ESTIMATION OF WATER BALANCE OF BARSACHHU WATERSHED IN CHUKHA BHUTAN USING REMOTE SENSING AND GIS

Gautam Thapa[1], Kaushila Timshina[2], Krishna Kumar Subedi[3]
Freelance consultant and Corresponding author [1], Freelance Researcher [2]
Chhukha Higher Secondary School, Ministry of Education [3]
gautamama@gmail.com[1], kausicare@gmail.com[2], technologyspace75@gmail.com[3]
DOI: 10.54417/jaetm.v2i1.53

Abstract—The water balance of a watershed is critical for the estimation of the water budget to meet the present and future domestic and economic demand and supply of water. Water balance parameters like precipitation, temperature, evapotranspiration soil moisture content deficit and surplus determine the water budget of a watershed which is further influenced by factors like land use, soil types, seasonal variation and other environmental factors. This paper intends to estimate the water balance of the Barsachhu watershed using Thornthwaite and Mather (TM) model. The use of Remote Sensing data and GIS as a tool were used in deriving the required data in executing the model. The study indicates that the monthly soil moisture content (deficit or surplus) is substantially influenced by the change in monthly rainfall, temperature and land use land cover pattern. April to October remain water surplus months while November to March remains a period of deficit. The soil moisture content has a different response to different land use in the Barsachhu watershed. The maximum annual moisture deficit and surplus of the basin are 126.27 mm and 2430.79 mm respectively and is observed in built-up areas. The runoff coefficient of the Barsachhu watershed computed from the runoff simulation of the TM model is 0.63.

Keywords— water balance, water deficit, water surplus, thornthwaite and mather (TM) model, barsachhu watershed

I. INTRODUCTION

1.1 General

The rising global economies, urbanization, climate change and increasing population induce pressure on land use and land cover change, which inversely impact the water budget of a watershed. The changes in the water storage of a watershed are greatly determined by hydrological components like precipitation, evapotranspiration, total runoff, surface runoff, base flow and groundwater infiltration [1]. These hydrological components vary in different land use and with the changing land use. The negative impacts of the land use land cover change are associated mostly with urbanization and industrialization intensified by climate change [2]. An 18% increase in urban, impervious areas in the Little Eagle Creek watershed in Indiana, the USA between 1973 and 1991, resulted in an estimated 80% increase in annual average runoff [3]. The increase in surface runoff and water yield in the streamflow across the Ganga River watershed is a result of urbanization, while there is increased irrigation, and increased evapotranspiration in the agricultural land undergoing rapid commercialization [4]. While the major source of water for domestic use and commercial agriculture in the US is being extracted faster than its replenishment in the Ogallala aquifer [5]. Land-use changes study using Landsat TM imageries taken in 1980, 1990 and 2000 and hydrological model MIKE SHE within the Gyeongancheon watershed in Korea. The analysis showed an increase in total runoff (5.5%) and overland flow (24.8%) as a response to the land-use change dominantly urbanization [6]. Water Balance becomes particularly crucial with the domestic and economic demand and the availability of water in the watershed. In simple terms, a water balance is a budgeting exercise that accesses the proportions of rainfall that becomes streamflow, evapotranspiration, and drainage or groundwater recharge [7]. The estimation of the water budget is essential for meeting the demand and supply for irrigation, domestic and other municipal use in the present and future [8]. Water balance, which calculates catchment inputs and outputs, is another way of understanding the hydrologic setting and functioning of spring systems, as well as analyzing the sustainability of groundwater [9]. The Thronthwaite model is the most commonly used model to understand and analyze the water balance of a basin. The simplicity of the formula and the availability of temperature and rain data for long periods at many stations have been the main reason for its widespread use. In fact, it is the best known and most widely used of all the empirical formulas in places where there is insufficient data and other meteorological factors [10].

With precipitation, potential evapotranspiration is also a major driver of the hydrological cycle of a watershed. Evapotranspiration is evaporation from an extended surface of short green crops, actively growing, completely shading in the ground, of uniform height and not short of water [11]. The impact of potential evapotranspiration on the annual water budgets can be very significant with evapotranspiration contributing to precipitation which in turn determines the amount of discharge and infiltration [12]. Potential evapotranspiration from vegetation in hydrology is used with other hydrological data to determine the water balance and estimates of soil moisture to calculate actual evaporation and runoff [13].

Water resources though seemingly abundant are scarce in several pockets of the country. Topographically inaccessible rivers, higher dependence on rainwater for agriculture, and drying up of sources of drinking water, which are majorly springs, due to land-use change and climate variability [14]. Further demand from different users like the rapidly increasing hydropower and allied industries, rapid urbanization of 3.2%, and population growth of 1.2% per annum have increased pressure on water resources [15]. Thus effective watershed management is crucial for water resources conservation and viable use, where use and management of information systems become critical.

Therefore the current study aims to find the water balance of the Barsachhu watershed using Thornthwaite and Mather (TM) model with the help of remote sensing and GIS. And, also compute the runoff coefficient of the watershed with the simulation value obtained from the TM model.

1.2 Study Area

The Barsachhu watershed is located between 26°50’17.90” N to 26°95’49.89’’N latitude and 89°26’ 31.28’’E to 89°32’’14.16” E longitude covering a total area of 58.23 sq. km. The watershed is characterized by hills, ridges that are incised by streams and a portion of flat land towards the tail end of the watershed. It lies in the Himalayan foothills with an elevation rising from 228 m to 1700 m above sea level.

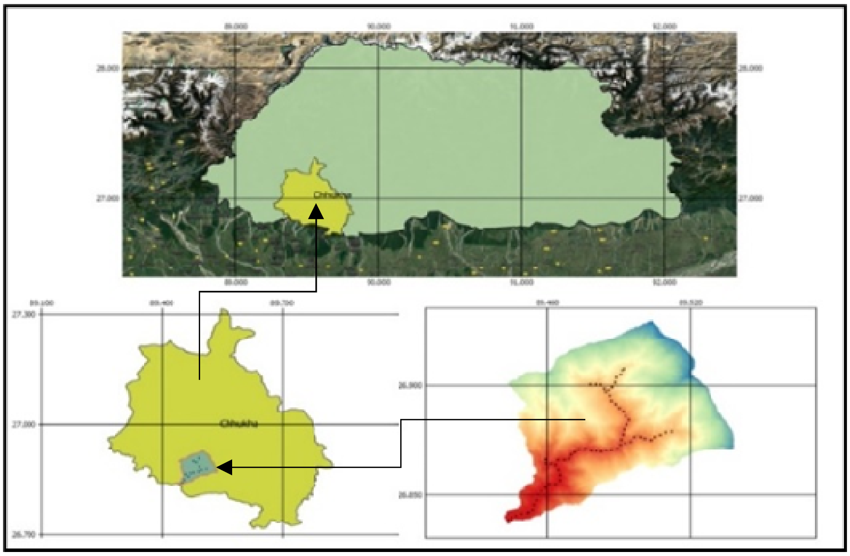

Fig. 1. Location of the study area

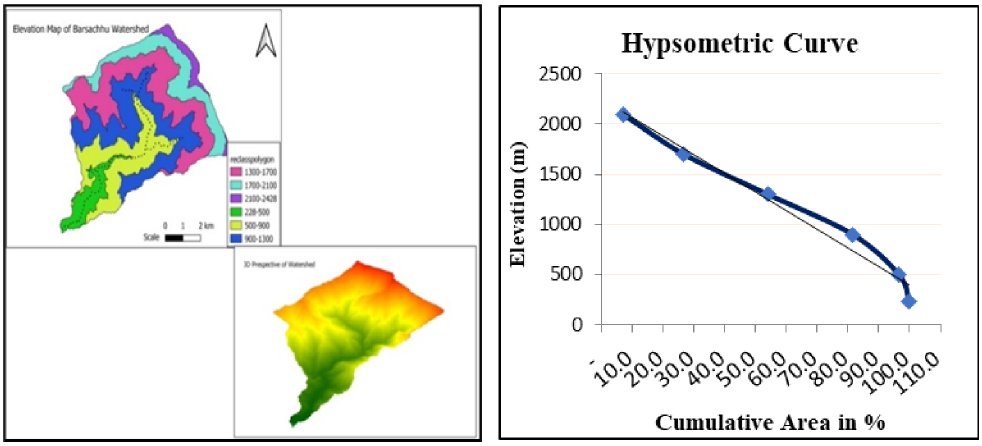

Fig. 2. (a) Elevation and 3D perspective of watershed **(b)** Elevation gradients in Hypsometric curve

The graphical representation (hypsometric curve) in (Fig. 2b) of the geographical area shows that more than 50% of the area lies between elevations of 900m to 1700m.

II. Materials and Methods

2.1 Data and Source

In the study, both spatial and non-spatial data were collected from relevant agencies of Bhutan and the relevant websites. The daily rainfall data is from the Class A meteorological station (1996-2013) within the watershed. The watershed boundary and drainage network of the study area were delineated using a 12m resolution digital elevation model from ALOS PALSAR downloaded from earth explorer. The national scale digital LULC map from Landsat 8 OLI using Object-based machine learning algorithms with a spatial resolution of 30m was acquired [16]. Data on cultivated land, shrubs, forests and meadows were obtained [17]. The table below shows the details of the data source.

TABLE 1: Spatial and non-spatial data and its source

Spatial and non-spatial data	Sources	Resolutions
Digital Land use and Land cover Map (2016)	Forest Research and Management Division, Ministry of Agriculture	30 m
Precipitation (1996-2013)	National Centre for Hydrology and Meteorology, Ministry of Economic Affairs	Daily Temporal Resolution
Temperature (1996-2013)	National Centre for Hydrology and Meteorology, Ministry of Economic Affairs	Daily Temporal Resolution (Min.-Max.)
Digital Elevation Models (ALOS PALSAR)	USGS Earth Explorer	12 m
Digital Soil map	FAO Global Digital Soil map	1 km

2.1.1 *Rainfall and Temperature*

The Barsachhu watershed falls under the subtropical climatic zone. The average annual rainfall is 1500mm (1996-2013) as in Fig.3a, with monthly mean rainfall as high as 900mm

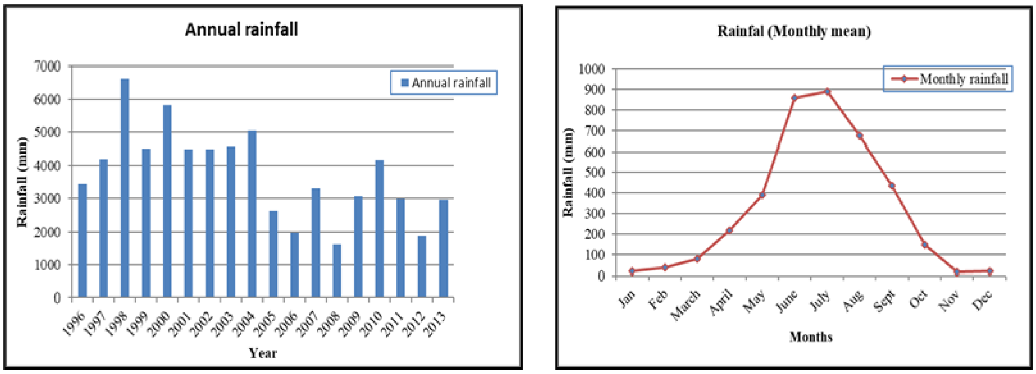

Fig. 3. (a) Annual rainfall trends 1996-2013 **(b)** Monthly mean rainfall trends

In the last two decades, the highest daily rainfall recorded was 495.3mm a day. June and July months receive the highest rainfall (Fig.3b). The monthly mean temperature varies between 21ºC to 30ºC, the month of June, July and August are the hottest months, while January is the coldest month of the year (Fig.4).

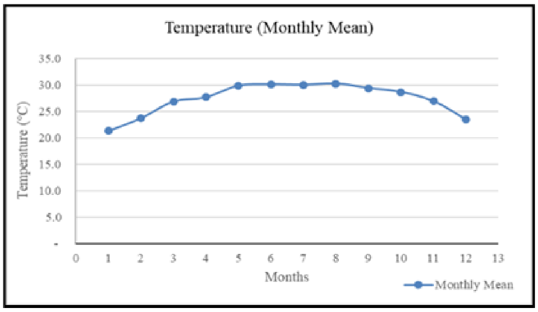

Fig. 4. Monthly Mean Temperature Trend

2.1.2 *Land Use and Vegetation*

The Barsachhu watershed is a forest dominant land cover with more than 90% of the area covered by broad-leaved forest. On the lower tail end of the catchment, the built-up and cultivated area is dominant occupying 2% of the total area. The built-up area consists of rural households, mostly occupied by large industries along the Barsachhu river banks. Different land use land cover is shown in Fig.5 and its relative coverage area in Table1.

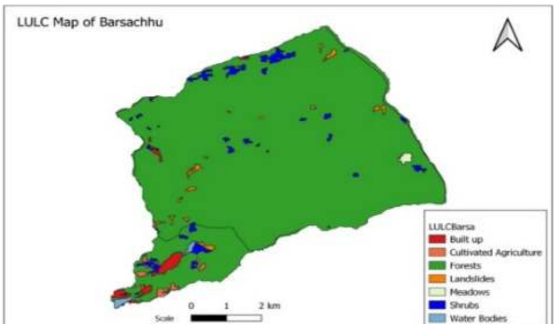

Fig. 5. Land use Land cover map of Barshachhu watershed

TABLE 2. Distribution of different Land use and land cover area of the Barshachhu watershed

Land use	Area (km2)	Area %
Built-up	1.19	2.04
Cultivated Agriculture	0.56	0.96
Forests	53.98	92.70
Landslides	0.33	0.57
Meadows	0.18	0.31
Shrubs	1.71	2.93
Water bodies	0.28	0.48

2.1.3 Geological settings

Geologically, the Barsachhu watershed falls along the fragile foothills of Bhutan Himalaya. The watershed occupies four geological formations, those are Phuentsholing formation which covers the lower area, Shumar Formation overlays the Phuentsholing formation, which is then overlaid by the Jaishidanda formation and surey formation. The watershed is geologically fragile and is susceptible to landslides with 9% of the watershed being under landslide-prone areas. Flash floods at the Barsa river have been a repeated event causing serious threats to the residents and the industries [17](WMD 2018). The geophysical characteristics of the Barsachhu watershed indicate that the water budget of the Barsachhu watershed is constantly changing and geohazards like landslides and flash floods are triggered by heavy rain. The existing and scars of old landslides are visible in abundance.

III. METHODS

3.1 Water Balance

The most simplified and widely used Water balance model is as

$$Q = P - ET - \Delta S \qquad (1)$$

Where: P: Precipitation, Q: Discharge, ET: Evapotranspiration, ΔS: Change in Storage

The proposed methodology is used to derive the water balance of the Barshachhu watershed using GIS and TM model approaches. Thronthwaite and Mather established some of the first water balance models.

The Thornthwaite model is one of the simplest models used to determine the water balance up to field level to watersheds. The model requires monthly temperature and precipitation as its input, while the outputs are monthly potential and actual evapotranspiration, soil moisture storage, snow storage, surplus, and runoff [18]. The model is one of the simplest models to get a good water balance result. The amount of water that can be evaporated in an enabling environment with the availability of sufficient water in the soil is Potential Evapotranspiration (PET) and is calculated using the equation

$$PET = 1.6\, x\, f\, x \left(\frac{10xT}{I}\right)^{a} \qquad (2)$$

Where PET is the potential evapotranspiration (mm month-1), T is the monthly temperature (°C), I is annual heat index for the 12 months in a year (I = ∑i), i is the monthly heat index (i=[T/5]1.514), a= 6.75 x 10-7 x I3 – 7.71 x 10-5 x I2 + 1.792 x 10-2 x I + 0.49239 and f is a correction factor for Sunshine duration for each month considering its geographical location (Latitude). The present study area lies at latitude 26.88N, the monthly adjustment factors are shown in table 3.

TABLE 3. Monthly adjustment factors "f" of the study area as per geographical location

Table for 'f' value to be used in Thornthwaite method												
North Lat.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.97	0.98	1.01	1.03	1.05	1.06	1.05	1.03	1.08	0.99	0.98	0.96
20	0.93	0.96	1.00	1.05	1.09	1.11	1.10	1.07	1.03	0.98	0.93	0.91
26.86	0.89	0.94	1.00	1.07	1.12	1.16	1.14	1.09	1.03	0.97	0.90	0.87
30	0.87	0.93	1.00	1.08	1.14	1.18	1.16	1.10	1.03	0.96	0.88	0.85
40	0.80	0.89	0.99	1.10	1.20	1.25	1.23	1.15	1.04	0.93	0.83	0.78
50	0.72	0.84	0.98	1.15	1.28	1.37	1.33	1.21	1.06	0.90	0.76	0.68

The PET computed from the above equation-2 is considered an unadjusted PET. The unadjusted PET is considered as actual PET upon applying the correction factor. The quantitative water excess (+) or deficit (-) is determined using the formula below

$$\text{Excess or Deficit} = Pm - PETm \qquad (3)$$

If P_m >=PET_m, , then ET= PET_m, but if P_m <=PET_m then ET= P_m- ΔSM

Where P_m is the monthly mean precipitation, ET Evaporation Transpiration and ΔSM change in storage. The Accumulated Potential Water Loss (AWPL) is considered zero for the months with excess or positive (P-PET), and starting with the first month of having a deficit or negative value, the accumulation with the previous month is considered. The Actual Storage of Soil Moisture (STOR) for each month was computed as

$$STOR = AWC \times e\left(\frac{APWL}{AWC}\right) \qquad (4)$$

Where the Available Water Capacity(AWC) or moisture storage capacity, the amount of water that a soil can store and that is available for use by plants were computed about land use, soil texture and rooting depth as suggested [18]Thronthwaite & Mather (1955). Available water is often stated for a common depth of rooting where 80% of the roots occur and expressed as a volume fraction [19]. The AWC depends on soil properties, soil field capacity and root zone depth. In absence of field data, the estimation of rooting depth and fraction of water available for different soil formations was determined through literature for similar types of soil and vegetation found in the contributing watershed.

TABLE 4. Available Water Capacity in different land use and soil type

Land Use	Soil Texture	AWC %	Rooting Depth	AWC of Root Zone(mm)
Built-up	Sandy	10	0.5	50
Cultivated Agriculture	Sandy loams	15	0.6	90
Forests	Sandy clay loam	15	2	300
Barren land/Landslides	Sandy Clay	15	1	150
Meadows	Sandy Clay	15	0.7	105
Shurbs	Sandy Clay	15	0.7	105
Water bodies	Sandy	10	0.5	50

The changes in the actual storage (ΔSM) for all the months are calculated as follows

$$\Delta SMmonth = STORmonth - STOR\ previous\ month \quad (5)$$

The negative value of ΔSM represents that water from the storage to be used for evapotranspiration, whereas a positive value of ΔSM indicates that the excess water infiltrates into the soil and addition to the soil moisture storage. Equations 6 & 7 were applied to compute Actual Evapotranspiration (AET) based on the change in storage of soil moisture of the preceding/succeeding month.

$$AET = \Delta SM + P \qquad \Delta SM < 0 \quad (6)$$

$$AET = PET \qquad \Delta SM > 0 \quad (7)$$

When the Actual evapotranspiration is more than the PET, there is a deficit in the soil. The water deficit (DEF) for crop evapotranspiration in each month was calculated for the months having negative (P-PET) as follows

$$DEF = PET - AET \quad (8)$$

When there is an excess amount of water it infiltrates deeper into the soil. This is denoted as moisture surplus (SUR)

$$SUR = P - PET \quad (9)$$

When the storage of soil is not to its capacity, no surplus exists, where soil moisture storage capacity is just satisfied, SUR is obtained using the equation

$$SUR = P - (AET + \Delta SM) \quad (10)$$

The computed surface runoff using the TM model varies for different landuse/land cover-texture classes. From the Surplus water available, 50% of water is considered surface runoff as suggested by [18].

IV. RESULT

4.1 Seasonal variation in water availability

The Accumulated Potential Water Loss (APWL) for the Barshachu watershed is derived from the monthly rainfall and temperature. There is both deficit and surplus in soil moisture during the dry and wet seasons respectively. The outcome of the analysis indicates that the plants during the months (April to October) have access to soil moisture while during the months (November to March) the plants would relatively remain water-stressed and the soil would mostly remain dry shown in Table 5.

TABLE 5: Monthly Accumulated Potential Water Loss

	Jan	Feb	Mar	Apr	May	Jun
P	18.7	31.9	76.3	218.8	390.3	859.9
PET	40.2	61.7	102.3	134.9	170.0	187.5
P-PET	(21.5)	(29.7)	(25.9)	83.8	220.2	672.4
APWL	(119.1)	(148.8)	(174.8)	-	-	-

	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	890.4	676.2	434.9	148.0	12.7	11.0	3,769.0
PET	186.8	180.8	154.0	125.1	75.9	45.4	1,464.5
P-PET	703.6	495.4	280.9	22.8	(63.2)	(34.4)	2,304.5
APWL	-	-	-	-	(63.2)	(97.6)	(603.5)

The deficit in soil moisture was observed minimum in an evergreen broad-leaved forest (42.3mm) followed by barren land (71.5mm), meadows (89.63mm), and agricultural land (94.85mm) and built-up area and water bodies (126.27mm). Similarly, the annual surplus of moisture in the soil is minimum in an evergreen broad-leaved forest (2,346.8mm) followed by barren land (2,376.1mm), meadows (2,394.15mm), agricultural land (2,399.36mm) and built-up area and water bodies (2,430.79mm) and is presented in Table 6. The area-weighted annual deficit of the watershed is 46.6mm, while the surplus is 2350.89mm.

TABLE 6: Monthly water balance for different land-use in the Barshachhu watershed

	Jan	Feb	Mar	Apr	May	Jun	
Evergreen broadleaved forest, AWC: 300							
Precip	18.7	31.9	76.3	218.8	390.3	859.9	
PET	40.2	61.7	102.3	134.9	170.0	187.5	
P-PET	(21.5)	(29.7)	(25.9)	83.8	220.2	672.4	
APWL	(119.1)	(148.8)	(174.8)	-	-	-	
store	201.7	182.7	167.5	83.8	300.0	300.0	
ΔSM	(15.0)	(19.0)	(15.1)	(83.7)	216.2	-	
AET (mm)	33.7	51.0	91.4	134.9	170.0	187.5	
Deficit	6.5	10.7	10.8	-	-	-	
Surplus	-	-	-	167.5	4.0	672.4	
Tot. Q	52.5	26.2	13.1	167.5	87.8	716.3	
Runoff	26.2	13.1	6.6	83.8	43.9	358.2	
GWR	26.2	13.1	6.6	83.8	43.9	358.2	
	Jul	Aug	Sep	Oct	Nov	Dec	Total
Evergreen broadleaved forest, AWC: 300							
Precip	890.4	676.2	434.9	148.0	12.7	11.0	3,769.0
PET	186.8	180.8	154.0	125.1	75.9	45.4	1,464.5
P-PET	703.6	495.4	280.9	22.8	(63.2)	(34.4)	2,304.5
APWL	-	-	-	-	(63.2)	(97.6)	(603.5)
store	300.0	300.0	300.0	300.0	243.0	216.7	2,895.5
ΔSM	-	-	-	-	(57.0)	(26.3)	-
AET (mm)	186.8	180.8	154.0	125.1	69.7	37.3	1,422.2
Deficit	-	-	-	-	6.2	8.1	42.3
Surplus	703.6	495.4	280.9	22.8	-	-	2,346.8
Tot. Q	1,061.8	1,026.3	794.1	419.9	209.9	105.0	4,680.5
Runoff	530.9	513.1	397.0	209.9	105.0	52.5	2,340.3
GWR	530.9	513.1	397.0	209.9	105.0	52.5	2,340.3

	Jan	Feb	Mar	Apr	May	Jun
Barren Land, AWC: 150						
Precip	18.7	31.9	76.3	218.8	390.3	859.9
PET	40.2	61.7	102.3	134.9	170.0	187.5
P-PET	(21.5)	(29.7)	(25.9)	83.8	220.2	672.4
APWL	(119.1)	(148.8)	(174.8)	-	-	-

	Jan	Feb	Mar	Apr	May	Jun	
store	67.8	55.6	46.8	83.8	150.0	150.0	
ΔSM	(10.4)	(12.2)	(8.8)	37.0	66.2	-	
AET (mm)	29.2	44.1	85.1	134.9	170.0	187.5	
Deficit	11.0	17.5	17.1	-	-	-	
Surplus	-	-	-	46.8	154.0	672.4	
Tot. Q	52.8	26.4	13.2	46.8	177.4	761.1	
Runoff	26.4	13.2	6.6	23.4	88.7	380.6	
GWR	26.4	13.2	6.6	23.4	88.7	380.6	
	Jul	Aug	Sep	Oct	Nov	Dec	Total
Barren Land, AWC: 150							
Precip	890.4	676.2	434.9	148.0	12.7	11.0	3,769.0
PET	186.8	180.8	154.0	125.1	75.9	45.4	1,464.5
P-PET	703.6	495.4	280.9	22.8	(63.2)	(34.4)	2,304.5
APWL	-	-	-	-	(63.2)	(97.6)	(603.5)
store	150.0	150.0	150.0	150.0	98.4	78.2	1,330.7
ΔSM	-	-	-	-	(51.6)	(20.2)	-
AET (mm)	186.8	180.8	154.0	125.1	64.3	31.2	1,392.9
Deficit	-	-	-	-	11.6	14.2	71.5
Surplus	703.6	495.4	280.9	22.8	-	-	2,376.1
Tot. Q	1,084.2	1,037.5	799.7	422.7	211.3	105.7	4,738.9
Runoff	542.1	518.7	399.8	211.3	105.7	52.8	2,369.5
GWR	542.1	518.7	399.8	211.3	105.7	52.8	2,369.5

	Jan	Feb	Mar	Apr	May	Jun
Meadows, AWC: 105						
Precip	18.72	31.92	76.32	218.78	390.25	859.89
PET	40.20	61.65	102.25	134.94	170.04	187.47
P-PET	(21.48)	(29.73)	(25.93)	83.83	220.21	672.42
APWL	(119.09)	(148.82)	(174.76)	-	-	-
store	33.78	25.45	19.88	83.83	105.00	105.00
ΔSM	(7.67)	(8.33)	(5.57)	63.96	21.17	-
AET (mm)	26.38	40.25	81.89	134.94	170.04	187.47
Deficit	13.81	21.40	20.36	-	-	-
Surplus	-	-	-	19.88	199.05	672.42
Tot. Q	52.96	26.48	13.24	19.88	208.99	776.92
Runoff	26.48	13.24	6.62	9.94	104.49	388.46
GWR	26.48	13.24	6.62	9.94	104.49	388.46

	Jul	Aug	Sep	Oct	Nov	Dec	Total
Meadows, AWC: 105							
Precip	890.38	676.19	434.88	147.96	12.70	10.97	3,768.97
PET	186.76	180.80	153.95	125.11	75.89	45.39	1,464.45
P-PET	703.62	495.40	280.93	22.84	(63.19)	(34.42)	2,304.51
APWL	-	-	-	-	(63.19)	(97.61)	(603.47)
store	105.00	105.00	105.00	105.00	57.52	41.44	891.90
ΔSM	-	-	-	-	(47.48)	(16.08)	-
AET (mm)	186.76	180.80	153.95	125.11	60.18	27.05	1,374.82
Deficit	-	-	-	-	15.71	18.34	89.63
Surplus	703.62	495.40	280.93	22.84	-	-	2,394.15
Tot. Q	1,092.08	1,041.44	801.65	423.67	211.83	105.92	4,775.05
Runoff	546.04	520.72	400.83	211.83	105.92	52.96	2,387.53
GWR	546.04	520.72	400.83	211.83	105.92	52.96	2,387.53

	Jan	Feb	Mar	Apr	May	Jun
Agricultural land, AWC: 95						
Precip	18.72	31.92	76.32	218.78	390.25	859.89
PET	40.20	61.65	102.25	134.94	170.04	187.47
P-PET	(21.48)	(29.73)	(25.93)	83.83	220.21	672.42
APWL	(119.09)	(148.82)	(174.76)	-	-	-
store	27.12	19.83	15.09	83.83	95.00	95.00
ΔSM	(6.88)	(7.29)	(4.74)	68.74	11.17	-
AET (mm)	25.60	39.21	81.05	134.94	170.04	187.47
Deficit	14.60	22.44	21.20	-	-	-
Surplus	-	-	-	15.09	209.05	672.42
Tot. Q	52.99	26.49	13.25	15.09	216.60	780.72
Runoff	26.49	13.25	6.62	7.55	108.30	390.36
GWR	26.49	13.25	6.62	7.55	108.30	390.36

	Jul	Aug	Sep	Oct	Nov	Dec	Total
Agricultural land, AWC: 95							
Precip	890.38	676.19	434.88	147.96	12.70	10.97	3,768.97
PET	186.76	180.80	153.95	125.11	75.89	45.39	1,464.45
P-PET	703.62	495.40	280.93	22.84	(63.19)	(34.42)	2,304.51
APWL	-	-	-	-	(63.19)	(97.61)	(603.47)
store	95.00	95.00	95.00	95.00	48.85	34.00	798.73
ΔSM	-	-	-	-	(46.15)	(14.85)	-
AET (mm)	186.76	180.80	153.95	125.11	58.86	25.82	1,369.60
Deficit	-	-	-	-	17.04	19.57	94.85
Surplus	703.62	495.40	280.93	22.84	-	-	2,399.36

	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tot. Q	1,093.98	1,042.39	802.13	423.91	211.95	105.98	4,785.48
Runoff	546.99	521.19	401.06	211.95	105.98	52.99	2,392.74
GWR	546.99	521.19	401.06	211.95	105.98	52.99	2,392.74

	Jan	Feb	Mar	Apr	May	Jun	
Built-up area/water bodies, AWC=50							
Precip	18.72	31.92	76.32	218.78	390.25	859.89	
PET	40.20	61.65	102.25	134.94	170.04	187.47	
P-PET	(21.48)	(29.73)	(25.93)	83.83	220.21	672.42	
APWL	(119.09)	(148.82)	(174.76)	-	-	-	
store	4.62	2.55	1.52	83.83	50.00	50.00	
ΔSM	(2.48)	(2.07)	(1.03)	82.32	(33.83)	-	
AET (mm)	21.20	33.99	77.35	134.94	170.04	187.47	
Deficit	19.00	27.66	24.90	-	-	-	
Surplus	-	-	-	1.52	254.05	672.42	
Tot. Q	53.14	26.57	13.28	1.52	254.81	799.83	
Runoff	26.57	13.28	6.64	0.76	127.40	399.91	
GWR	26.57	13.28	6.64	0.76	127.40	399.91	
	Jul	Aug	Sep	Oct	Nov	Dec	Total
Built-up area/water bodies, AWC=50							
Precip	890.38	676.19	434.88	147.96	12.70	10.97	3,768.97
PET	186.76	180.80	153.95	125.11	75.89	45.39	1,464.45
P-PET	703.62	495.40	280.93	22.84	(63.19)	(34.42)	2,304.51
APWL	-	-	-	-	(63.19)	(97.61)	(603.47)
store	50.00	50.00	50.00	50.00	14.13	7.10	413.75
ΔSM	-	-	-	-	(35.87)	(7.03)	0.00
AET (mm)	186.76	180.80	153.95	125.11	48.58	18.00	1,338.18
Deficit	-	-	-	-	27.32	27.39	126.27
Surplus	703.62	495.40	280.93	22.84	-	-	2,430.79
Tot. Q	1,103.54	1,047.17	804.52	425.10	212.55	106.28	4,848.29
Runoff	551.77	523.58	402.26	212.55	106.28	53.14	2,424.14
GWR	551.77	523.58	402.26	212.55	106.28	53.14	2,424.14

In terms of precipitation and evapotranspiration, the result indicates that June, July and August have the highest level of evapotranspiration. While it is lowest in January, February, November and December showed in Fig.6.

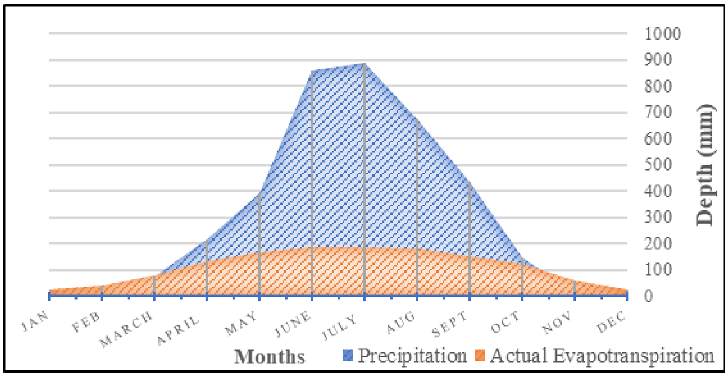

Fig. 6. Monthly precipitation and actual evapotranspiration

4.2 Surface Runoff of Barsachhu

In absence of any available data, the simulated runoff from the TM model was compared with the sporadic runoff observed by the officials from the National Centre for Hydrology and Meteorology during the routine site visit to the area of study. The observed runoff value recorded were in Table 7.

TABLE 7: Observed discharge of Barsachhu for the month of March

Date of Measurement	Year	Discharge (m3/s)	Remarks
13.03.01	2001	0.394	lean period
27.03.02	2002	0.662	lean period
25.03.03	2003	0.857	lean period
30.03.04	2004	0.428	lean period
23.03.05	2005	0.92	lean period
18.03.06	2006	0.527	lean period
22.03.07	2007	0.527	lean period
13.03.08	2008	0.568	lean period

The runoff is derived from the Thronthwaite model (TM) in millimeters (mm) and cumec. is shown in Table 8.

TABLE 8: Simulated runoff from TM model

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Simulated runoff (m)	0.03	0.01	0.01	0.01	0.11	0.39	0.55	0.52	0.40	0.21	0.11	0.05
Simulated runoff (m3/s)	0.54	0.30	0.13	0.16	2.26	7.90	11.07	10.55	8.12	4.29	2.22	1.07

Since the basin is not equipped with hydrometric equipment and in absence of observed runoff data of Barsachhu for validation, no clear conclusion could be drawn on the discharge values simulated from the TM model with respect to observed values. While the simulated data when plotted against the observed rainfall showed significant coherence of model and catchment response as shown in Figure 7.

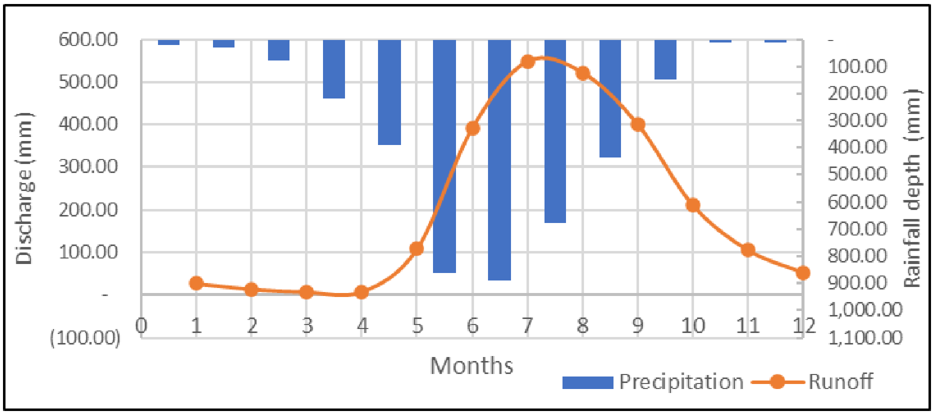

Fig. 7: Monthly precipitation and discharge

Therefore monthly simulated discharge data could be applied to determine, the impact of climate change and water shortage in the catchment.

4.3 Catchment runoff coefficient

The runoff coefficient is one of the most important parameters to determine the runoff volume for an ungauged catchment in absence of observed discharge data. Tay and Afshar (2014) studied a small land parcel of 80 hectares with similar land use and cover pattern in Malaysia and concluded the runoff coefficient to the range of 0.5 to 0.8. and subsequently, the land use type was categorized as "Light industrial" for the derived range of runoff coefficient. In this study the runoff coefficient computed from the observed rainfall and discharge from the TM model was 0.63, this watershed is also considered an industrial estate.

V. CONCLUSION

Estimation of the water budget for monitoring and planning of the Barsachhu watershed management is crucial and critical for many reasons considering the watershed blended to industries and rural household settings. The water balance of the Barsachhu watershed computed using Thornthwaite and Mather (TM) model reflects that the soil moisture content variation through different months of the year, Accumulated Potential Water Loss (APWL) is directly proportional to change in monthly rainfall and temperature. Precipitation and evapotranspiration are high during the monsoon months of June, July and August and the lowest in the fall months of January, February, November and December. The plants during the wet months of April to October have excess water while during the dry months of November to March, the plants remain water-stressed.

The different land use in the Barsachhu watershed had a different response to the soil moisture content. The deficit in soil moisture is minimum in the evergreen broad-leaved forest (42.3mm), barren land (71.5mm), meadows (89.63mm), agricultural land (94.85mm) and maximum in the built-up area and water bodies (126.27mm). The annual surplus soil moisture is minimum in the evergreen broad-leaved forest (2,346.8mm) barren land (2,376.1mm), meadows (2,394.15mm), and agricultural land (2,399.36mm) and the maximum in the built-up area and water bodies (2,430.79mm). The area-weighted annual deficit of the watershed is 46.6mm, while the surplus is 2350.89mm. The simulated runoff against rainfall showed a significant and coherent catchment response to the precipitation pattern. Due to high rainfall and high-level antecedent soil moisture from preceding months, the month of July showed the highest discharge of 550m, with a runoff coefficient of 0.63. The runoff and runoff coefficient further need to be investigated with data from a hydrometric ground station.

REFERENCES

[1] Brent Porter Heerspink, Anthony D.Kendall, Michael T. Coe, David W.Hyndman, “Trends in Streamflow, evapotranspiration, and groundwater storage across the Amazon Basin linked to changing precipitation and land cover,” Journal of Hyrdology: Regional Studies, Vol.32, Dec. 2020. Doi 10.1016/j.ejrh.2020.100755.

[2] Hassan Z, Shabbir R, Ahmad SS, Malik AH, Aziz N, Butt A, Erum S, “Dynamics of land use and land cover change (LULCC) using geospatial techniques a case study of Islamabad Pakistan.” SpringerPlus. 5:812, 2016.

[3] Matt Grove, Jon Harbor, Bernie Engel & Suresh Muthukrishnan, “Impacts Of Urbanization on Surface Hydrology, Little Eagle Creek, Indiana, and Analysis of Lthia Model Sensitivity to Data Resolution,” Physical Geography, 22:2, 135-153, 2001. doi: 10.1080/02723646.2001.10642734.

[4] Anand.J.et al., “Prediction of land use changes based on Land Change Modeller and attribution of changes in the water balance of Ganga basin to land use change using the SWAT model,” Science of The Total Environment, Volume 644, 503-519, 10 Dec 2018. Available: https://doi.org/10.1016/j.scitotenv.2018.07.017

[5] Scoot.M., “National Climate Assessment: Great Plains’ Ogallala Aquifer drying out,” 2019.

[6] Im, S., Kim, H., Kim, C. Jang., “Assessing the impacts of land use changes on watershed hydrology using MIKE SHE,” Environ Geol 57, 231, 2009. Available: https://doi.org/10.1007/s00254-008-1303-3

[7] Tahereh Ensafi Moghaddam, “An estimation of Thronthwaite monthly water balance in Mighan sub-basin. Natural Environment Change,” Vol. 3, No. 1, pp. 71-80, (2017).

[8] The Japan International Cooperation Agency (JICA), Chapter 3 Present And Future Water Demand Projection, 2005. Available: https://openjicareport.jica.go.jp

[9] Dingman SL., Physical Hydrology. 2nd ed. New Jersey: Prentice Hall, 2002.

[10] Mahdavi, M., “A Statistical analysis of the climate in the margin of the Dasht-E-Kavir, Central Iran (A case study of the Kashan meteorological station),” Desert (Scientific Research), Tehran University and Director. Iran Desert Research Center, No. 18, P. 30-35, 1987.

[11] Penman, H. L., Estimating evaporation. American Union Transactions, 1956, 37(1): 43-50.

[12] Gulliver, J.S., Erickson, A.J., Weiss, P.T., "Storm water Treatment: Assessment and Maintenance." University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN,” 2010. Available: http://stormwaterbook.safl.umn.edu/

[13] Bell .A. et al., “Estimating Potential Evaporation from Vegetated Surfaces for Water Management Impact Assessments Using Climate Model Output,” Journal of Hydrometerology.

[12] Singh. Vishal, Anvita Pandey, “Urban water resilience in Hindu Kush Himalaya: issues, challenges and way forward,” Water Policy. 22 (2020) 33–45, 2020.

[13] World Bank, “ Population growth (annual %), Bhutan,”2019.

[14] Rai A, Phuntsho P., Chenga T., Sangay P., Rinchen D., Sangita, P., “Land use and land cover of Bhutan 2016 maps and statistics,” Forest Resources Management Division Department of Forests & Park Services, Ministry of Agriculture and Forests Thimphu, Bhutan, 2017.

[15] Watershed Management Division Department of Forest & Park Services Ministry of Agriculture & Forest Royal Government of Bhutan, “Integrated Watershed Management Plan for Barsa Watershed Chukha Dzongkhag,” 2018.

[16] Thornthwaite, C.W., & Mather, R.J., “The Water Balance,” Publications in Climatology 8, 1–86. DIT, Laboratory of Climatology, Centerton, New Jersey, USA,1955.Available:https://oregondigital.org/catalog/oregondigital:df70pr001#page/4/mode/1up

[17] National Soil Survey Centre and Soil Quality Institute, USDA, 1998.