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M.S.A. TALUCDER, M.A. BATEN AND M.N. ELNESR

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ANOMALIES OF REFERENCE CROP EVAPOTRANSPIRATION AND RELATED CLIMATIC PARAMETERS IN SYLHET AND MAULBIBAZAR OF BANGLADESH

M.S.A. TALUCDER[1*], M.A. BATEN[2] AND M.N. ELNESR[3,4]

[1]Department of Agroforestry and Environmental Science, Sylhet Agricultural University, Sylhet-3100, Bangladesh;
[2]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh;
[3]Desert Research Center, Egypt; [4]Alamoudi Chair for Water Research, King Saud University, Riyadh, Saudi Arabia.

[*]Corresponding author & address: Mohammad Samiul Ahsan Talucder, E-mail: samiulsau@gmail.com
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ABSTRACT

Talucder MSA, Baten MA, Elnesr MN (2016) Anomalies of reference crop evapotranspiration and related climatic parameters in Sylhet and Maulbibazar of Bangladesh. *Int. J. Sustain. Crop Prod.* 11(1), 9-17.

Understanding the variability in reference crop evapotranspiration (ET_0) is a vital issue for sustainable agriculture under the projected consequences of global warming and climate change. The objectives of this study were to estimate ET_0 and evaluating the variation of ET_0 between two neighboring districts. The ET_0 was estimated based on the United Nations Food and Agriculture Organization Penman-Monteith (FAO-PM) model from daily weather data of Sylhet sadar and Shreemangal upazila of Maulbibazar district meteorological station for a period of over 21 years (1988-2013) using FAO CROPWAT 8.0 software. In Sylhet the mean annual temperature (T), relative humidity (RH), vapor pressure deficit (VPD), wind speed (u_2), sunshine hour, solar radiation (R_n) and ET_0 were 25.5±0.5°C, 78.9±1.4 %, 0.7±0.1 kPa, 1.3±0.1 m/s, 5.9±0.3 hrs day^{-1}, 16.0±0.3 MJ m^{-2} day^{-1} and 1246±35 mm year^{-1}, respectively. Whereas in Shreemangal the mean annual temperature (T), relative humidity (RH), vapour pressure deficit (VPD), wind speed (u_2), sunshine hour, solar radiation (R_n) and ET_0 were 25.1±0.3°C, 80.8±1.0%, 0.6±0.0 kPa, 1.1±0.2 m/s, 6.3±0.4 hrs day^{-1}, 16.7±0.5 MJ m^{-2} day^{-1}, and 1267±42 mm year^{-1}, respectively. The annual T and VPD showed increasing pattern in Sylhet whereas Shreemangal showed comparatively slight increasing pattern. Annually R_n and u_2 showed decreasing trend in Sylhet whereas R_n showed slightly decreasing trend and u_2 showed slightly increasing trend in Shreemangal. The results indicated that the values of ET_0 in the two stations were approximately the same (correlation coefficient $\approx$0.94). Specifically, ET_0 ranged from 0.9 to 8.6 mm day^{-1}, 1.0 to 7.5 mm day^{-1} and the average values were 3.4 mm day^{-1} and 3.5 mm day^{-1} in Sylhet sadar and Shreemangal, respectively with the maximum values were recorded in March, April and May in both sites.

***Key words:** FAO-PM method, reference evapotranspiration, climate change, water security, FAO CROPWAT 8.0*

INTRODUCTION

Most of the impacts of climate change on agriculture are expected to result from changes in the water cycle. Reference evapotranspiration (ET_0) is an important balancing component of the water cycle, and plays a key role in estimating crop growth, water demand and irrigation water management for sustainable agriculture (Nam *et al*. 2015).

The ET_0 was defined as the rate of evapotranspiration from a hypothetic crop with specific crop height, and fixed canopy resistance, and albedo (Allen *et al.* 1994). This would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height (0.12 m), actively growing, completely shading the ground and not short of water (Allen *et al*. 1998). The concept of the ET_0 was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the surface of reference evapotranspiration, soil factors do not affect ET_0. The ET_0 values that are measured or calculated at different locations or in different seasons are comparable as they refer to the evapotranspiration from the same reference surface. The only factors affecting ET_0 are climatic parameters. Consequently, ET_0 is a climatic parameter and can be computed from weather data, e.g., air temperature, relative humidity, wind speed, sunshine hour etc. ET_0 expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (Allen *et al.* 1998).

Although several methods exist to determine ET_0, the FAO-PM method (Allen *et al*. 1998) has been recommended as the appropriate combination method to determine ET_0 from climatic data on temperature, humidity, sunshine and wind speed (Pereira *et al*. 2015). The FAO-PM model has two advantages over many other methods. 1: it is a predominately physically based approach, indicating that the method can be used globally without any need for additional parameter estimations. 2: the method is well documented, implemented in a wide range of software, and has been tested using a variety of lysimeters (Droogers and Allen, 2002).

Various researchers from around the world have monitored ET_0 for different climates (e.g., Nam *et al.* 2015 in South Korea; Kousari and Ahani, 2012 in Iran; Al-Ghobari 2000 in Saudi Arabia). In Bangladesh, Mojid *et al.* (2015) reported the trend of ET_0 and its controlling climatic parameters in Dinajpur and Bogra district of Bangladesh over the period of 1990-2010. Karim *et al*. (2011) also reported the trend of ET_0 and its controlling climatic parameters in Dhaka and Mymensingh district. In this study, we estimated ET_0 based on FAO-PM method using CROPWAT 8.0 software over the period of 21 years (1988-2013) and documented variability of ET_0 and its governing climatic parameters in Sylhet sadar and Shreemangal upazila of Maulbibazar district.

The overall objective of this study was to estimate and documenting ET_0 and its controlling climatic parameters in Sylhet sadar and Shreemangal upazila of Maulbibazar district. Specific objectives were to: (i) document the climatology of study sites, (ii) compare the ET_0 between the study sites; and (iii) document the correlation between ET_0 and its governing climatic parameters during the study period.

MATERIALS AND METHODS

Study site

Sylhet sadar (24.90 N, 91.88 E, 33.53 m above m.s.l) and Shremanagal upazila (24.30 N, 91.73 E, 21.95 m above m.s.l) of Maulbibazar district under the North-East Hydrological Region of Bangladesh (WARPO 2001) were selected for this study (Fig. 1). This region is an interesting study area because of its diversified terrestrial and wetland ecosystem. The annual average precipitation is 4048±659 mm in Sylhet and 2351±427 mm in Shreemangal over 29 years (1986-2014).

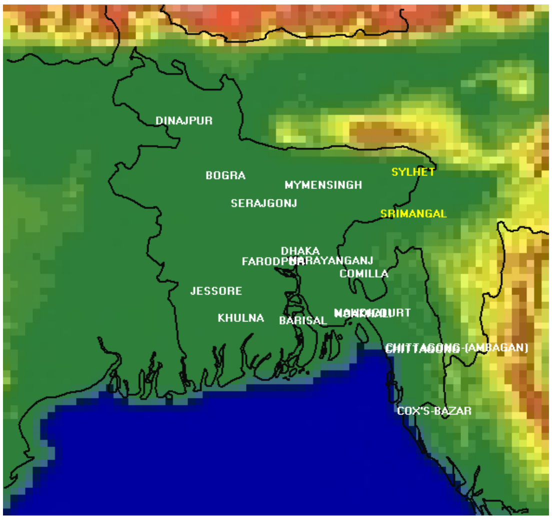

Fig. 1. Showing the study locations (yellow color)

Meteorological data collection

Daily meteorological data i.e., maximum and minimum temperatures (°C), relative humidiy (%), wind speed (Knot) measured at 10 m height and sunshine duration (hrs) of Sylhet sadar and Shreemangal upazila of Maulbibazar district for a period of 21 years (1988–2013) were collected from the Bangladesh Meteorological Department (BMD). In the time series, 1990-91, 1996-97 and 2006 data were not used in this study due to missing data. BMD follows the World Meteorological Organization (WMO) regulations for quality control of data. Vapor pressure deficit (VPD) values were calculated from relative humidity (%) as: $SVP\ (Pa) = 610.7 * 10^{7.5T/(237.3+T)}$ where SVP is saturation vapor pressure and T is daily mean air temperature (°C), $VPD(Pa) = \left(1 - \frac{RH}{100}\right) * SVP$

Estimation of ET_0 by FAO CROPWAT 8.0 software

Unit of wind speed data of BMD were converted (Knot to m/s) to adjust the data into the format accepted by FAO CROPWAT 8.0 software. Then wind speed data obtained for 10 m height (u_z, ms^{-1}) were adjusted to the standard height of 2 m (u_2) for FAO-PM model, using the following logarithmic wind speed profile equation (Allen *et al.* 1998):

$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)}$$

Where u_2 wind speed at 2 m above ground surface (m/s), u_z measured wind speed at z m above ground surface (m/s) and z height of the measurement above ground surface (m). Other meteorological variables were remained same. In addition, FAO CROPWAT 8.0 software required altitude, latitude and longitude for the respective station (Fig. 2). Finally FAO CROPWAT 8.0 software estimated ET_0 based on following FAO-PM model (Allen *et al.* 1998):

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

where ET_0 is the daily reference evapotranspiration (mm day^{-1}), R_n is the net radiation available at the crop surface (MJ m^{-2} day^{-1}), G is the ground heat flux density at the soil surface (MJ $m^{-2}day^{-1}$), T is the mean air temperature at 2 m height (°C), U_2 is the mean wind speed at 2 m height (ms^{-1}), e_s is the saturation vaporpressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure versus the air temperature curve (kPa°C^{-1}), and γ is the psychometric constant (kPa °C^{-1}).

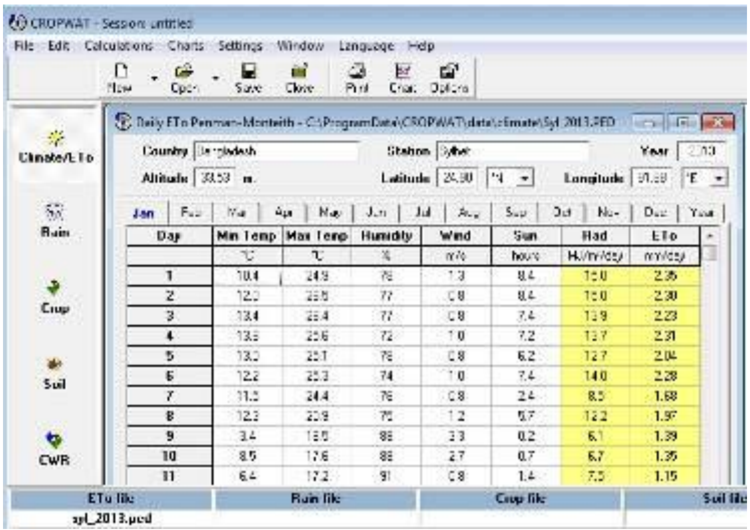

Fig. 2. Screenshot of FAO CROPWAT 8.0 software for estimating solar radiation and reference ET from meteorological variables of Bangladesh Meteorological Department

Statistical analysis

Anomalies of ET_0 and its controlling climatic parameters were calculated as the ratio between the difference of the actual value and the mean value with its standard deviation. The correlation coefficient between ET_0 and its controlling climatic parameters were also computed.

RESULTS AND DISCUSSION

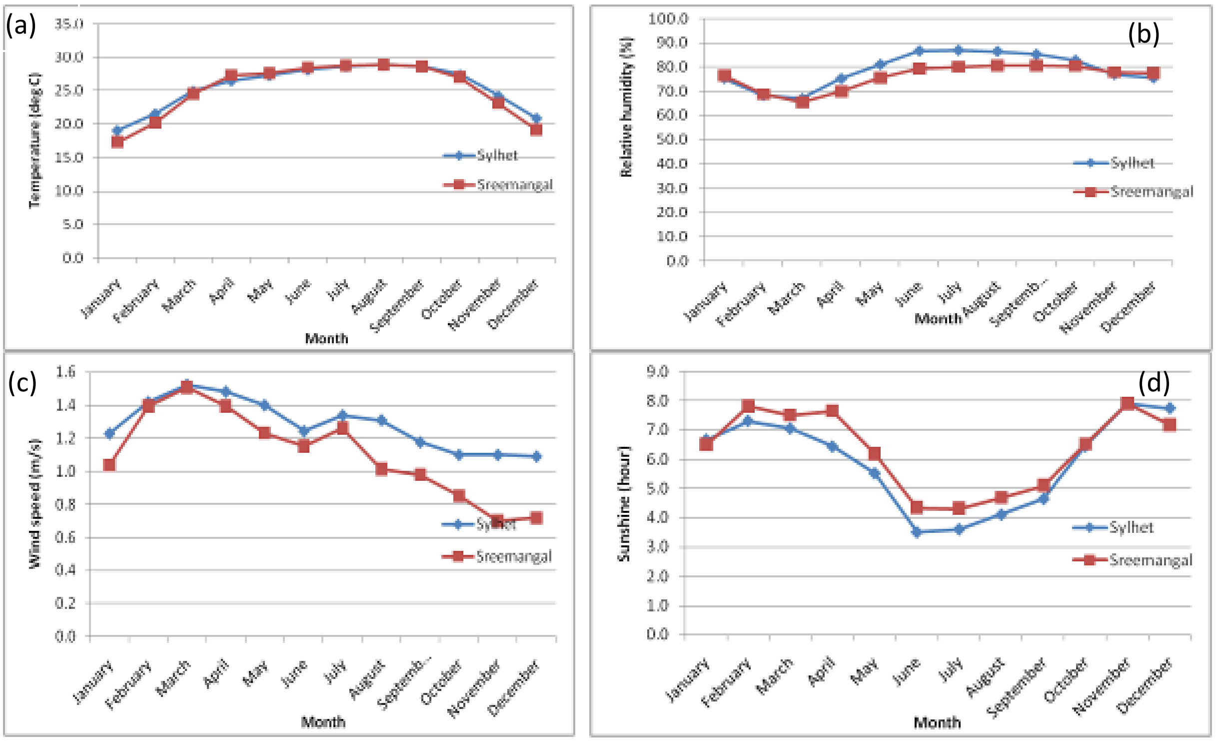

Fig. 3. Mean monthly (a) temperature (°C), (b) relative humidity (%), (c) wind speed (m/s) and (d) sunshine duration (hour) over the period 1988-2013 (except 1990, 1991, 1996, 1997 & 2006) of Sylhet and Maulbibazar districts

Air Temperature

In Sylhet, the average of annual air temperature during the study period (1988-2013) was 25.5±0.5°C ranging from 24.5°C to 26.3°C. Monthly average ranged from 19.1 (±0.9)°C in January to 28.8 (±0.5)°C in August. Air temperature showed increasing pattern that showed in its anomaly (Fig. 4). The highest negative anomaly was found in 1992 whereas highest positive anomaly was found in 2009. The increase of T can increase the rate of ET_0 by giving a warm environmental condition. In Shreemangal upazila of Maulbibazar district, annual average air temperature during the same study period was 25.1±0.3°C varying from 24.6°C to 25.8°C. Monthly average ranged from 17.3 (±0.8)°C in January to 28.9 (±0.3)°C in August. Air temperature of Shreemangal also showed slightly increasing pattern. The highest negative anomaly was found in 1993 whereas highest positive anomaly was found in 1999 (Fig. 4b). During winter season, Shreemangal showed slightly low temperature than Sylhet (Fig. 3a).

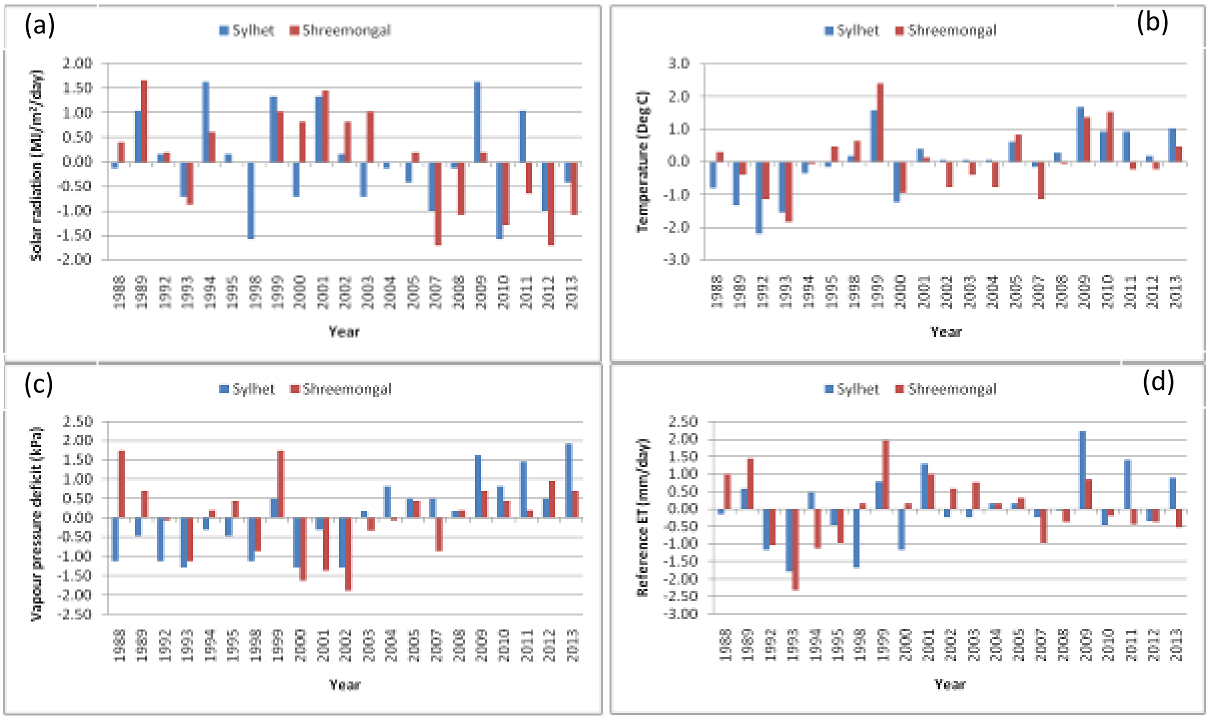

Fig. 4. Anomaly of (a) solar radiation (MJ/m^2/day), (b) Temperature (^{0}C), (c) vapor pressure deficit (kPa) and (d) reference ET (mm/day) (baseline 1988-2013, except 1990, 1991, 1996, 1997 & 2006)

Relative humidity

Relative humidity (RH) is the measure of vapor amount in the air where 100% corresponds to saturation and lower percentages indicate drier conditions. RH showed small inter annual variation during the study period in both sites. The mean annual RH was 78.9±1.4% ranging from 76% to 81% in Sylhet and 80±1.0% ranging from78% to 82% in Shreemangal. In Sylhet, monthly average ranged from 67.0 (±5.3) % in March to 86.9 (±2.5)% in July. In Shreemangal, monthly average ranged from 69.9 (±3.8)% in March to 85.5 (±1.4)% in October. Monthly average RH of Sylhet slightly higher than Shreemangal during the month of April to September (Fig. 3b). RH showed slightly decreasing pattern in Sylhet while Shreemangal showed slightly increasing pattern.

Wind speed

Mean annual wind speed (u_2) showed small fluctuation in both sites over the study period (1988-2013). In Sylhet, mean annual u_2 was 1.3±0.1 m/s ranging from 1.1 m/s to 1.6 m/s. In Shreemangal, mean annual u_2 was 1.1±0.2 m/s ranging from 0.6 m/s to 1.5 m/s. February to April were comparatively windy than other months in both site during the study period. Monthly average u_2 of Sylhet was slightly higher than Shreemangal except February and March (Fig. 3c). The value u_2 showed slightly decreasing pattern in Sylhet and slightly increasing pattern in Shreemangal.

Sunshine hour

In Sylhet, the average of annual sunshine hour during the study period (1988-2013) was 5.9±0.3 hrs ranging from 5.5 hrs/day to 6.4 hrs/day with coefficient variation was 4%. Monthly average ranged from 3.5 hrs/day in June to 7.9 hrs/day in November. In Shreemangal, the average of annual sunshine hour during the same period was 6.3±0.4 hrs/day ranging from 5.7 hrs/day to 6.9 hrs/day with coefficient variation was 6%. Monthly average ranged from 4.3 hrs/day in June and July to 7.9 hrs/day in November. Shreemangal showed comparatively more clear sky than Sylhet (Fig. 3d). The highest negative anomaly was found in 2010 whereas highest positive anomaly was found in 1999 in Sylhet. The highest negative anomaly was found in 2007 whereas highest positive anomaly was found in 1989 in Shreemangal. Sunshine hours showed decreasing pattern in Sylhet and slightly decreasing pattern in Shreemangal over the study period.

Solar radiation

The mean value of integrated annual solar radiation or net radiation (R_n) was 5855±129 MJ m^{-2} $year^{-1}$ with coefficient variation (CV) for annual value is 2 in Sylhet and 6102±174 MJ m^{-2} $year^{-1}$ with CV for annual value is 3 in Shreemangal. R_n showed fluctuation pattern where 1998 received lowest R_n (5644 MJ m^{-2}) and 1994 received highest R_n (6076 MJ m^{-2}) in Sylhet whereas 2007 received lowest R_n (5802 MJ m^{-2}) and 1989 received highest R_n (6383 MJ m^{-2}) in Shreemangal. In Sylhet, the highest positive anomalies observed in year1994 and 2009 whereas highest negative anomaly observed in 1998. In Shreemangal, the highest positive anomalies observed in year 1989 and highest negative anomaly observed in 2007 and 2012 (Fig. 4a). R_n showed decreasing pattern in Sylhet and slightly decreasing pattern in Shreemangal.

Vapor pressure deficit

Vapor pressure deficit (VPD) is the difference between saturation vapor pressure and actual vapor pressure $(e_s - e_a)$ and eventually VPD follows the T pattern. In Sylhet, annual average VPD value was 0.7±0.1 kPa varying from 0.6 kPa to 0.8 kPa with CV for annual value is 9%. Monthly average ranged from 0.5±0.1 kPa in June-July to 1.1±0.2 in March. In Shreemangal, annual average VPD value was 0.6±0.0 kPa varying from 0.6 kPa to 0.7 kPa with CV for annual value is 6%. Monthly average ranged from 0.4±0.1 kPa in December-January to 0.9±0.2 in March-April. The interannual fluctuation of VPD is showed in the Figure 4c. VPD showed increasing pattern in Sylhet whereas almost flat pattern in Shreemangal over the study period.

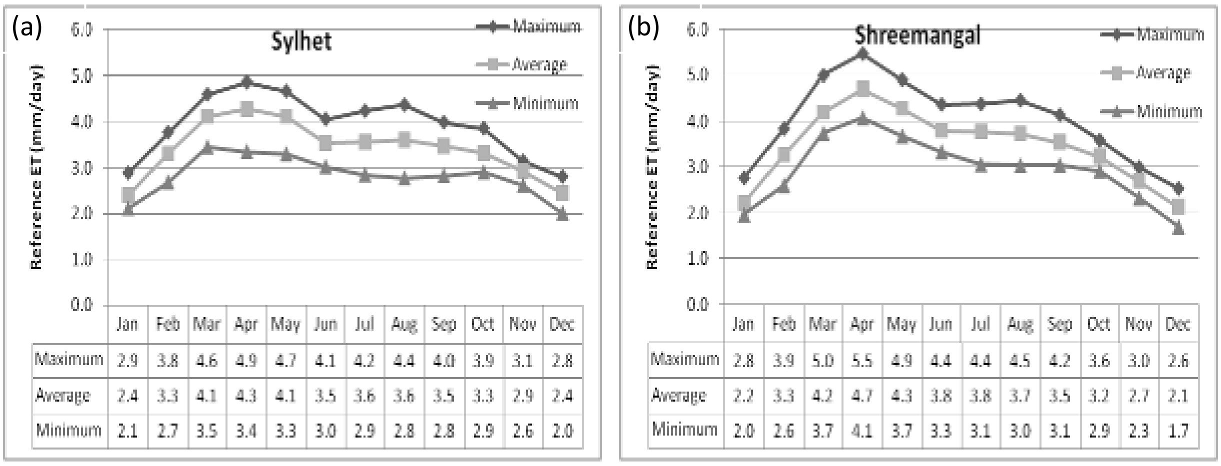

Fig. 5. 21 years averages of Maximum, average and minimum daily reference evapotranspiration (mm/day) of (a) Sylhet sadar and (b) Shreemangal upazila of Maulbibazar district (baseline 1988-2013, except 1990, 1991, 1996, 1997 & 2006)

Reference evapotranspiration

The mean value of integrated annual reference evapotranspiration (ET_0) was 1246±35 mm $year^{-1}$ with CV for annual value is 3 in Sylhet and 1267±42 mm $year^{-1}$ with CV for annual value is also 3 in Shreemangal. ET_0 showed fluctuation pattern where 1993 showed lowest ET_0 (1183 mm $year^{-1}$) and 2009 showed highest ET_0 (1324 mm $year^{-1}$) in Sylhet whereas 1993 showed lowest ET_0 (1168 mm $year^{-1}$) and 1999 showed highest ET_0 (1348 mm $year^{-1}$) in Shreemangal. In Sylhet, the highest positive anomalies observed in year 2009 whereas highest negative anomaly observed in 1993. In Shreemangal, the highest positive anomalies observed in year 1999 and highest negative anomaly observed in 1993 (Fig. 4d).

The daily values for every month through the time period (1988-2013) were presented in Tables 1 and 2, as the output of FAO CROPWAT 8.0 software.

The monthly ET_0 is useful to determine the lowest and highest water requirement zones and its monthly variation along the year. The 21 years daily average ET_0 for each month was calculated along with the average maximum and minimum values, and the results are shown in figure 5. The mean value of daily ET_0 in Sylhet throughout the study period (1988-2013) ranging from 2.4 mm day^{-1} to 4.3 mm day^{-1} and the average value is 3.4 mm day^{-1} (Fig. 5a). The mean value of daily ET_0 in Shreemangal over the same study period ranging from 2.1 mm day^{-1} to 4.7 mm day^{-1} and the average value is 3.5 mm day^{-1} (Fig. 5b).

Table 1. Annual and monthly mean daily reference ET (mm/day) of Sylhet sadar for a period of 21 years

	1988	1989	1992	1993	1994	1995	1998	1999	2000	2001	2002	2003	2004	2005	2007	2008	2009	2010	2011	2012	2013	Mean	Standard deviation
January	2.88	2.52	2.2	2.17	2.45	2.38	2.13	2.79	2.36	2.53	2.43	2.33	2.44	2.27	2.24	2.11	2.4	2.59	2.18	2.21	2.46	2.4	0.20
February	3.52	3.37	2.69	2.99	3.09	2.85	3.16	3.77	2.97	3.15	3.63	3.35	3.4	3.33	3.2	3.11	3.57	3.36	3.47	3.67	3.69	3.3	0.29
March	4.18	4.47	3.76	3.78	3.47	4.07	3.92	4.35	3.61	4.43	4.45	3.97	4.43	3.46	4.47	3.65	4.47	4.37	4.14	4.26	4.6	4.1	0.37
April	4.4	4.61	4.39	4.04	4.31	4.59	3.36	4.51	4.04	4.8	4.03	4.21	3.63	4.46	4.03	4.86	4.61	3.84	4.67	3.85	4.59	4.3	0.40
May	3.31	4.67	3.97	3.62	4.26	4.5	4.18	3.85	3.72	4.21	4.05	4.27	4.33	3.91	4.49	4.44	4.64	3.92	4.01	4.29	3.65	4.1	0.36
June	4.06	3.53	3.84	3.4	3.49	3.4	3.33	3.7	3.45	3.48	3.03	3.3	3.5	3.78	3.4	3.51	3.89	3.06	3.7	3.15	3.99	3.5	0.28
July	3.2	3.31	3.2	3.62	4.24	3.47	2.85	3.33	3.96	3.68	2.85	3.75	3.48	3.84	3.38	3.46	4.21	3.59	3.67	3.88	3.69	3.6	0.37
August	2.78	3.89	3.81	3.28	3.88	3.57	3.04	3.37	3.27	4.01	3.58	3.97	4.37	3.33	3.94	3.22	3.44	3.56	3.73	3.88	3.56	3.6	0.37
September	3.43	3.05	3.32	3.39	3.99	3.27	3.61	3.17	2.94	3.71	3.94	3.27	2.83	3.77	3.23	3.75	3.82	3.31	3.85	3.51	3.51	3.5	0.33
October	3.51	3.03	3.22	3.11	3.27	3.49	3.5	3.18	3.48	3.12	3.51	2.91	3.29	3.25	3.17	3.37	3.42	3.55	3.86	3.22	3.14	3.3	0.22
November	3.06	2.87	2.86	2.87	2.62	2.7	3.08	3.12	3.02	2.86	2.83	2.89	2.97	3.03	2.9	3.14	2.78	2.91	2.88	2.68	3.04	2.9	0.14
December	2.41	2.28	2.37	2.63	2.45	2.16	2.78	2.71	2.8	2.51	2.4	2.46	2.52	2.69	2.27	2.34	2.28	2.42	2.42	2.01	2.12	2.4	0.21
Annual	3.4	3.47	3.3	3.24	3.46	3.37	3.25	3.49	3.3	3.54	3.39	3.39	3.43	3.43	3.39	3.41	3.63	3.37	3.55	3.38	3.5	3.4	0.10

Table 2. Annual and monthly mean daily reference ET (mm/day) of Shreemongal upazila of Maulbibazar district for a period of 21 years

	1988	1989	1992	1993	1994	1995	1998	1999	2000	2001	2002	2003	2004	2005	2007	2008	2009	2010	2011	2012	2013	Mean	Standard deviation
January	2.78	2.38	1.96	2.05	2.14	2.05	2.04	2.46	2.37	2.49	2.41	2.22	2.11	2.28	2.02	2.04	2.33	2.2	2.07	2.05	2.18	2.22	0.21
February	3.65	3.42	2.6	2.98	2.93	2.62	3.45	3.73	3	3.38	3.85	3.42	3.37	3.51	3.01	2.85	3.67	3.38	3.2	3.53	3.25	3.28	0.35
March	4.31	4.58	4.28	3.75	3.74	3.97	4.17	5	3.79	4.18	4.49	4.01	4.53	3.84	4.26	3.82	4.09	4.71	3.85	4.53	4.37	4.20	0.35
April	4.82	5.47	4.86	4.4	4.32	4.73	4.38	5.35	4.64	4.88	4.52	4.97	4.08	4.85	4.34	5.21	4.51	4.84	4.56	4.44	4.62	4.70	0.35
May	3.96	4.91	4.37	3.72	4.46	4.65	4.26	4.16	3.91	4.07	4.06	4.46	4.52	4.37	4.67	4.55	4.45	4.24	4.01	4.56	3.68	4.29	0.32
June	4.38	4.1	4.08	3.5	3.74	3.8	4.02	3.98	3.93	3.84	3.63	3.44	3.73	3.99	3.53	3.66	4.09	3.34	3.64	3.46	4.13	3.81	0.28
July	3.73	3.77	3.26	3.64	4.3	3.77	3.45	3.74	4.39	4.14	3.06	4.19	3.5	3.76	3.62	3.58	4.21	3.7	3.75	3.96	3.94	3.78	0.34
August	3.22	4.08	3.97	3.39	3.04	3.64	3.66	3.72	3.75	4.17	3.81	4.22	4.47	3.52	3.81	3.61	3.64	3.78	3.65	3.96	3.5	3.74	0.33
September	3.72	3.21	3.49	3.33	3.9	3.29	3.74	3.44	3.38	3.79	4.15	3.57	3.05	3.65	3.25	3.96	3.74	3.06	3.9	3.41	3.47	3.55	0.30
October	3.41	2.92	3.05	3.08	3.2	3.32	3.54	3.21	3.33	3.15	3.38	3.13	3.37	3.19	3.18	3.2	3.32	3.33	3.6	3.1	3.08	3.24	0.17
November	2.84	2.71	2.36	2.55	2.33	2.45	2.82	3.01	2.9	2.7	2.75	2.95	2.78	2.71	2.61	2.87	2.68	2.71	2.8	2.47	2.81	2.71	0.19
December	2.26	2.13	1.88	1.99	2.04	2.09	2.42	2.55	2.51	2.24	2.31	2.18	2.33	2.4	2.03	1.8	2.06	2.07	1.95	1.7	1.88	2.13	0.23
Annual	3.59	3.64	3.35	3.2	3.34	3.36	3.49	3.7	3.49	3.59	3.54	3.56	3.49	3.51	3.36	3.43	3.57	3.45	3.42	3.43	3.41	3.47	0.12

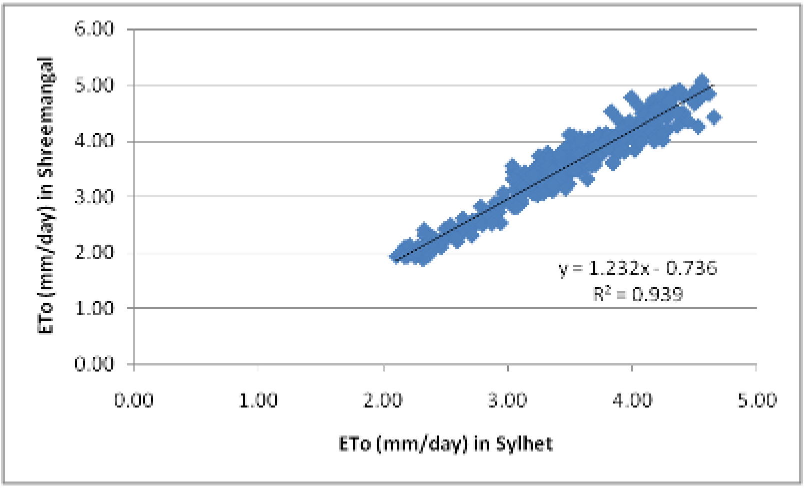

Fig. 6. The relationship of daily mean ET_0 from Sylhet and Shreemangal over 21 years (1988-2013, except 1990, 1991, 1996, 1997 & 2006)

Regression analyses were run between mean daily ET_0 of Sylhet and Shreemangal station over the study period (Fig. 6) to find the degree of relationship of ET_0 between two stations. Coefficient of determination value indicated the close relation of ET_0 between two stations and ET_0 of Shreemangal was slightly higher than ET_0 of Sylhet.

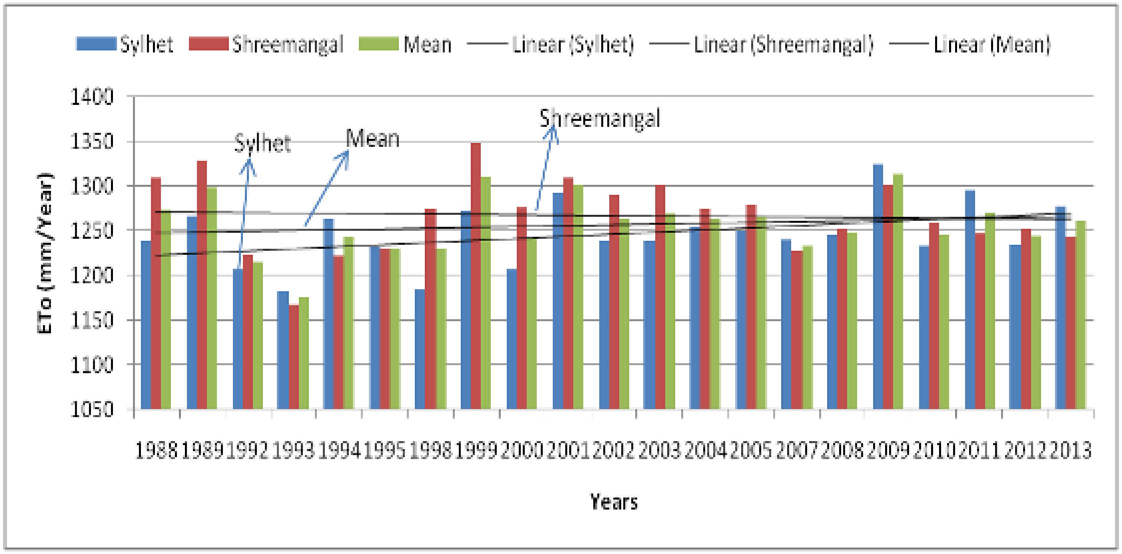

Fig. 7. Integrated annual reference evapotranspiration (mm/year) of Sylhet sadar and Shreemangal upazila and their mean with their linear trend line for a period of 21 years

Figure 7 presents the mean annual ET_0 values estimated by FAO Penman-Monteith method over the study period. The three straight lines refer to the average values of the ET_0, in which the upper line explain the mean values of Shreemangal and the lower explain the values of Sylhet, while the middle line is the average values from both stations. From the trend line, the values of both stations, even the mean values were indicating that the ET_0 was slightly increasing.

In Sylhet, the ET_0 was very significantly (p=0.01) correlated with R_n and VPD in all the months of the year (Table 3). ET_0 was also significantly correlated with average daily temperature in 9 months and u_2 in only 3 months of the year. Wang *et al.* (2012) observed that the ET_0 decreases with the reduced wind speed. The increased VPD resulting from the increase in daily maximum temperature contributed increasing ET_0. The negative contributions of u_2 and R_n in ET_0 was offset by the positive contribution of VPD, implying that the contribution of climatic parameters with increasing trends (T and VPD) were slightly dominant over that of the parameters with decreasing trends (R_n and u_2). Based on significant correlations (r_{xy}; p=0.05) between ET_0 and the governing parameters, the most influential ET_0-determining climatic parameters was identified (Table 3). No specific set of parameters was found accountable for the increasing pattern of ET_0 for all the months of the year; the responsible parameters differed over the months of the year.

Table 3. Correlation coefficients (r_{xy}) of ET_0 with net radiation (R_n), average air temperature (T), saturation vapor pressure deficit $(e_s - e_a)$ and wind speed (u_2) for different months in the year in Sylhet sadar (baseline 1988-2013, except 1990, 1991, 1996, 1997 & 2006)

Month	Correlation coefficient of ET_0 with				Responsible climatic parameters for ET_0 variability			
	R_n	T	$(e_s - e_a)$	u_2	Net Radiation	Av. Temperature	VPD	Wind speed
January	0.94^{**}	0.75^{**}	0.93^{**}	0.18	✓	✓	✓	
February	0.93^{**}	0.94^{**}	0.96^{**}	0.74^{**}	✓	✓	✓	✓
March	0.73^{**}	0.51^{**}	0.75^{**}	0.67^{**}	✓	✓	✓	✓
April	0.92^{**}	0.70^{**}	0.76^{**}	0.004^{ns}	✓	✓	✓	
May	0.98^{**}	0.08^{ns}	0.94^{**}	0.29^{ns}	✓		✓	
June	0.99^{**}	0.01^{ns}	0.81^{**}	0.38^{*}	✓		✓	✓
July	0.99^{**}	0.88^{**}	0.93^{**}	0.25^{ns}	✓	✓	✓	
August	0.99^{**}	0.81^{**}	0.89^{**}	0.19^{ns}	✓	✓	✓	
September	0.98^{**}	0.75^{**}	0.78^{**}	0.13^{ns}	✓	✓	✓	
October	0.87^{**}	0.28^{ns}	0.66^{**}	0.20^{ns}	✓	✓	✓	
November	0.85^{**}	0.90^{**}	0.74^{**}	0.05^{ns}	✓	✓	✓	
December	0.89^{**}	0.86^{**}	0.94^{**}	0.29^{ns}	✓	✓	✓	

* and ** signs indicate P value is less than 0.05 and 0.01, respectively. ^{ns} sign indicates P value is higher than 0.05

In Shreemangal, both R_n and VPD were also very significantly (p=0.01) correlated with ET_0 in all the months of the year (Table 4). Mean air temperature had significant positive correlations with ET_0 in all the months in a year except May and June. u_2 was significantly correlated with ET_0 in January and February. Table 4 provides the most influential ET_0-determining climatic parameters that were identified based on significant correlations (r_{xy}; p=0.05) between ET_0 and the governing parameters. Similar to Sylhet district, no specific set of parameters was found accountable for the increasing pattern of ET_0 for all the months of the year in Shreemangal. Our result of increasing pattern of ET_0 is consistent with Liang *et al.* (2011) found an increasing trend of ET_0 under the combined effects of decreasing relative humidity and increasing air temperature.

Table 4. Correlation coefficients (r_{xy}) of ET_0 with net radiation (R_n), average air temperature (T), saturation vapour pressure deficit $(e_s - e_a)$ and wind speed (u_2) for different months in the year in Shrimangal upazila of Maulbibazar district (baseline 1988-2013, except 1990, 1991, 1996, 1997 & 2006)

Month	Correlation coefficient of ET_0 with				Responsible climatic parameters for ET_0 variability			
	R_n	T	$(e_s - e_a)$	u_2	Net Radiation	Av. Temperature	VPD	Wind speed
January	0.94^{**}	0.61^{**}	0.95^{**}	0.46^{**}	✓	✓	✓	✓
February	0.90^{**}	0.91^{**}	0.96^{**}	0.75^{**}	✓	✓	✓	✓
March	0.66^{**}	0.73^{**}	0.83^{**}	0.18^{ns}	✓	✓	✓	
April	0.95^{**}	0.66^{**}	0.62^{**}	0.07^{ns}	✓	✓	✓	
May	0.99^{**}	0.08^{ns}	0.88^{**}	0.04^{ns}	✓		✓	
June	0.97^{**}	0.05^{ns}	0.76^{**}	0.03^{ns}	✓		✓	
July	0.99^{**}	0.74^{**}	0.88^{**}	0.22^{ns}	✓	✓	✓	
August	0.99^{**}	0.76^{**}	0.81^{**}	0.18^{ns}	✓	✓	✓	
September	0.97^{**}	0.71^{**}	0.83^{**}	0.19^{ns}	✓	✓	✓	
October	0.72^{**}	0.46^{**}	0.75^{**}	0.32^{ns}	✓	✓	✓	
November	0.80^{**}	0.91^{**}	0.78^{**}	0.03^{ns}	✓	✓	✓	
December	0.96^{**}	0.79^{**}	0.92^{**}	0.04^{ns}	✓	✓	✓	

** sign indicates P value is less than 0.01 and ^{ns} sign indicates P value is higher than 0.05

CONCLUSION

Variability and pattern of ET_0 and its controlling climatic parameters of Sylhet sadar and Shreemangal upazila of Maulbibazar district over the 21 years were documented. This paper also compared the ET_0 of two districts under the North-East Hydrological Region of Bangladesh. The mean values of ET_0 throughout the study period (1988-2013) in Sylhet and Shreemangal ranged from 0.9 to 8.6 mm day^{-1}, 1.0 to 7.5 mm day^{-1} and the average values were 3.4 mm day^{-1} and 3.5 mm day^{-1}, respectively. The correlation coefficient of ET_0 between two stations were also high $(r_{xy} = 0.94)$. Both stations had increasing trend in ET_0. Therefore it can be concluded that ET_0 values in two stations were approximately the same. Correlations between ET_0 and the governing climatic parameters were found. In both sites, no specific set of parameters was found accountable for the increasing pattern of ET_0 for all the months of the year; the parameters responsible for the variability of ET_0 varied over the months of the year. This study might be used as the preliminary basis for examining the water footprint in this North-East Hydrological Region of Bangladesh.

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