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Climate Variability over a Tropical Perennial Cropland of Gubawan Watershed Using Remotely Sense Data

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Abstract— *Sensible heat (Qs), latent heat (QL), and ground heat (Qg) flux energy partitioning are essential to determine the development of boundary layer. The study purposely to identify the seasonal and inter-annual variation of some climatic parameters and factors that affect the changed in Bowen ratio (β) on the perennial cropland of the Gubawan watershed. Remote sensing data sets for 10 -years (2009-2018) used and downloaded using the google earth engine. During the period it was observed the ranged values of sensible heat flux (Qs) (92.2 - 148.8 KW/m^2), latent heat flux (QL) (244.3-340.4 KW/m^2), ground heat flux (Qg) (0.19-1.31 KW/m^2), rainfall (1112-2402 mm), and soil moisture content (30.0-34.8 kg/m^2). The Bowen ratio β computed by getting the ratio of sensible heat and latent heat fluxes, has values ranged from 0.28 to 0.67 with a mean value of 0.4. The rainfall was significantly related to the Bowen ratio β during the wet season (March -July) and fewer rainfall months. Moreover, the Bowen ratio has positive linear relationships with sensible and ground heat fluxes with R^2 values of 0.8735 and 0.2224, while latent heat (R^2 = 0.4713) and soil moisture content (R^2 = 0.7948) has inverse relationships. Therefore, there were clear indications of seasonal and inter-annual climate and Bowen ratio variability based on considered climate variables.*

Keywords— *Gubawan Watershed, Bowen Ratio, Basilan.*

I. INTRODUCTION

Agricultural land use has significant effects on energy partitioning as it changes vegetation morphology at large scales (Bagayoko, Fafre, et al., 2006). Energy partitioning among cropland ecosystem sensible (Qs), latent heat (QL), and ground heat fluxes are essential for the determination of forming boundary layer, weather, and climate, as well as the hydrological cycle (Wilson et al., 2002; Knapp et al., 2002, Yue et al., 2018) and calculating energy fluxes and water budgets in land-surface transfer schemes (LSTs) (Dickinson et al., 1993; Sellers et al., 1996). Latent and sensible heat are essential parameters that directly drive variations in climate and can, in turn, alter the environmental variables driving the mass and energy exchange between the ground and the atmosphere (Falge et al., 2005). Thus, latent and sensible heat fluxes are important variables in meteorological, hydrological and ecological analyses.

Cropland energy partitioning is influenced by the interactive effects of physiological and environmental factors. Some field studies have indicated that increases in rainfall variability may exert a strong control on energy partitioning (Knapp et al., 2002; Heisler-White et al., 2008). In addition, according to Grünwald and Bernhofer (2007) that the annual precipitation primarily affected energy partitioning in which the effective precipitation frequency indirectly affected the energy partitioning by its effect on shallow soil water content (Tang et al., 2014). The amount of soil moisture content could to potential significant changes in regional and global climate (Ham and Knapp, 1998; Betts, 2001; Li et al., 2005; Schaeffer et al., 2006).

Temperature is one of the most important climatological factors which has an influence on the fluxes of radiant energy transfer such as Qs and Q_L. These fluxes are significant on the atmospheric circulation. Both observations and climate modeling results indicate that global temperature has increased with time (Trenberth et al. 2007), and this trend will continue in the future (Randall et al. 2007). Additionally, it is most important variable in the hydrologic cycle. The sensitivity of energy partitioning to temperature is a critical issue to understand the interaction between the land surface and climatic system.

The Bowen ratio (β), which is the ratio of sensible heat flux (Qs) to latent heat flux (Q_L), determine the microclimates and hydrological cycles at all scales through its warming effect on the extent of available energy to the surface air (Tang et al., 2014). However, the variability of β on the cropland is significant considering the since the ecosystem is easily threatened by constant changes both in the soil moisture condition and precipitation compared with forests (Wilson et al., 2002; Zha et al., 2010, Yue et al., 2012), and inter-annual variations of Bowen ratio (β) in response to varying magnitudes of some climatic factors have yet to be analyzed. Therefore, the aim of this study to determine possible the seasonal and inter-annual variation of some climatic parameters and major climatic factors that affect Bowen ration (β) in the perennial cropland of the Gubawan Watershed.

II. MATERIALS AND METHODS

2.1. The Study Area

The Gubawan watershed (Fig. 1a) has a total delineated land area of 19,348.48 hectares (193.48 sq. km) bounded within 122^0 2' 16" West, 122^0 12' 14" East, 6^0 41'15" North, and 6^0 31' 35" South. The area is mostly planted with coconut and rubber trees, as they are the main crops of the province. Under modified corona climate classification, the province is under type III climate with no very pronounced maximum rain period, with a short dry season lasting only from one to three months, either during the period from December to February or from March to May. The study area has a significant rainfall with an average of 1725 mm and an average temperature of 27^0C. The soil type in the study area is mostly Nitosols and Luvisols (FAO), which are greatly affected by water erosion and loss infertility.

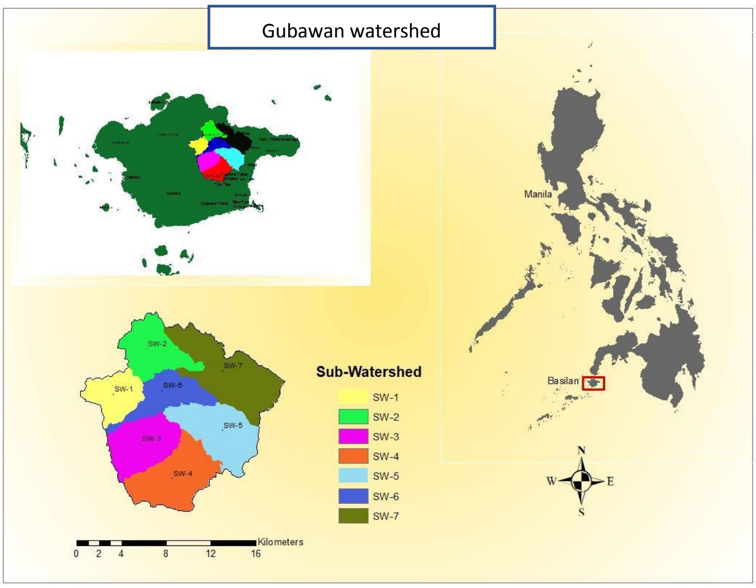


Fig. 1a. Gubawan Watershed

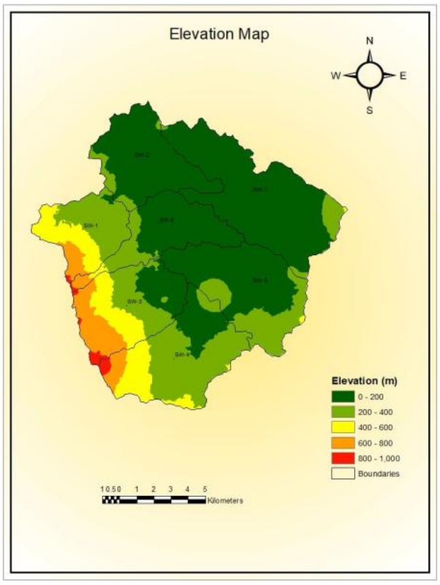


Fig. 1b. Elevation map

The elevation of the watershed area (Fig. 1b) showed that more than half the area has an elevation ranged from 0 -200 m above sea level while parcels of the watershed along the crest on the South-West are elevated at the ranged of 800-1000 m.

2.2. Collection and Sources of Data

The 10-year (2009-2018) data of sensible heat, latent heat, ground heat, soil moisture content at 10 cm, temperatures, and rainfall were all remotely sense data, stored and downloaded using google earth engine.

2.2.1. Energy fluxes and soil moisture content

The values of energy sensible heat, latent heat, and ground heat in watt per square meter and soil moisture content data downloaded from the Global Land Data Assimilation System (GLDAS). It is an ingests satellite and ground-based observational data products and uses advanced land surface modeling and, data assimilation techniques to generates optimal fields of land surface states and fluxes. The simulation used the GLDAS datasets for land cover (MCD12Q1: Friedl et al., 2010), land-water mask (MOD44W: Carroll et al., 2009), soil texture (Reynolds, 1999), and elevation (GTOPO30). The data sets have a pixel resolution of 0.25 arc degrees with 3 hours cadence interval. A soil moisture content (0_10 cm) data sets was considered as a factor for a possible variation of the Bowen ratio. The SMC reading was instantaneous and measured in kilogram per square meter.

2.2.2. *Temperature*

The TerraClimate, a Monthly Climate and Climatic Water Balance for Global Terrestrial Surfaces, University of Idaho recorded and tabulated the maximum and minimum temperatures in degree Celsius on average monthly. It's a dataset of monthly climate and climatic water balance for global terrestrial surfaces. It uses climatically aided interpolation, a combining high spatial resolution climatological normal from the WorldClim dataset, with a spatial resolution of 2.5 arc minutes. The pixels of Tmax and Tmin falls within three sites inside the watershed basin area, average values were computed to represent temperatures of the entire basin area.

2.2.3. Rainfall

A daily rainfall data in millimeter downloaded from Climate Hazards Group InfraRed Precipitation with Station Data (version 2.0 final) (CHIRPS) Daily. (CHIRPS) is a 30+ year quasi-global rainfall dataset. It incorporates a 0.05° resolution satellite with a 1-day cadence, imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. Average rainfall computed from three sites' rainfall data.

2.3. Computation

The climatic index called Bowen ratio calculated using an equation: Bowen ratio =(Q_S/Q_L) (Bowen, 1926), where Qs and Q_L are sensible and latent heat fluxes. Similarly, net radiation is computed through a summation of sensible, latent, and heat fluxes are given by $Rn = Q_S + Q_L + Qg$ (Arya, 2001).

III. Results and Discussion

3.1. Climatic Conditions

Average air temperature showed multiple peaks however, the average temperature usually starts rising from February to June and peaks in March and declining starts from July to January and lowest usually in December to January (Figure 2a). The average annual Tmax and Tmin ranges from 30.9 ^{0}C (2009-2010) -31.7 ^{0}C (2015-2016) and 21.1 ^{0}C (2018) – 22.2 ^{0}C (2016) with the mean and SD values of 31.3^{0}C and 0.3, 21.8^{0}C and 0.3 respectively (Table 1). The CV values of Tmax and Tmin of 1.1 and 1.3 respectively indicate of very least variability for the whole 10-year period.

The annual amount of rainfall (R) varied moderately, from 1112 mm/yr (2015) to 2489 mm/yr (2017). The mean, standard deviation, and percent coefficient of variance (CV) are 2025.2, 467.7mm, and 23.1 respectively. In the years 2014, 2015, 2016, and 2018, the amount of rainfall for each year was below the mean of 2025.2 mm. Figure 2b described that rainfall usually occurring from March to July. It is a cropping period for most of the annual crops. However, from 2011 to 2013 and 2017 to 2008, seasonal and inter-annual variations have changed drastically. During these periods, extreme rainfall has occurred that changed the pattern. In addition, the area usually experiencing southwest monsoon from March to July, and northeast monsoon happened from early October until February each year.

TABLE 1. Summary of annual energy fluxes and climatic parameters for the 10-year period (2009-2018)

Year	Q_L (KW/m^2)	Qs (KW/m^2)	Qg (KW/m^2)	Rn (KW/m^2)	β	Tmax (^0C)	Tmin (^0C)	P (mm)	SMC (kg/m^2)
2009	320.1	148.8	0.60	469.5	0.46	30.9	21.7	2320	34.8
2010	309.6	145.6	0.47	455.6	0.47	30.9	21.4	2382	34.8
2011	340.4	113.6	0.82	454.9	0.33	31.0	21.6	2226	35.7
2012	323.4	108.0	0.55	431.9	0.33	31.2	22.0	2402	34.8
2013	321.7	89.4	0.54	411.7	0.28	31.0	21.8	2345	35.4
2014	302.6	108.6	0.98	412.2	0.36	31.2	21.5	1552	33.3
2015	262.0	176.2	1.31	439.4	0.67	31.7	21.5	1112	30.0
2016	244.3	138.7	0.92	383.9	0.57	31.7	22.2	1729	30.8
2017	265.7	95.0	0.19	360.9	0.36	31.4	21.9	2489	33.4
2018	330.6	92.2	0.81	423.6	0.28	31.6	22.1	1694	36.0
Mean	302.0	121.6	0.7	424.4	0.4	31.3	21.8	2025.2	33.9
SD	33.0	29.1	0.3	33.7	0.1	0.3	0.3	467.7	2.0
CV (%)	10.9	23.9	43.9	7.9	31.6	1.1	1.3	23.1	6.0

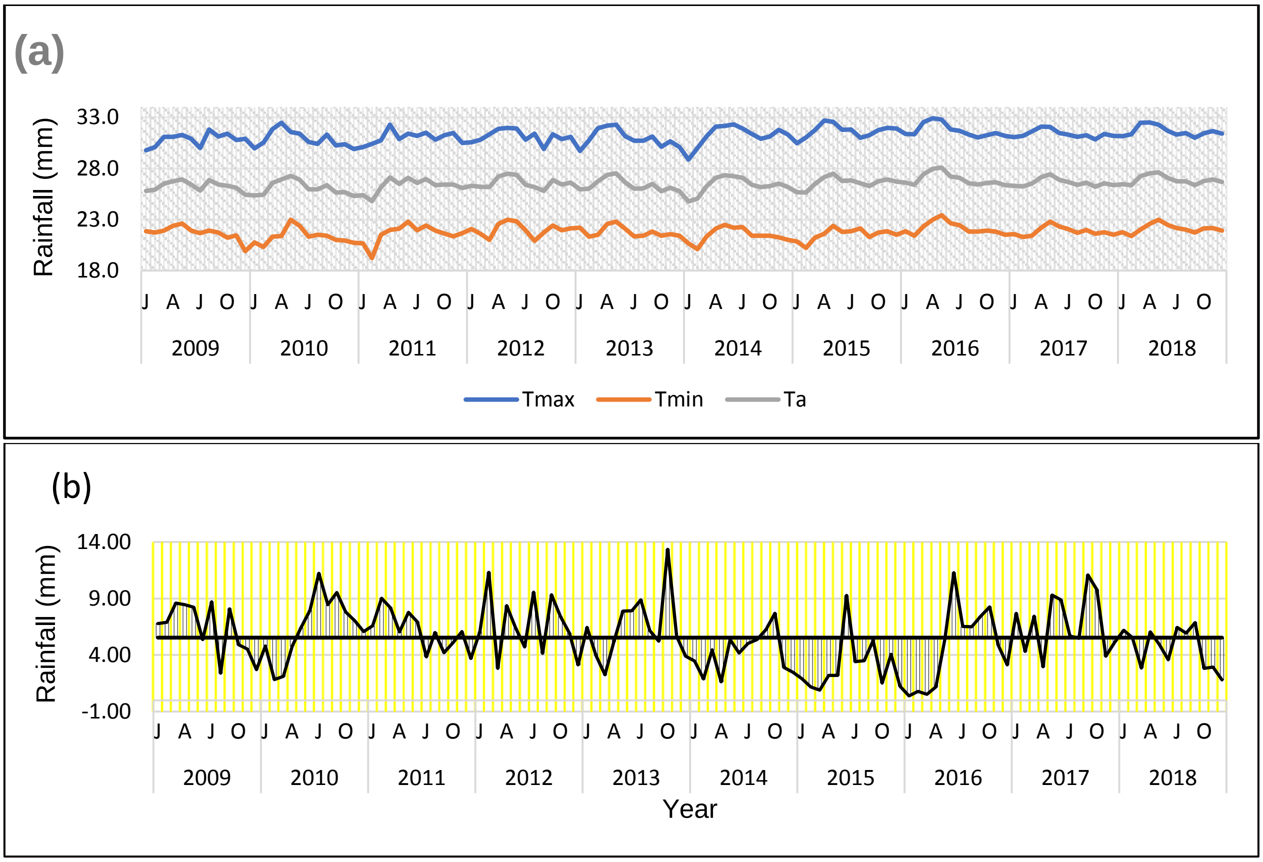


Fig. 2. Seasonal and Inter-Annual Variability of the Environmental Parameters; (a) monthly mean air temperatures (Tmax, Ta and Tmin), (b) mean monthly rainfall

3.2. Energy Fluxes Variations

The amount of latent, sensible, and ground heat fluxes ranged from 244.3 (2015) to 340.4 KW/m2 (2011), 92.2 (2018) to 176.2 KW/m2 (2015), 0.19 (2017) to 1.31 KW/m2 (2015) respectively. Based on the annual total values, three years of latent heat flux has valued below the mean of 302

KW/m^2 while sensible heat has six years below the mean of 121.6 KW/m^2 (Table 1). Figure 3a illustrated a seasonal and inter-annual variation due to significantly decreased sensible heat flux from 2011 to 2014 and 2017 to 2018. A reduced Qs relatively due to higher rainfall during the same periods.

In figures 3a, 3b, and 3c, as sensible heat flux increased above the mean, there was a corresponding decrease of latent heat flux and vice versa. It explained that while the evaporation slowed down at any given time through the decreased amount of latent heat, the atmosphere at the vicinity started to be warmed up as indicated in the rise of sensible heat, which means relatively an increase in air temperature. Likewise, as sensible heat flux increased, the ground heat flux also increased. It is happening when the atmosphere is warming up, soil skin/surface temperature consequently increases as ground heat flux is also a function of a temperature difference between the soil surface and sub-surface. On the other hand, as the amount of ground heat flux increased, there was a corresponding decrease in latent heat flux.

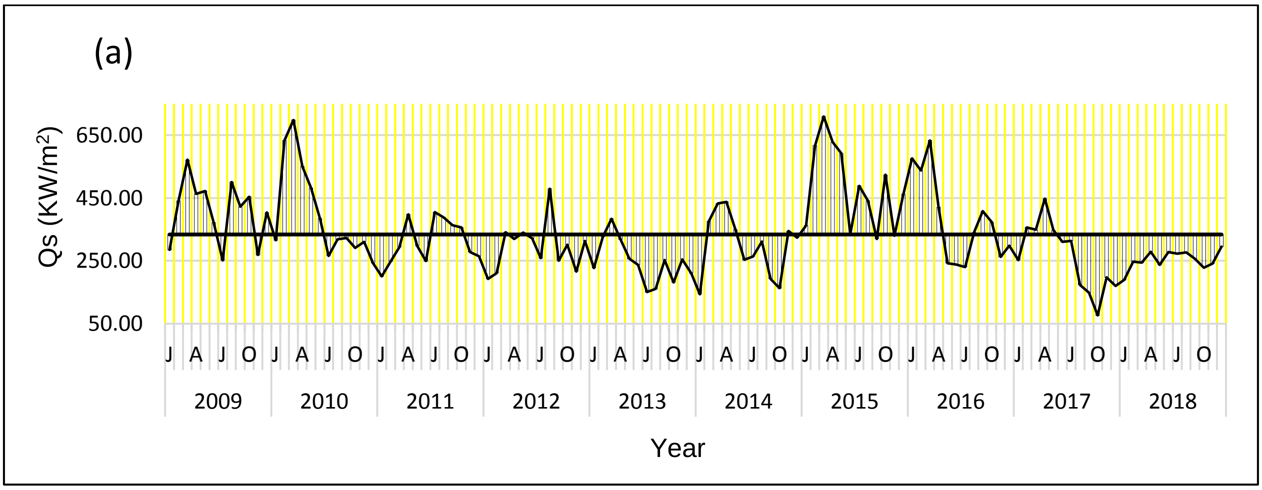
There was seasonal and inter-annual variability based on energy fluxes, as showed in figures 3a, 3b, and 3c. The number of energy fluxes differed most of the seasons and years. For Qs in 2009, mid-2010, 2016, and 2015, the values were above the average while, from mid-2010 to 2014, mostly below the mean. Likewise, QL has similar trends with Qs, except the former is in the opposite orientation with the latter. On the other hand, the Qg trends formed regularly up and down but differed in magnitudes and duration.

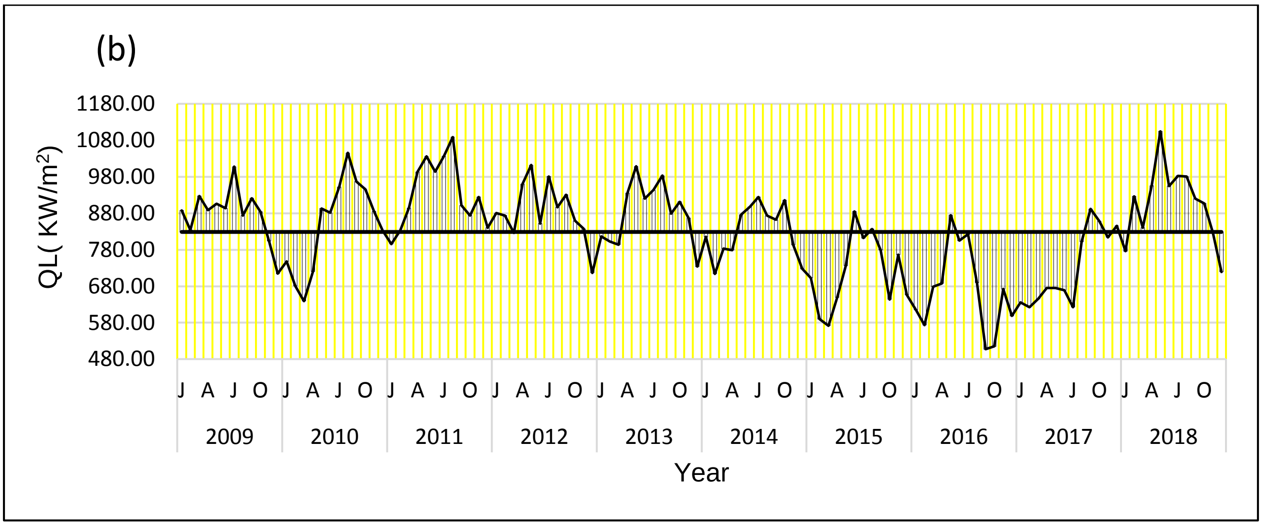
3.3. Net Radiation, Soil Moisture Content, and Bowen Ratio Variations

The amount of net radiation (Rn), soil moisture content (SMC), and Bowen ratio (β) ranged from 361 (2017) to 469 (KW/m2) (2009), 29.96 (2015) to 35.99 (kg/m2) (2018), 0.28 (2018) to 0.67 (2015) respectively. Among the three variables, the computed values of the Bowen ratio (β) were more deviated from the mean as having a higher percent CV of 31.6 compared with 7.1 and 6.0 for net radiation and soil moisture content. The dispersed values of the Bowen ratio attributed to highly varied values of sensible (Qs) and latent (QL) heat fluxes.

The seasonal and inter-annual variation based on net radiation (Rn) (figure 4a) indicated that, from 2009 to 2011 and 2015-mid 2016, Rn values exceeded the mean wherein, from 2016 to 2017, Rn values mostly lower than the mean. For the rest of the years, the Rn values have almost equal proportions with the average value. The higher Rn values indicate a relatively warmed atmosphere. Similarly, the trends for SMC (figure 4b), from 2009 to 2014 and mid-2017 to 2018, the amount of soil moisture is relatively higher than the mean value due to lower sensible (Qs) and higher latent (QL) fluxes, which mean the soil is relatively wet on those years. The Bowen ratio (β), as shown in figure 4c, indicated that a higher correlation with soil moisture content (SMC), from 2010 to 2014 and 2018, the Bowen ratio values were below average while SMC was above average in the same period. Likewise, for the periods from 2015 to 2017.

Based on net radiation, soil moisture content, and Bowen ratio as plotted in Figure 4, the seasonal and inter-annual variability in the study area doesn't have distinct and regular trends.





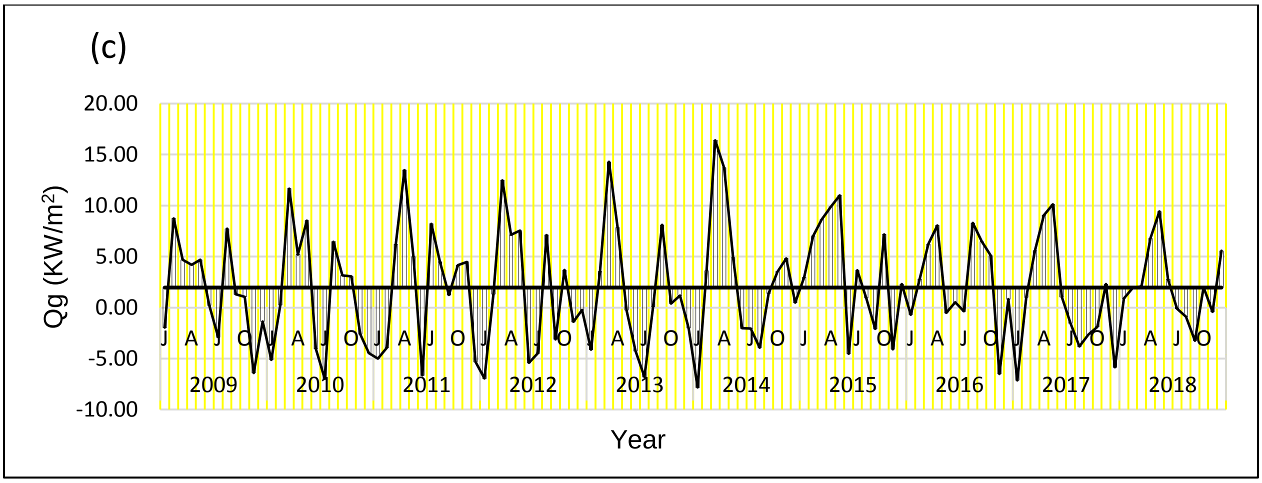
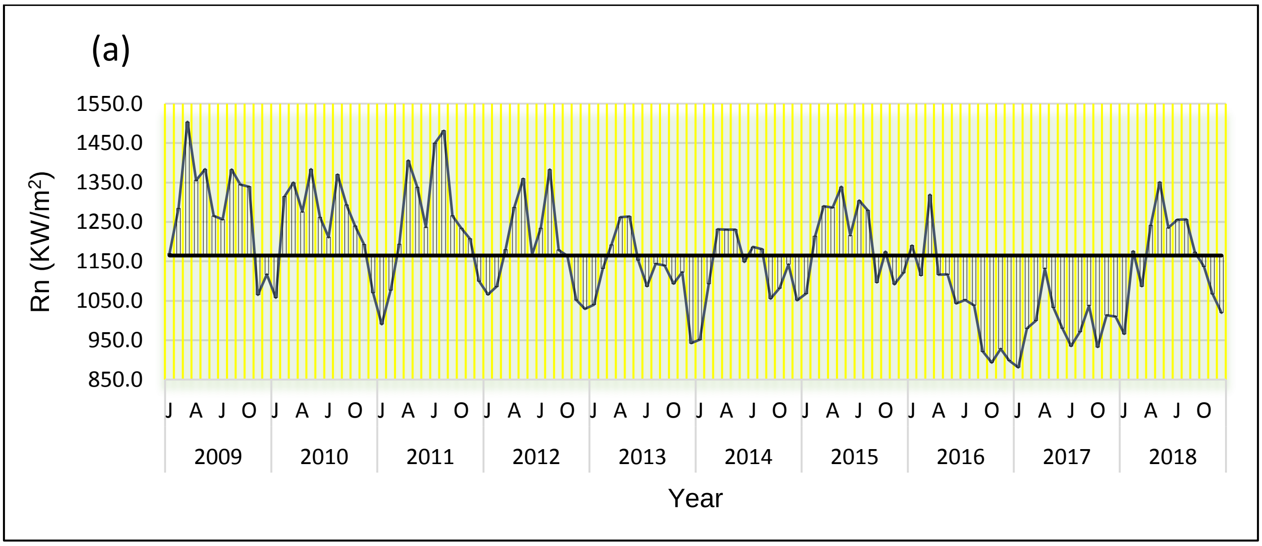


Fig. 3. Seasonal and Inter-Annual Variability of monthly mean; (a) sensible heat flux, (b) latent heat flux, (c) ground heat flux



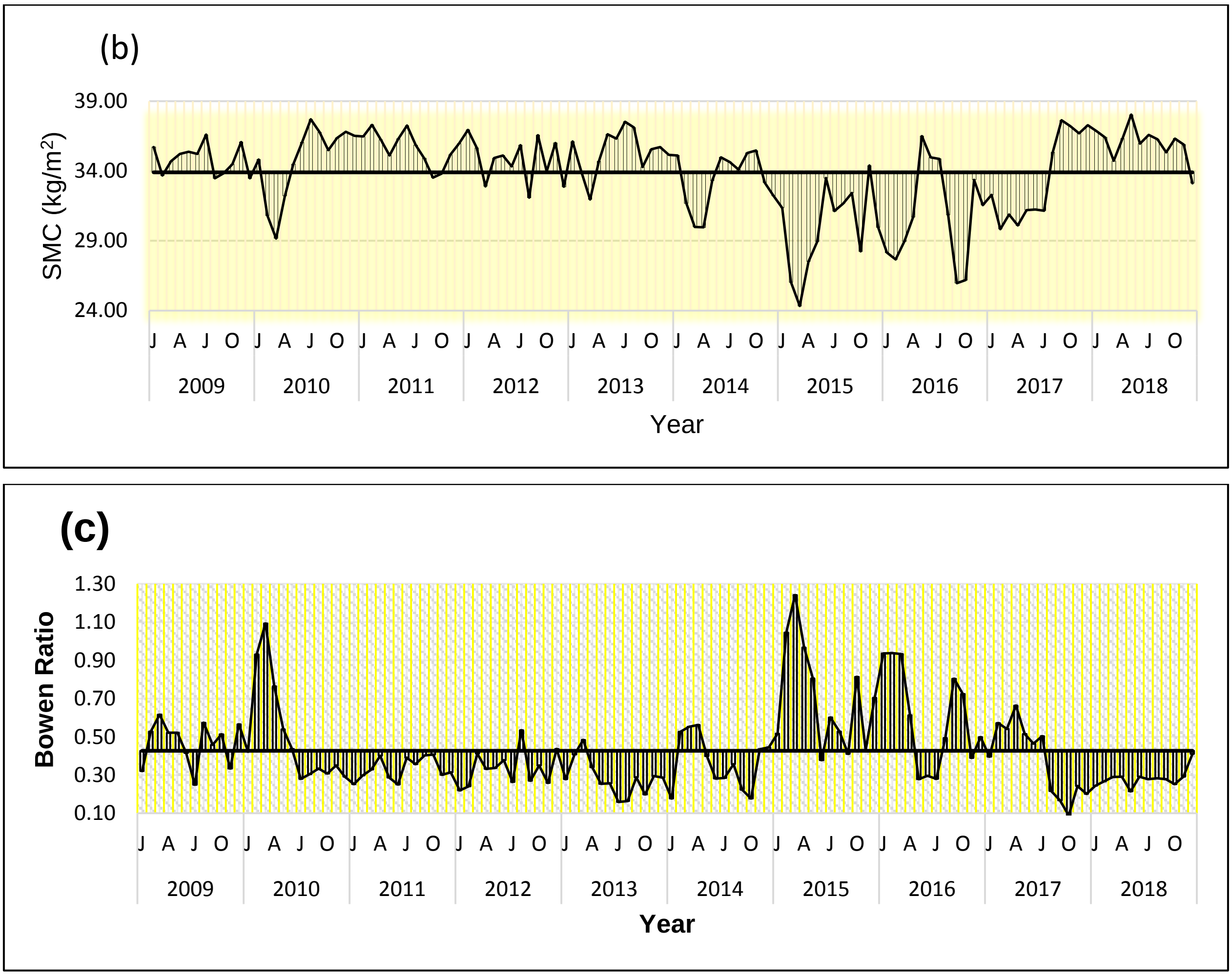
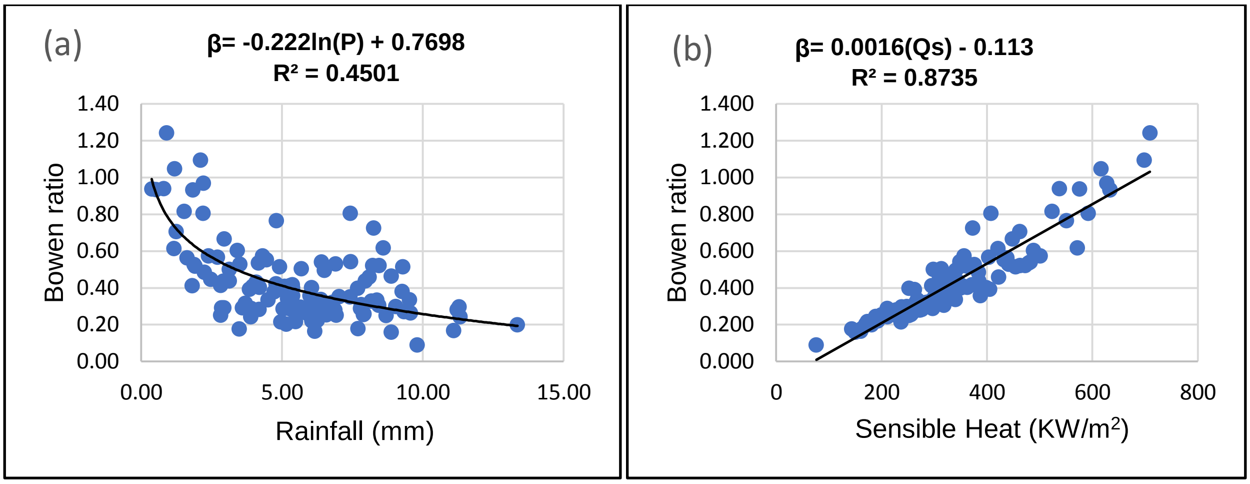


Fig. 4. Seasonal and Inter-Annual Variability of monthly mean; (a) net radiation, (b) soil moisture content, (c) Bowen ratio



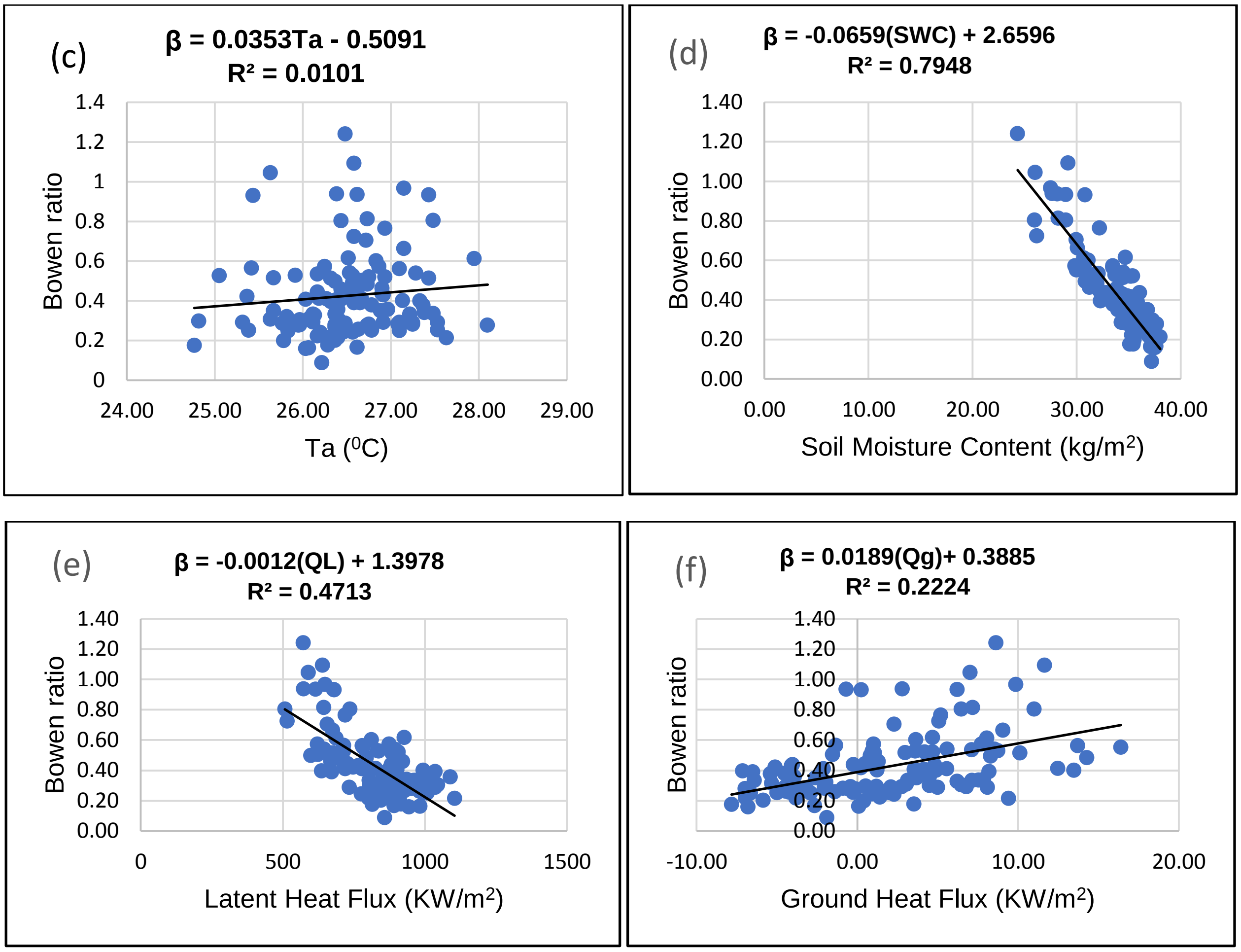


Fig. 5. Relationship of Bowen ratio to climatic parameters; (a) rainfall, (b) sensible heat flux, (c) Average air temperatures, (d) soil moisture content, (e) latent heat flux, (f) ground heat flux

3.4. Factors affecting the Bowen ratio

Figure 5 showed the plots of the Bowen ratio to each factor. Accordingly, the Bowen ratio has a positive linear correlation with sensible heat (Qs) (figure 5b) and ground heat (Qg) fluxes (figure 5f), R2 of 0.8725 and 0.2224. In theory, as sensible heat flux increases, the Bowen ratio is also increasing. Likewise, ground heat flux is also dependent on sensible heat flux. On the other hand, according to (Yue, P. et al., 2018), β is negatively related to T ($\beta = 1/\alpha\varepsilon + 1/\alpha - 1$, ε is a function of Ta), and monthly β decreased with the increasing Ta, it is noting that there are outliers in figure 5c which make it insignificant on having R^2 of only 0.01.

The relationship of Bowen ratio with latent heat flux (QL) (figure 5e) and soil moisture content (SWC) (figure 5d) were negative linear correlations. The Bowen ratio correlations R2 value and equations were 0.7948 and β = -0.0659(SWC) + 2.5696 with soil moisture content and 0.4713 and β = -0.0012(QL) + 1.3975 with latent heat flux. The negative slopes signify inverse correlation. It means, as the amount of soil moisture and latent heat flux increases, the Bowen ratio is decreasing. The higher the soil moisture content, the greater evaporation which, consequently increases latent heat flux.

With regards to rainfall, figure 5a indicated that the Bowen ratio logarithmically correlated with rainfall. It has R^2 of 0.4501 with generated equation of β = -0.222ln(P) + 0.7698. It means, as rainfall increases, the Bowen ratio decreases as well. In concept, during the rainfall period, air temperature relatively dropped to a minimum due to an increase in relative humidity of the air result to increase in latent heat flux.

IV. CONCLUSIONS

There was seasonal and inter-annual climate variability in terms of environmental and other factors. Monthly average temperatures usually raised above the mean from February to June and peak in March and declined from July to January. Rainfall relatively higher from March to July, a period considered as cropping period, but from 2014 to mid-2016, its patterns changed. The changes in rainfall patterns have a corresponding effect on the magnitude of sensible heat, latent heat, and ground heat fluxes, and soil moisture content. As the amount of rainfall increased, SMC and latent heat consequently increase, while sensible and ground heat fluxes declined.

As for seasonal and inter-annual Bowen Ratio variability. Any changes in the amount of sensible heat, latent heat, ground heat fluxes, soil moisture content, and rainfall affect the Bowen ratio. When sensible heat and ground heat fluxes increase, the Bowen ratio increases linearly, whereas the soil moisture content, latent heat, and rainfall have an opposite reaction.

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