep slope which develops high surface runoff. Generally, the slope of the district is from north east to south west and most of the seasonal streams flow down and while spreading gravels/pebbles on its way. The study area has so many (1,210,741) tributaries ranking from 1 to 9 stream order and all of them terminates in Ghaggar river. The study area constitutes of different land use and land cover as shown in figure 1, about 78.18% of area is covered by forest (Open forest and Scrub forest), 16.31% of area is occupied by agricultural land (Terrace cultivation and Old agricultural plantation),

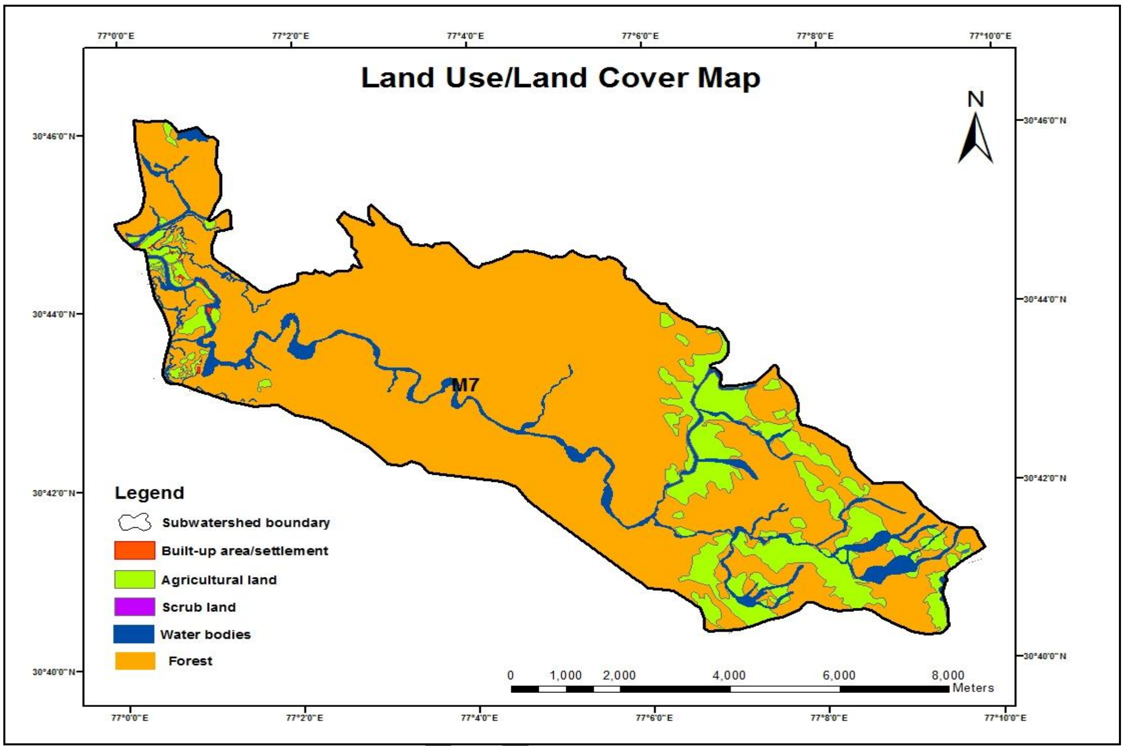


Fig.1 - Land use/Land cover of study area

0.06% and 0.24% is under built up area/settlement and scrub land, respectively and rest of the 5.21% of the area is found to be under water bodies viz. natural pond and river course.

3. METHOD AND MATERIALS

GIS database was prepared with combination of different thematic layers viz. climatic, soil, Land use/land cover, topography. Each layer was developed separately and composed of various sub layers. Climatic data base was prepared from the reference and crop Evapotranspiration and effective rainfall of the sub watershed. Point layer is created on monthly and annual basis for maximum, minimum temperature and average precipitation then Spatial interpolation was performed using inverse distance weighted method in ARCGIS 10. Soil database as well as WORLDVIEW-2 satellite data for DEM extraction was collected from Haryana Space Applications Centre , Hisar. Based upon the data present and specific need, the layers are integrated and used for the creation of thematic maps using ARCGIS 10 and ERDAS IMAGINE 2011 software. Climatic water surplus/deficit was calculated by analysing the input data and resulted as a difference between crop evapotranspiration and effective rainfall.

3.1 CLIMATIC DATABASE

In order to calculate crop water requirement /irrigation management practices reference evapotranspiration, crop evapotranspiration, monthly rainfall, effective rainfall and climatic water deficit was calculated for a period of 102 years (1901-2002) at various meteorological stations surrounding the area of interest i.e. Morni sub watershed. All the required climatic data was obtained from Indian Meteorological Department.

3.2 REFERENCE AND CROP EVAPOTRANSPIRATION

Monthly reference evapotranspiration was calculated for each location through minimum and maximum temperature and latitude of the meteorological stations using the Hargreaves method (Hargreaves and Samani, 1985). Then, the climatic water deficit is calculated as a difference between precipitation (effective rainfall) and reference evapotranspiration.

Hargreaves formulae used to determine Reference Evapotranspiration is given as:

$$ETo = 0.0023 \left(\frac{Tmax.+Tmini.}{2} + 17.8\right)\left(\sqrt{Tmax.-Tmini.}\right).Ra$$

whereas,

ETo = reference evapotranspiration(mm d^{-1})

Tmax. = maximum daily air temperature (°C)

Tmini. = minimum daily air temperature (°C)

Ra = extra-terrestrial solar radiation (MJ $m^{-2}d^{-1}$)

Crop coefficient was considered for only two main crops i.e. Rice and wheat as shown in table 1.

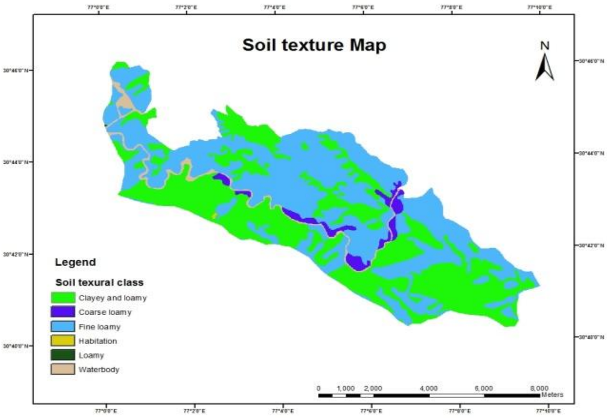
Table 1: Value of Crop Coefficient for different crops

Sr. no.	Crop	Crop period	Value of Crop Coefficient (Kc)
1	Wheat	November to May	0.632
2	Rice	June to October	1.1

Crop evapotranspiration (ETc)= Reference Evapotranspiration (ETo) x Kc

Using this formula crop evapotranspiration for each month (January to December) was determined.

3.3 EFFECTIVE RAINFALL (PEFF.)



Effective rainfall is the rainfall that is available in plant root zone, allowing the plant to germinate or maintain its growth. Part of precipitation might be lost by surface runoff and by deep percolation that will eventually reach the water table. Effective rainfall was considered as the 80% of the total rainfall receiving by the earth surface and calculated on monthly basis.

Soil database-The sub watershed has a constant value of organic content (0.75%) whereas soil texture was observed different at different places of study area. Mainly four classes of study area were noted viz. clayey & loamy, coarse loamy, fine loamy and loamy as shown in figure 2. **A small area covered by waterbody and habitation was assumed as rocky surface due to unavailability of data**. Fine loamy textured soil was observed in most of the land surface of sub watershed followed by clayey & loamy soil.

Fig. 3.1 - Soil textural classification map

A DEM, Digital Elevation Model, is a raster file that depicts elevation in dark and light pixels; dark pixels denoting low areas of elevation, and light pixels denoting high areas of elevation. From the processed imagery DEM was extracted by specifying cell size of 2x2 m in x, y coordinates of LPS Project Manager toolbar. Elevation of high quality generated DEM ranges from 448.15m to1453.43m with mean elevation of 925m and has a higher resolution of 2m. Contours (fig. 4) were generated from the extracted DEM as shown in figure 3 below:

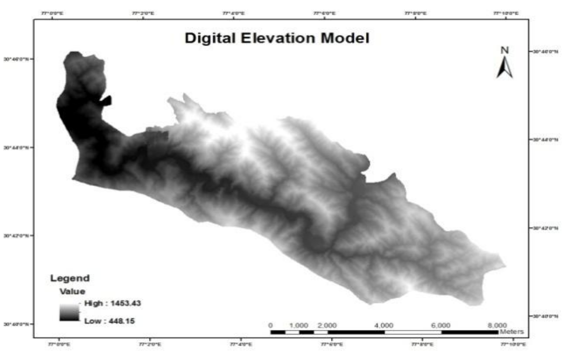


Fig. 3.2 - Digital Elevation Model map

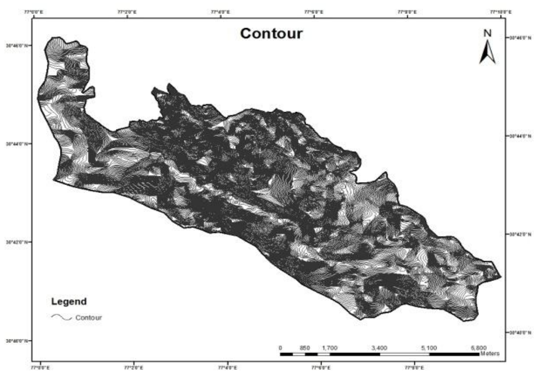


Fig. 3.3 - Contour map

3.5 CLIMATIC WATER DEFICIT (ΔW)

Water balance was analyzed as a difference between monthly effective rainfall (Peff.) and monthly crop evapotranspiration (ETc).

$$\Delta W = P_{eff.} - ETc$$

4. RESULTS AND DISCUSSION

4.1 EFFECTIVE RAINFALL (PEFF.)

For this study, precipitation data for 102 year (1901-2001) was used. The amount of monthly rainfall is found to be varying from 0-275.77 mm. the highest average effective rainfall was observed in the month of July (158.51mm) followed by August (139.25mm) and June (109.73mm). Mini average effective rainfall was noticed in the month of October (10.04mm), April (12.28mm) and November (13.25mm) as shown in table 2.

Table 4.1 Monthly effective Rainfall (Minimum, Maximum and Average)

Sr. no.	Month	Minimum Effective Rainfall (mm)	Maximum Effective Rainfall (mm)	Average Effective Rainfall (mm)
1	January	1.10	53.22	27.16
2	February	1.17	50.02	25.595
3	March	1.71	51.27	26.49
4	April	0.99	23.57	12.28
5	May	3.18	39.82	21.5
6	June	9.28	210.17	109.725
7	July	41.25	275.77	158.51
8	August	31.98	246.51	139.245
9	September	14.69	198.95	106.82
10	October	0	20.07	10.035
11	November	0	26.49	13.245
12	December	0	31.55	15.775

4.2 CROP EVAPOTRANSPIRATION (ETC):

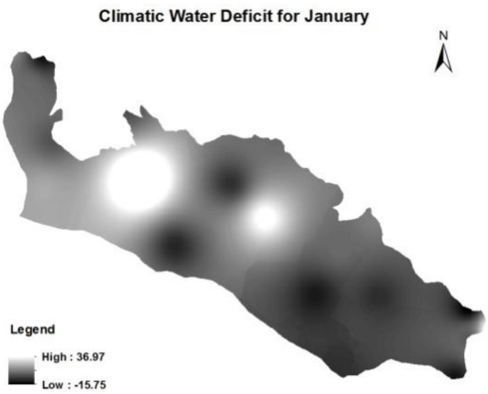
Reference evapotranspiration (ETo)-derived from Hargreaves methods- varies as the air temperature (mini. and max.) changes. Result shows (table 3) that minimum ETc ranged between 5.13 (February) to 222.78 (June), whereas maximum ETc increases from January to June (except February), when it reaches maximum, followed by a drop of values (July-December) during the winter months. Highest values of average ETc were observed as 239.39, 187.76, 154.17, 152.74, 143.22, 141.92, 122.21 in the months of June, July, August, September, May, October and April respectively.

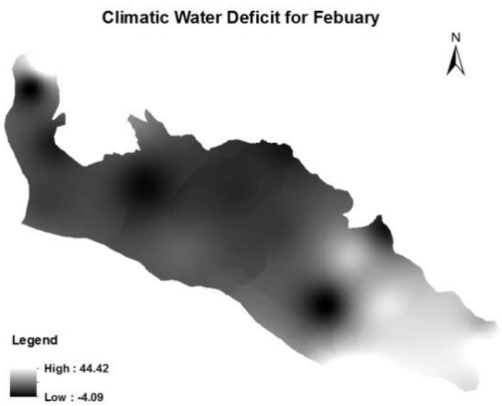
Table 4.2 Monthly Crop Evapotranspiration (Minimum, Maximum and Average)

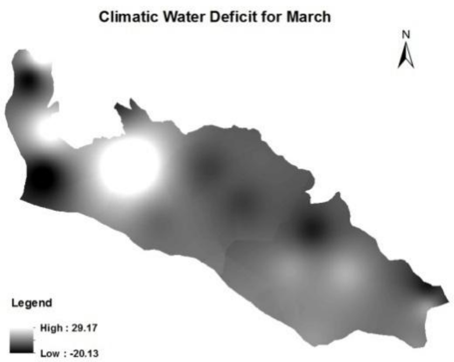
Sr. no.	Month	Minimum ETc	Maximum ETc	Average ETc
1	January	14.54	17.39	15.97
2	February	5.13	5.94	5.54
3	March	19.06	22.44	20.75
4	April	115.48	128.93	122.21
5	May	134.98	151.46	143.22
6	June	222.78	255.99	239.39
7	July	177.66	197.85	187.76
8	August	133.31	175.02	154.17
9	September	140.52	164.96	152.74
10	October	136.21	147.63	141.92
11	November	58.33	63.50	60.92
12	December	41.09	49.75	45.42

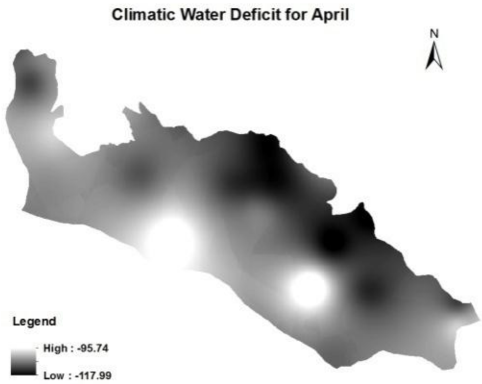
4.3 CLIMATIC WATER DEFICIT (CWD)

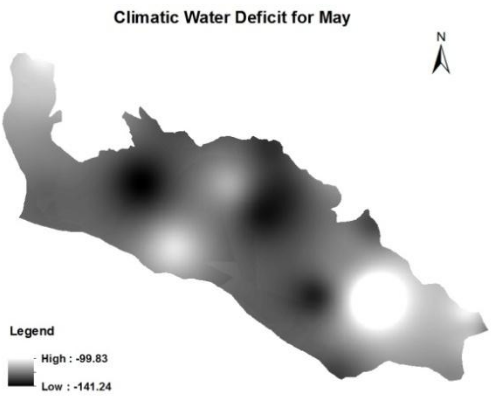
It appears from the result (table 4 and fig. 3) that highest values of CWD occurred in those months where temperature (mini., maxi.) is higher and effective rainfall is lower. Increased ETc leads to water deficiency in active root zone that has negative impact on plants growth and development. Monthly average CWD was found as -124.87, -133.79, -120.54, -106.87, -48.05, -31.96, -25.33 during the month of October, June, May, April, November, July, December and August respectively. The months January (10.61), February (20.17)and March (4.52) represents climatic water surplus, when ETc is less than the amount of effective rainfall.

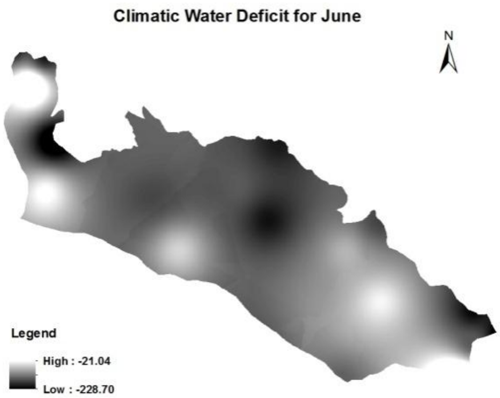

Climatic Water Deficit for January
N
Legend
High : 36.97
Low : -15.75

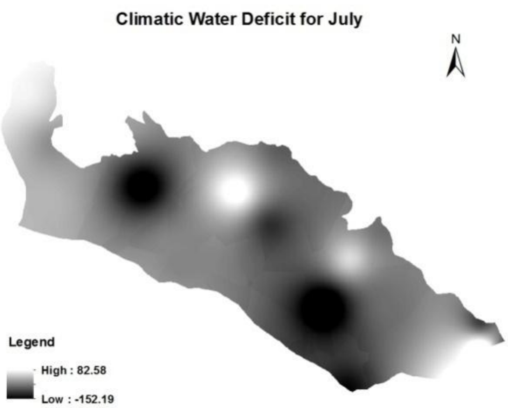

Climatic Water Deficit for Febuary
N
Legend
High : 44.42
Low : -4.09

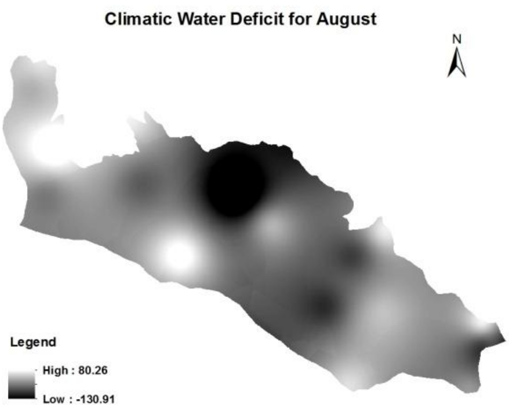

Climatic Water Deficit for March
N
Legend
High : 29.17
Low : -20.13


Climatic Water Deficit for April
N
Legend
High : -95.74
Low : -117.99


Climatic Water Deficit for May
N
Legend
High : -99.83
Low : -141.24


Climatic Water Deficit for June
N
Legend
High : -21.04
Low : -228.70


Climatic Water Deficit for July
N
Legend
High : 82.58
Low : -152.19


Climatic Water Deficit for August
N
Legend
High : 80.26
Low : -130.91

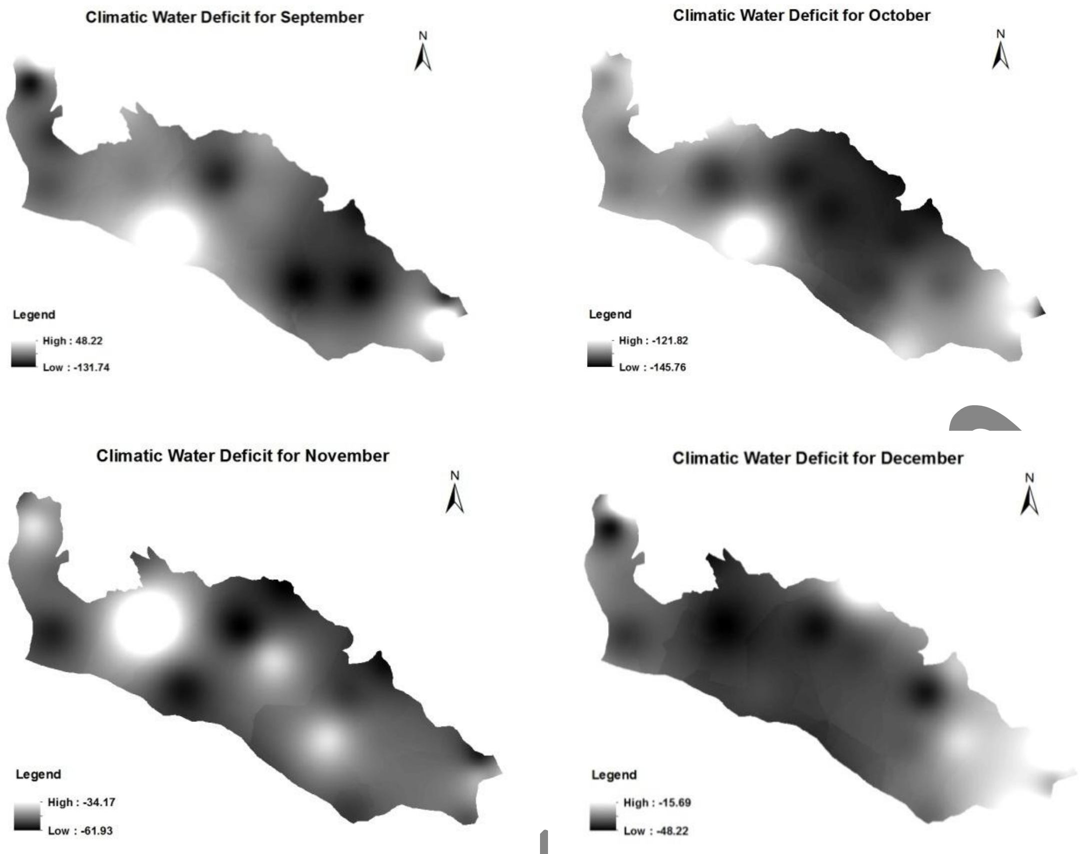


Fig. 4.1 Month wise Climatic Water Deficit map of study area (January to December)

Table 4.3 - Monthly Climatic Water Deficit (Minimum, Maximum and Average)

Sr. no.	Month	Minimum CWD	Maximum CWD	Average CWD
1	January	-15.75	36.97	10.61
2	February	-4.09	44.42	20.17
3	March	-20.13	29.17	4.52
4	April	-117.99	-95.74	-106.87
5	May	-141.24	-99.83	-120.54
6	June	-228.70	-21.04	-124.87
7	July	-152.19	82.58	-34.81
8	August	-130.91	80.26	-25.33
9	September	-131.74	48.22	-41.76
10	October	-145.76	-121.82	-133.79
11	November	-61.93	-34.17	-48.05
12	December	-48.22	-15.69	-31.96

4.4 ANNUAL PEFF, ETC AND CWD

Results revealed that annual Peff. ranges from 293.61 to 851.46mm, whereas annual ETc varied between 1244.46 to 1333.07 as shown in fig. 4. Annual CWD was recorded with a range between -978.44 to -439.10 which resembles a need for storage of water to avoid CWD problem.

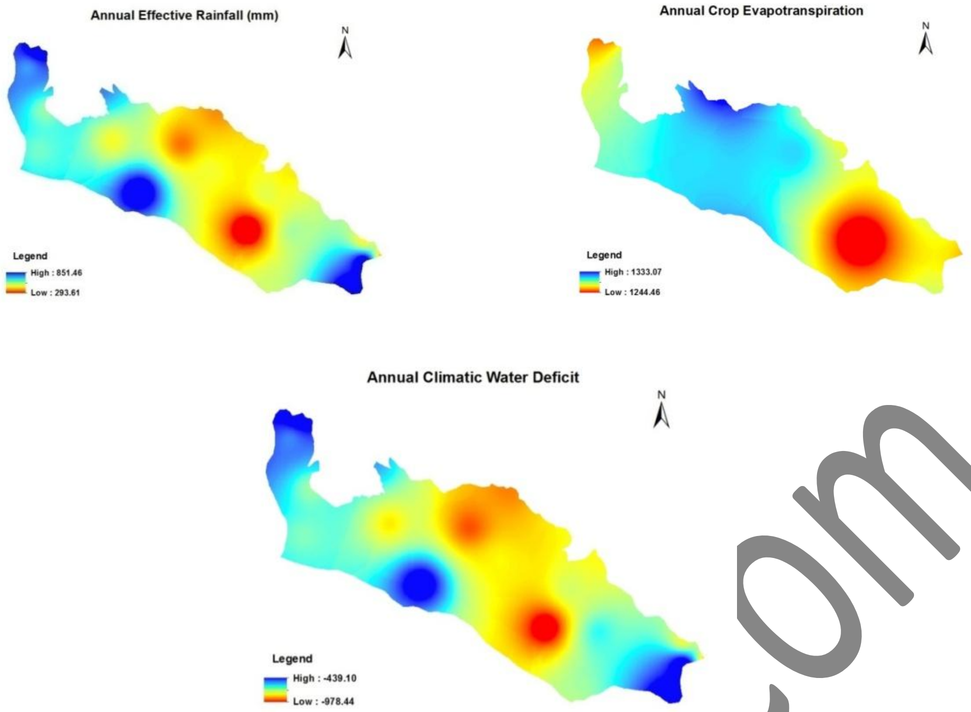


Fig. 4.2 Annual Effective Rainfall, Annual Crop Evapotranspiration and Annual Climatic Water Deficit map

CONCLUSION

ETc-calculated by Hargreaves method- followed by ETo varies from 5.54 to 239.39. Effective rainfall was obtained from monthly rainfall data, ranges from 21.5 to 158.51. Climatic water surplus was noticed during three months only viz. January, February and March whereas in rest of months (April to December) high value of CWD was recorded as shown in fig. 5 below:

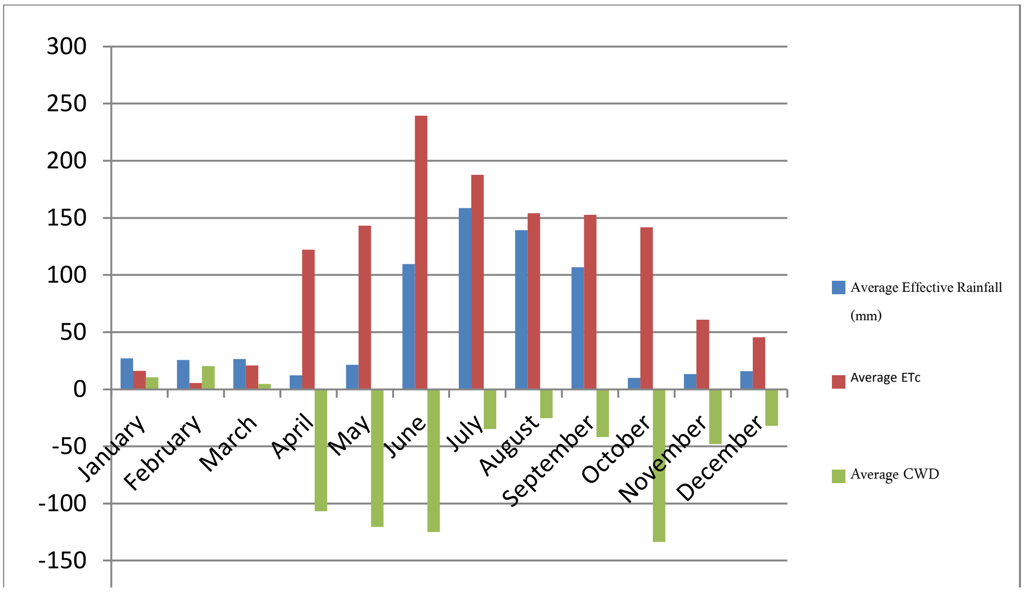


Fig. 5: Graphical representation of Peff., ETc and CWD

Negative values of CWD indicate the use of irrigation in agriculture is required. Hence water harvesting is a necessity in this region to increase agricultural productivity as well as social status.

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