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ESTIMATION OF NET WATER FLUX AND CROP MOISTURE REQUIREMENT DURING DIFFERENT GROWING SEASONS IN SUB-TROPICAL REGION OF ASSAM, INDIA

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ABSTRACT

Any agrarian region in Asian countries is typically dependent on rainwater for their crops. However, any shortage of rainwater during growing season may lead to low productivity. It is essential for policy makers to estimate the crop water requirement within their jurisdiction. Better planning of crop water management and irrigation can be achieved if water balance is known. For the purpose, a regional study was carried out to estimate the net water flux and crops (rice and oilseeds) moisture requirement during growing period in Assam, India. The daily gridded rainfall and temperature data with a spatial resolution of 1°x1^o was used to assess the net water flux and crop moisture requirement. The potential evapotranspiration (PET) was estimated using Thornthwaite's method. The severity of aridity of the region was evaluated using was the ratio of rainfall (P) and PET called Aridity Index. It was observed that the PET exceeds rainfall during mid-October to February. The trend of PET was observed to be increasing at 12.3 mm per 1^o rise in temperature during 1971-2007. All parts of Assam has surplus amount of water for sali, ahu, and bao rice except Dima Hasao district has water deficit during growing period of Boro rice. However, water deficit was observed during oilseeds growing period in major portion of Assam with exception of eastern Assam (Dibrugarh, Tinsukia, Sibsagar, and Lakhimpur) and southern Assam (Hailakandi and Karimganj).

Keywords: *water flux, crop moisture, sub-tropical, Assam, Potential evapotranspiration, IMD*

1 INTRODUCTION

Land surface evapotranspiration is a central component of the Earth's global energy balance and water cycle (Li et al., 2017). Understanding ET is important in quantifying the impacts of human influences on the hydrological cycle and thus helps improving water use efficiency and strengthening water use planning and watershed management (Li et al., 2017). To deal with both optimization and efficient water use for irrigation, it was necessary to handle methodologies to estimate crops' water consumption (Morales-Salinas et al., 2017). In addition to climate change, human activity can also affect the surface water cycle and thereby affect ET in a region (Li et al., 2017). Sunshine duration was the most important climatic factor that influenced ET in China. Wind speed affects water vapor transport during the evaporation process (Li et al., 2017). Evapotranspiration (ET) is an important component in water-balance models and irrigation scheduling, and is often estimated in a two-step process (Fisher et al., 2013).

Due to high variability of rainfall (Baruah, 2018; Deka et al., 2012; Goyal, 2014; Mahanta et al., 2013), the farmers are unable to predict the type of weather i.e. drought or flood or both in Assam. These unpredictable undependable situation leads to heavy loss to life and properties. The drought like situation and severe flood has brought heavy loss to crops and even livestock in Assam (Anom, 2009; Anom, 2014; Anom, 2017; Parida et al., 2015).In addition, of the total geographical region of Assam only 2.38 % (186806 Ha) was irrigated during 2013-14 (Baruah, 2018).Therefore, it has become imperative to estimate the evapotranspiration and water balance for irrigation and cultivation purpose. The net water flux (water balance) during growing period under different crops are assessed for 36 years (1971-2007) under climate change conditions (Fig. 9). Assessment of net water flux (water balance) during different grwoing periods under different crops has not been attempted previously in the context of Assam. Hence, this study leads to base level data inventory for further research related to change in the water balance into the surface.

2 STUDY AREA

Assam experiences humid-wet type of sub-tropical climate with highest rainfall and temperature during monsoon period (Baruah, 2018; Jain, 2013). The annual maximum and minimum temperature of the region was observed to be increasing during 1991-2003 (Kothawale et al., 2005). Agriculture is the mainstay economy of the people, with 33 % (cultivators) and 15.42% (agricultural labourer) to the total workers of Assam during 2011 (Baruah, 2018). Farmers were poor in adopting technology based farming practices like plant protection measures, manure and fertilizer application, seed treatment, etc. (Singha et al., 2011). The farmers are adopting to crop diversification due to limited time of flood free months for farming (Mandal et al., 2013). The normal, submergence and deep water rice varieties are not suitable for frequently inundated areas, whereas bao rice (deep water traditional rice) outperform in such situation (Neog et al., 2016). Although irrigation was reported to be insignificant in Assam, water harvesting for

artificial irrigation during dry period will help in enhancing rice yield in Assam (Mech, 2017).

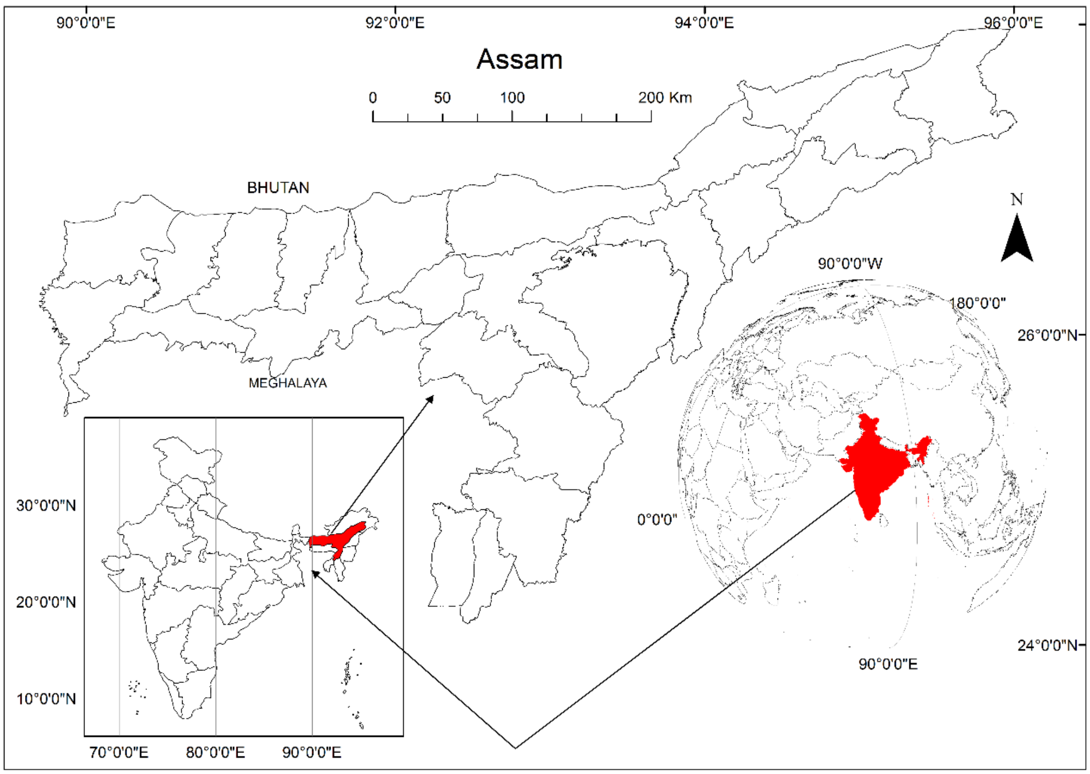

Fig. 1 Location of study area

3 DATABASE AND METHODS

3.1 Database

The district wise temperature and rainfall datasets were obtained from the gridded datasets (Rajeevan et al., 2005; Srivastava et al., 2009) of Indian Meteorological Department (IMD). These gridded daily data are available at a resolution of $1° \times 1^{o}$ latitude-longitude from 1803 well-distributed pan-Indian stations during 1971 to 2007.

3.2 Methods

Two crops species (rice and oilseeds) were selected to estimate the crop water requirement during the growing season. Three different growing season, were assessed from date of sowing to date of harvesting (AAU, 2009a; AAU, 2009b), for rice Sali rice (June-November), Ahu rice (February-June), Boro rice (November-May), Bao rice (April-Jan), and rapeseed rice (mid-October-January).

3.3 Estimation of rainfall minus evapotranspiration (P-E)

3.3.1 Thornthwaite's Equation (PET)

The potential evapotranspiration (Thornthwaite, 1948) in each area the relationship within the range of temperature involved was well expressed by an equation of the form

$e = ct^a$, in which 'e' was monthly evapotranspiration (cm) and 't' was mean monthly temperature in ^{o}C. The coefficients 'c' and 'a' vary from one place to another. The exponent a in the above equation varies from 0 to 4.25. Thus an equation having coefficients derived from observations made in a warm climate does not yield correct values of potential evapotranspiration for an area having a cold climate, and vice versa (Thornthwaite, 1948). Potential Evapotranspiration was calculated by following steps-

i. The Thornthwaite's Heat index was calculated by $i = \left(\frac{t}{5}\right)^{1.514}$, where 't' was mean monthly average temperature (^{o}C). The coefficient 'c' in equation in above varies inversely with 'I'

ii. Summation of the Thornthwaite's heat index gives the annual heat index (I). This heat index varies from 0 to 160,.given by

$$I = \sum_{i=1}^{12} i$$

iii. The unadjusted PET (UPET) was calculated as,

$$UPET = 1.6 \times \left(\frac{10t}{I}\right)^{a}$$

iv. Where, a was calculated by the equation,

$$a = 0.000000675 \times I^3 - 0.0000771 \times I^2 + 0.01792 \times I + 0.49239$$

v. Adjusted PET was given by - $PET = UPET \times \frac{N}{12} \times \frac{d}{30}$

where, N= theoretical sunshine hours for each month and d= number of days for each month.

3.3.2 P-E method

The net water flux into the surface or water balance was calculated using rainfall minus evapotranspiration (P-E) method (Byrne et al., 2015; Swenson et al., 2006). This method models net water balance over landmass and determines the sum of subsurface and runoff surface (Byrne et al., 2015). P-E method describes the water flux between the earth's surface and the atmosphere (Swenson et al., 2006).

3.3.4 Aridity Index (P/E)

Assam is categorised as a the humid region (Middleton et al., 1997; Thornthwaite, 1931; Thornthwaite, 1948; UNEP, 1992). The availability of moisture may vary according to location and season depending upon amount of PET and rainfall received. Therefore, the high degree of aridity may refer to non-availability of moisture under humid climate. In arid and semi-arid areas, the ratio P/PET expresses the degree of aridity better, because it gives the same value for all climates in which the potential water loss was proportionally the same in relation to rainfall (UNESCO, 1979). Inspite of AI capacity to show the degree of aridity of a place, it was unable to show the net water flux or water balance like rainfall minus evapotranspiration does. Aridity increases as values of this ratio decline (Middleton et al., 1997; UNESCO, 1979).

The index was utilized as the agro-climatological index, incorporating climatological specifications as well as crop moisture needs (Bannayan et al., 2010; Sadeghi et al., 2002; Tabari et al., 2013).

The aridity index was given by (UNEP, 1992)

$$Aridity\ Index\ (AI) = \sum_{i=1}^{12} \frac{P_i}{PET_i}$$

where, P = rainfall (mm) during ith month

PET= Potential evapotranspiration (mm) during ith month

i = ith month

According to Middleton et al. (1997) classification of regions on basis of degree of aridity, Assam was classified as humid region (AI value> 0.65). The value of AI>0.65 (Middleton et al., 1997; UNEP, 1992) considered as humid regions has been changed from AI> 0.75 (FAO, 1977). The AI has been calculated districtwise for the growing seasons to assess the moisture availability during the crop growth period (Table 1).

Table 1 Classification of regions on basis of aridity index (Middleton et al., 1997; UNEP, 1992)

Classification	Aridity Index	Global land area (%)
Hyperarid	AI < 0.05	7.5
Arid	0.05 < AI < 0.20	12.1
Semi-arid	0.20 < AI < 0.50	17.7
Dry sub-humid	0.50 < AI < 0.65	9.9
Humid	>0.65	39.2
Cold	>0.65	13.6

4 RESULTS AND DISCUSSION

It was observed that the highest PET (Fig. 2) was during the monsoon season and lowest being during the winter season. The effect was due to higher insolation during the summer/ monsoon season, when the temperature level was generally at the peak. The PET during July was 170 mm, while lowest during January (30 mm), during 1970-2007 in Assam along 23^{o}N latitude (Fig. 2).

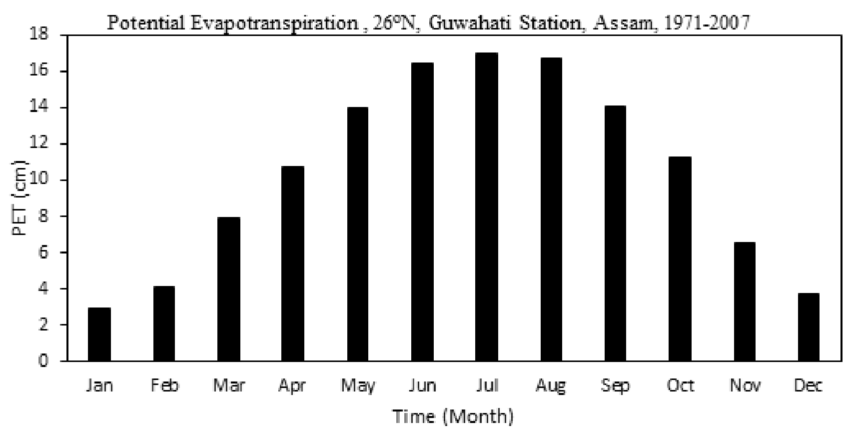

Fig. 2 Potential Evapotranspiration based on Thornthwaite's method, using Guwahati Station at 26^{o}N, Assam, 1971-2007

There was at least 200mm difference in annual normal PET between districts of Assam during 1971-2007. High PET concentration was observed in the eastern parts of Assam and lowest in the western parts of Assam. Therefore, the amount of moisture in these regions varies according to the PET. The moisture requirement in eastern districts (viz. Tinsukia, Dibrugarh, Sibsagar, Dhemaji, Lakhimpur, and Golaghat was the highest among all the districts (Fig. 3).

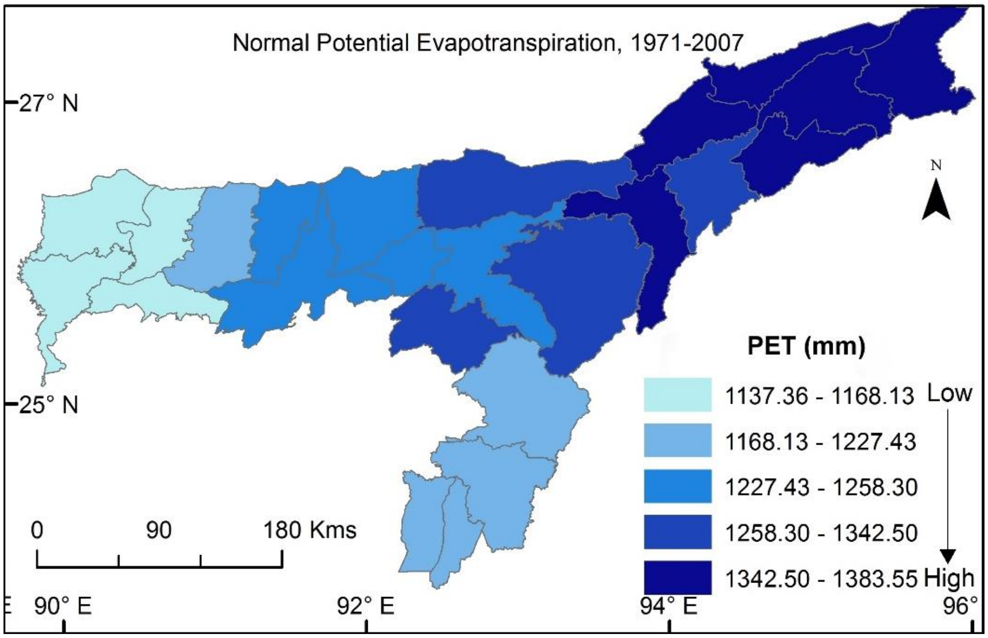

Fig.3 Normal potential evaporation in Assam, 1971-2007

The PET increased at the rate of 1.82 mm/ year during 1971-2007 (Fig. 4).

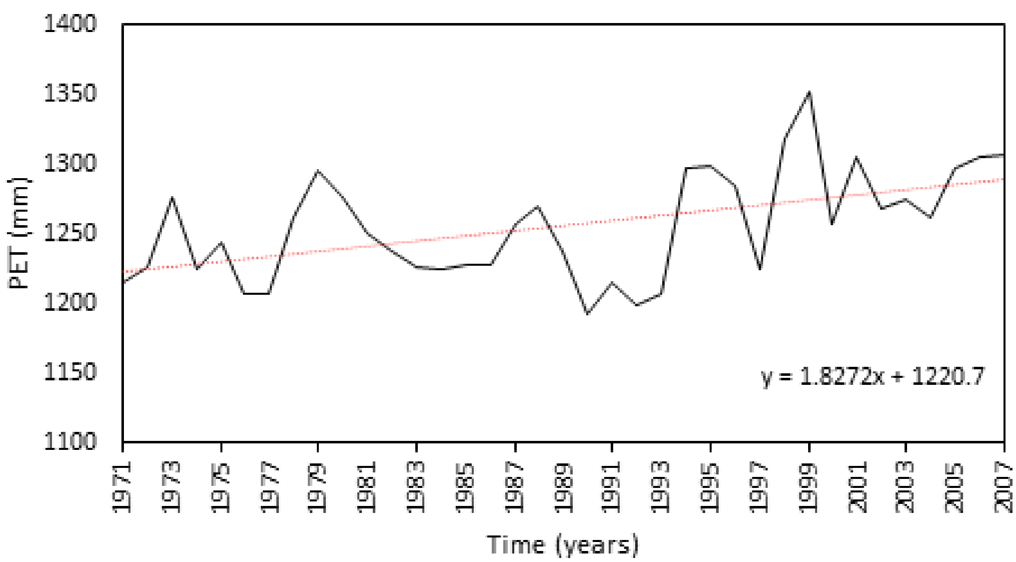

Fig.4 Trend of potential evapotranspiration in Assam using Thornthwaite's method (1948)

Strong relationship between mean monthly temperature and PET in Guwahati, 1971-2007 was observed with coefficient of determination (R^2=0.9584), which was statistically significant at 0.0001 level of confidence. It was observed that there was an increase in PET of 1.23 cm (12.3mm) per one degree rise in temperature (Fig. 5).

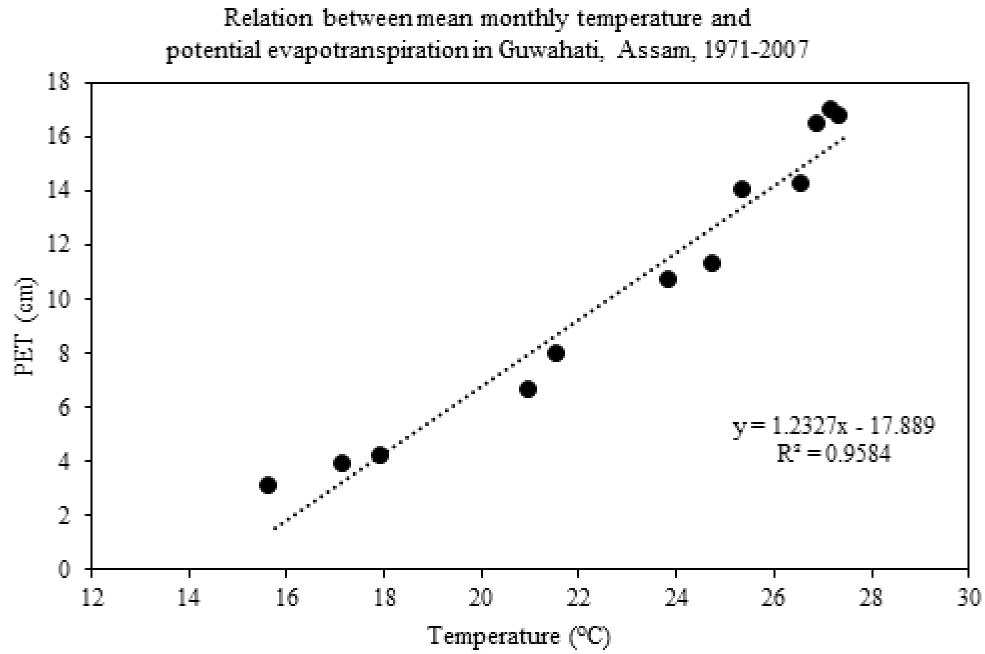

Fig.5 Relationship between mean monthly temperature, and PET, 1971-2007

The plot of normal potential evapotranspiration, rainfall, and temperature, Assam, 1971-2007 reveals the status of water budget (Fig. 6). The PET follow the same pattern with temperature. The evapotranspiration increases with increase in temperature. The amount of rainfall received during March-mid October was higher than the amount of PET, thus the region was water surplus during this period. During mid-October-March the amount of rainfall received was lower than the amount of PET resulting in dry conditions. This indicates the requirement of irrigational water for agricultural purpose. The amount of rainfall was high during monsoon season. Therefore, artificial irrigation was generally required during the dry growing season for proper growth of plants and crops (Fig. 6).

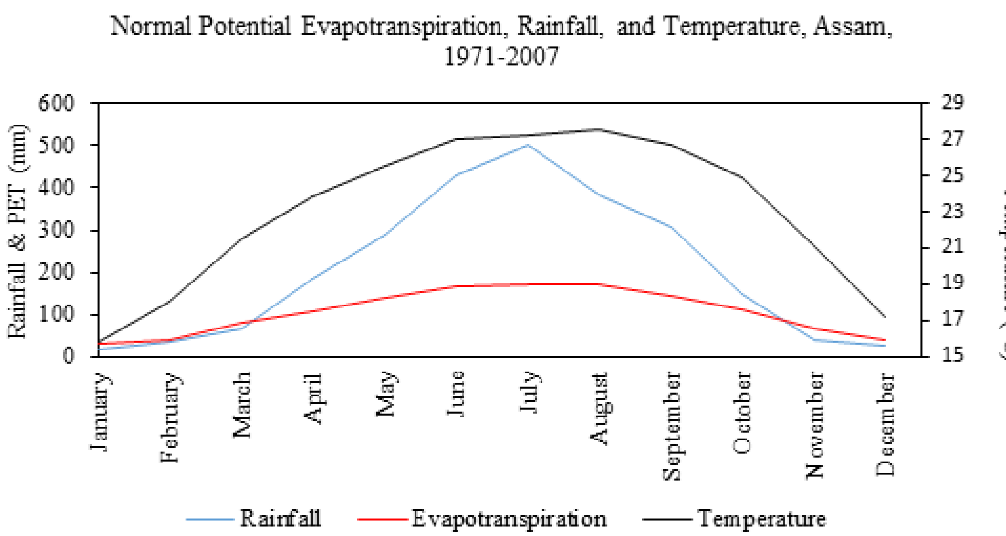

Fig.6 Inter-relationship between mean monthly rainfall, temperature and PET, 1971-2007

4.1 Net water flux

As evident from the figure (Fig.7), Assam receives varying amounts of annual rainfall, 1971-2007. The maximum difference between highest and lowest total annual rainfall was approximately 1263 mm. The extreme eastern (Dibrugarh, Tinsukia, and Dhemaji) and western districts (Kokrajhar, Goalpara, and erstwhile Bongaigaon, 2001 census) receives the highest amount of annual rainfall in Assam. The hill districts received the lowest rainfall during 1971-2007.

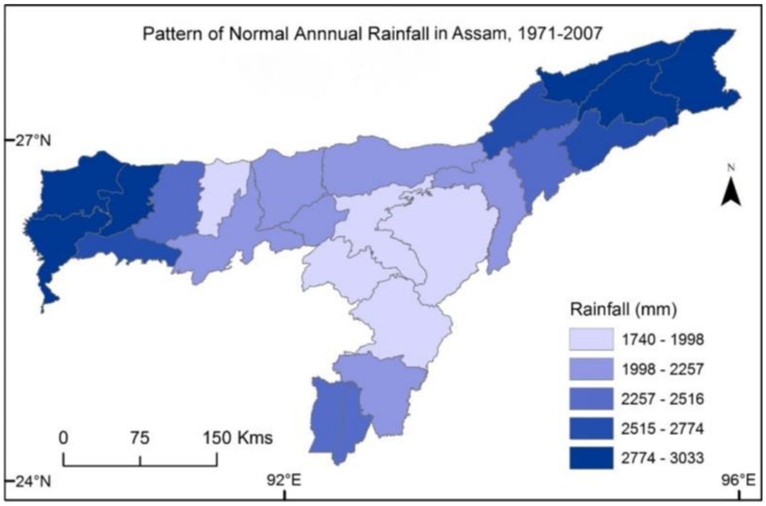

Fig.7 Pattern of normal annual rainfall in Assam, 1971-2007

4.2 Net water Flux or Water Balance using P-E Method

P-E was generally positive or close to zero because evapotranspiration cannot exceed rainfall in the mean time when averaged over a drainage basin (Byrne et al., 2015). The net water flux into surface was positive and the difference between the highest and lowest net water flux was approximately 1279 mm (Fig. 8). The normal net water flux revealed that the region was always at a surplus state, although, the highest contribution of annual rainfall may tends to occur in just 3-4 months during monsoon period. The extreme eastern and western districts of Assam viz. Tinsukia, Dibrugarh, Lakhimpur, Dhubri, Goalpara, Bongaigaon, Kokarajhar has highest surplus of water. Whereas, the hill districts viz. Dima Hasao and Karbi Anglong along with Golaghat have low surplus of water during 1971-2007.

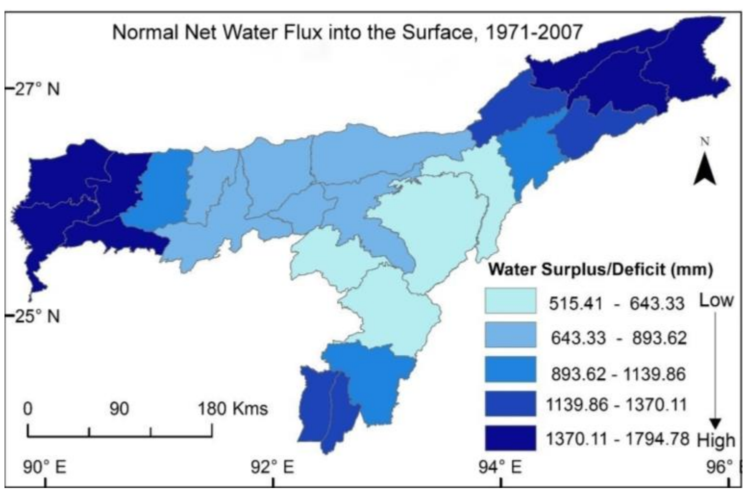

Fig.8 Normal annual water balance in Assam, 1971-2007

Water surplus was observed in all districts during the growing period of Sali, Ahu, Bao rice, and Boro rice (exception of Dima Hasao showing water deficit). With exception of Karimganj, Hailakandi, Tinsukia, Dibrugarh, Sibsagar, and Lakhimpur, all other districts undergo water deficit during the growing period of oilseeds

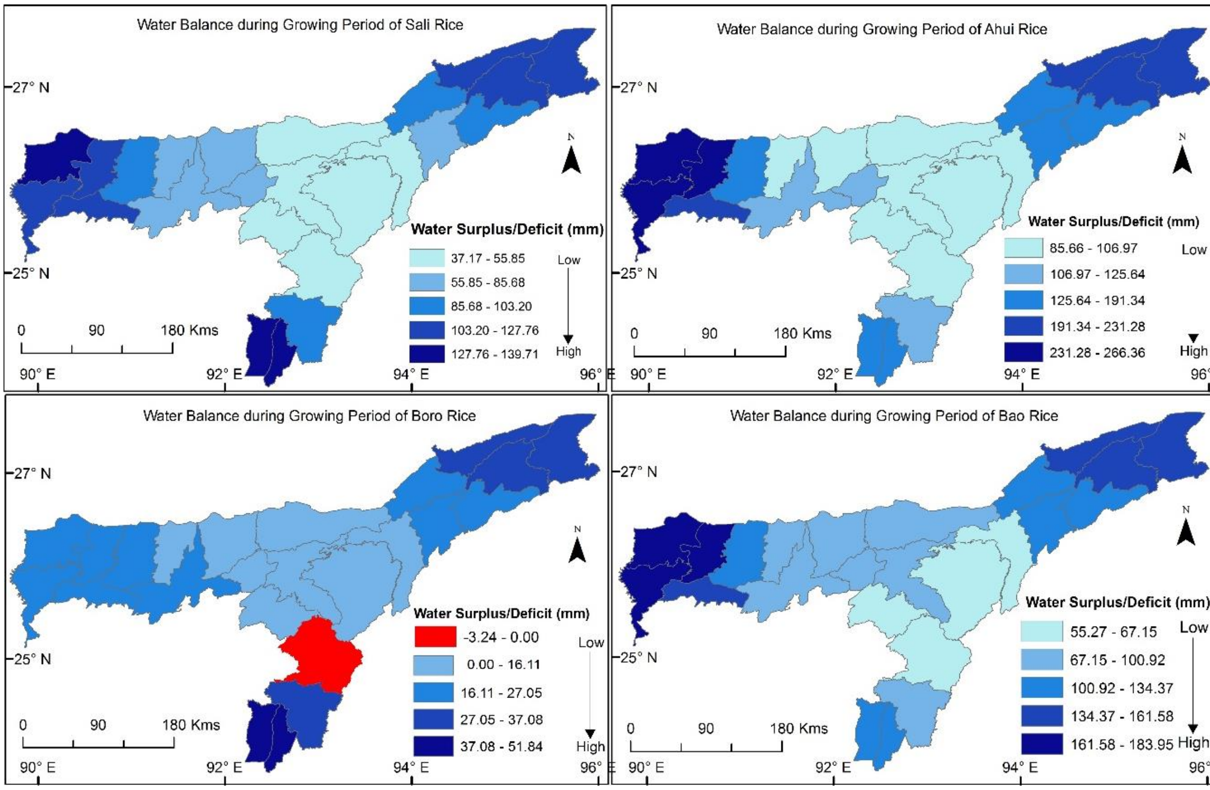

Fig. 9 Water balance or net water flux during different growing period under different crops (figure continued next page)

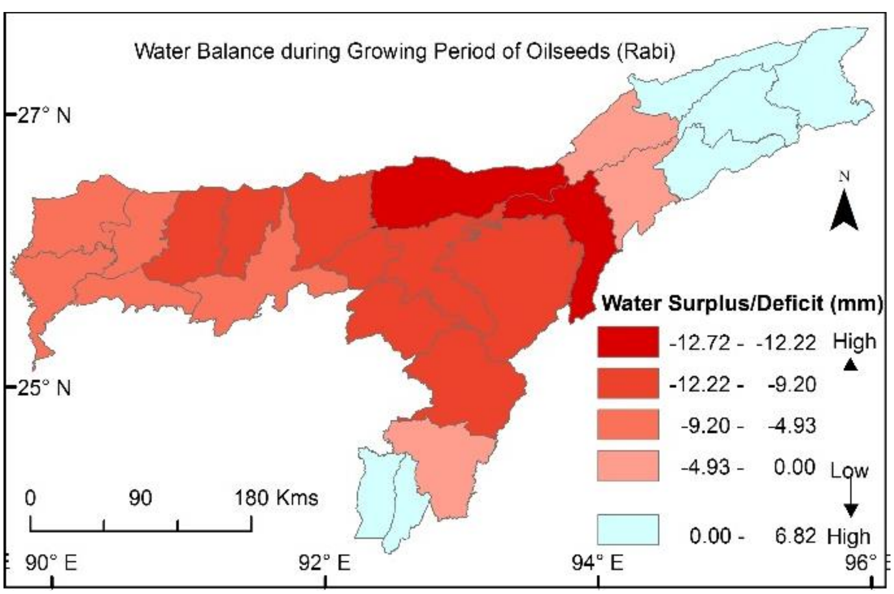

Fig. 9 Water balance or net water flux during different growing period under different crops

4.3 Crop moisture availablity

The ratio P/PET was used to assses the crop moisture avaialability in preference to the difference P – E, which refers rather to the amount of water available and which can be the same for many different climates (for example, P- PET = 400 can result from 1,000-600 or 800 - 400, or 600 - 200, etc.(UNESCO, 1979). The aridity index (AI) value reveals different moisture availability for different districts under different grwoing season. The AI for sali, ahu, and bao rice range from 1.35-3.17, indicating a moisture laden season for these crops. The AI for boro and rapeseed ranged 0.79-1.71 which was closer to designate dry sub-humid after FAO (1977). AI value>0.75, indicating the tendency of these regions to be dry during their growing period (mostly dry winter).Kokrajhar, Dhubri, Goalpara and Bongaigaon are highly moisture laden during growing period of bao rice (April-January), while the lowest was found for Hill districts and Golaghat. During ahu rice growing season (February-June), the degree of aridity was low or the level of moisture was high in the districts of Karimganj, Hailakandi, Kokrajhar, Dhubri, Goalpara and Bongaigaon. The districts viz. Sonitpur, Nagaon, Dima Hasao, Karbi Anglong, and Golaghat has low level of moisture with AI value (1.35-1.52) under ahu rice growing season.

During the growing period of sali rice, Kokrajhar, Dhubri, Goalpara and Bongaigaon has the highest level of moisture or low degree of aridity with AI value range 2.47-3.17 and lowest in hill districts and Golaghat.The rapeseed growing season has AI value very close to FAO (2010) AI value 0.75, indicating nearness to dry sub-humid climate during the growth period.

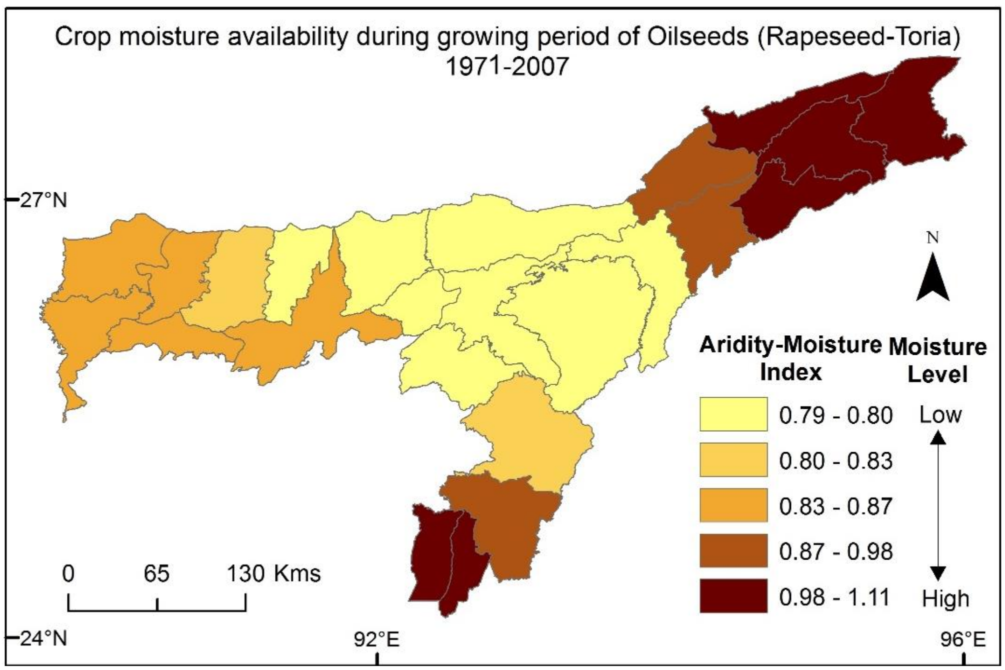

Fig. 10 Crop moisture availability during different growing periods for different crops, 1971-2007 (figure continued next page)

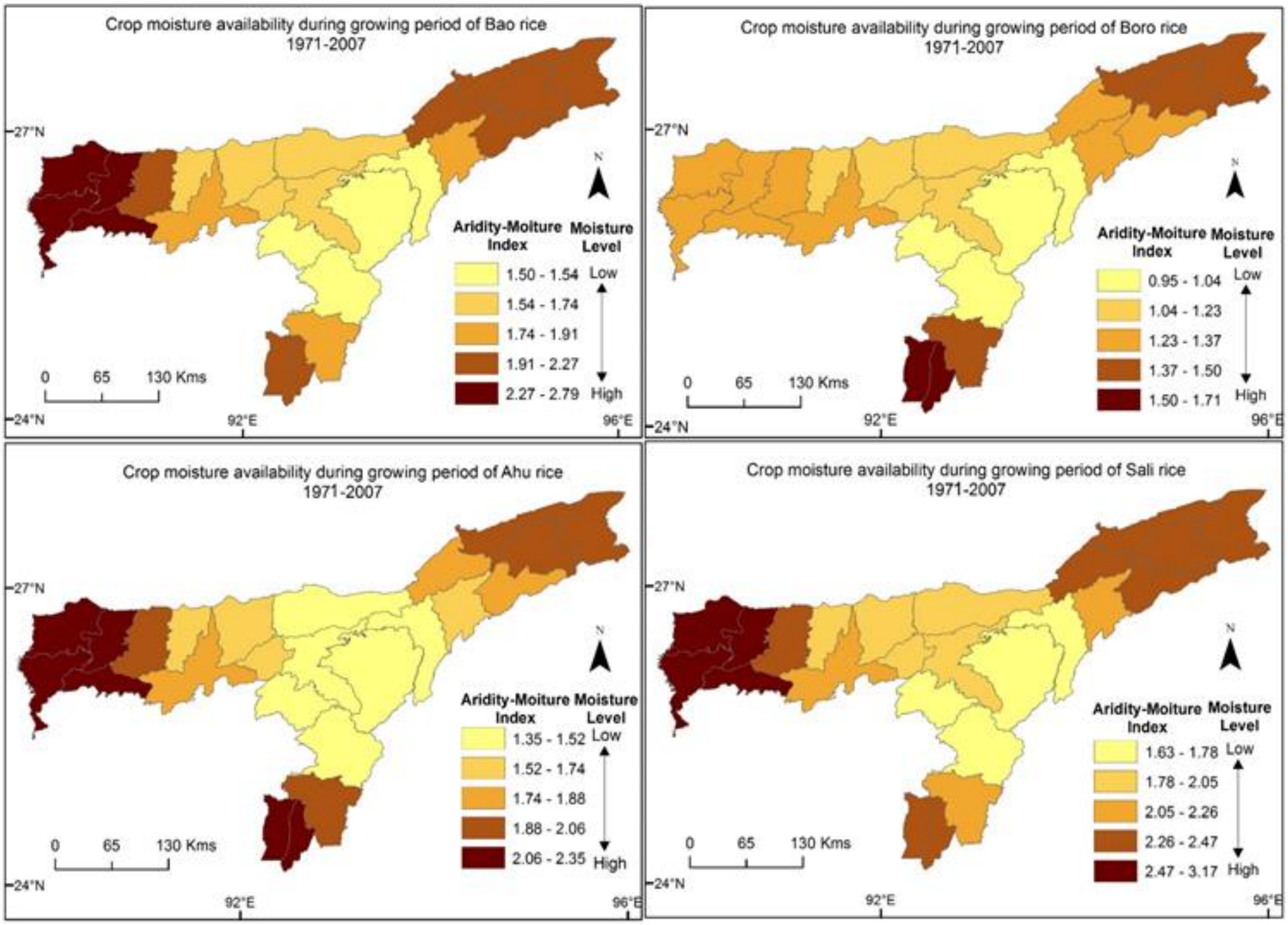

Fig.10 Crop moisture availability during different growing periods for different crops, 1971-2007 (figure continued from previous page)

5 CONCLUSION

Potential evapotranspiration (PET) was estimated for the first time in Assam using Thornthwaite's method. The potential evapotranspiration in Assam was observed to be high during monsoon season due to soaring temperature. The result indicates the existence of spatial variability of potential evapotranspiration and PET is higher in eastern Assam. The eastern and western part of Assam receives high amount of rainfall, which is a good indicator for rainfed agriculture. Additionally, the water budget of Assam also indicates availability of surplus water in eastern and western Assam. The aridity index (AI) revealed the crop water stress level in the tropical region of Assam. The aridity index during oilseeds and boro rice growing period reveals the tendency of Assam towards dry sub-humid region (AI >0.75).

Water availablity is the most important determining factors of agricultural production and yield. The agricultural regions with greater variability of climate are most likely affected by the non-availability of seasonal water. These water deficit during non-water availability period can be assessed and replenished by irrigation water. This management planning can be done effectively if the water budget is known for all the seasons. Therefore, potential evapotranspiration and aridity index plays a vital role in assessing water budget and irrigational management and planning.

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