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Estimation of Water Stress on Rice Crop Using Ecological Parameters.

Muhammad Saifullah[1], Bilal Islam[4], Saif-ul-Rehman[3], Muhmmad Shoaib[2], Ehsan ul Haq[1], Syeda Areeba Gillani[1], Nida Farooq[1] and Memoona Zafar[1].

1 Remote sensing and GIS group, Department of Space Science, University of the Punjab Lahore, Pakistan.
2 Geomatics, Collage of Earth & Environmental Science Punjab University Lahore.
3 Department of Geography GC University, Lahore.
4 Department of Physics, University of the Punjab Lahore, Pakistan.
* Correspondence: Muhammad Saifullah E-mail: saifafridi1994@gmail.com
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Abstract.

About half of world's population intake rice as a staple food. As being water baby, rice need surplus of water to get targeted yield. Water scarcity has become a global issue therefore it has become a need to enhance the rice yield with reduced amount of water. In this research we used ecological parameters e.g., temperature, pressure, actual vapor pressure, sunshine hours and the extraterrestrial radiation to compute net radiations, ground and sensible heat fluxes on daily basis. Net shortwave radiations were observed as 23087 w/m^2 in comparison to net longwave radiations which were 4387 w/m^2 for the complete Rice Growth Period (RGP). The soil heat flux G_o was observed as 3104 w/m^2. G_o was observed dependent upon the Leaf Area Index (LAI) with inverse relationship between them. Sensible heat flux (H) was measured as 1771 w/m^2 throughout the RGP. H was observed dependent upon net radiations with a direct relationship between them. R_n, G_o and H were used as input parameters to compute water stress which determines the excess of water in early growth stages of rice crop and water scarcity in the ripening stage. The flow of methodology is easily applicable at domestic level to determine water stress in rice fields.

Keywords: Net radiations, Soil heat flux, Shortwave radiations, long wave radiations, water stress.

1.0 Introduction.

Rice (Oriza Stiva L) has become a staple food for half of the world's population [1]. Global food security is largely dependent upon the supply of lowland irrigated rice [2]. Rice is considered as water baby that consumes plenty of water for its growth and development [3]. Various factors are the influencing the availability of fresh water for irrigation to paddy rice crop such as the addition of industrial discharge into rivers and canals [4, 5, 6]. The contribution of Asian countries toward rice production is about 90% in global market that intakes almost 91% of total fresh water for its preparation [7]. About 15 million hectors of irrigated rice area and 22 million hectors of dry season rice area in Asia is projected to suffer with water scarcity by 2025 [8]. Fresh water is the basic and most significant constituent that plays a vital role to obtain targeted agricultural productivity therefore, water conservation and sustainability has become the need of green future. Various techniques and methods have been suggested by many researchers to manage water demand by provision of optimized supply of water to crops to get acceptable yield [9]. All the techniques and methods were related to water saving for future. Kima et al 2014 [10] evaluated the quality of ground water available at various depths suitable for different crops [9]. A mutual finding of these researches was the achievement of healthy yield with reduced amount of water.

Sustainable rice production is related to increase productivity with reduced amount of water to fulfill the demands of increasing population [11]. Different parameters are essential to improve the rice productivity with reduce amount of water. These parameters include 1) soil type 2) soil pH and 3) soil Electric Conductivity (EC). Soil type is significant to improve to reduce the provision of water to rice crop e.g., sand is perfectly drained which is not suitable for rice crop plantation while sandy clay is highly drained which is considered less suitable, silty clay is well drained therefore considered moderately suitable and clay is imperfectly drained therefore considered as highly suitable for rice cultivation [12]. To reduce the amount of water, the rice land should be clayish because clay has highest water holding capacity. The electric conductivity of rice fields should be between 0.75- 1.50 and the EC values are considered less suitable above or below this range. Soil pH should be between 5.5-7.2 which is considered highly suitable for rice cultivation.

The main objective of this research was to estimate the water stress in rice fields using ecological parameters and to evaluate various factors affecting the water intake by rice crop.

2.0 Material and Methods.

Investigation site.

This research was conducted in district Sheikhupura in Punjab Pakistan. Sheikhupura is located at (31-32.5 N) latitude and (73-75E) longitude spatially mapped in figure 1. It is located at 230m above the sea level with paved network of water channels administered by Punjab Irrigation Department for irrigation purpose to crops. Climate is severe with a wide range of variations in temperature that crosses 45°C in summer and declines to 1 °C in winter. The test site is in range of monsoon therefore, it receives 500 mm rainfall annually [13]. It is a plain area where slop does not affect the water distribution process. Crop information is maintained by a person natively named as patwari.

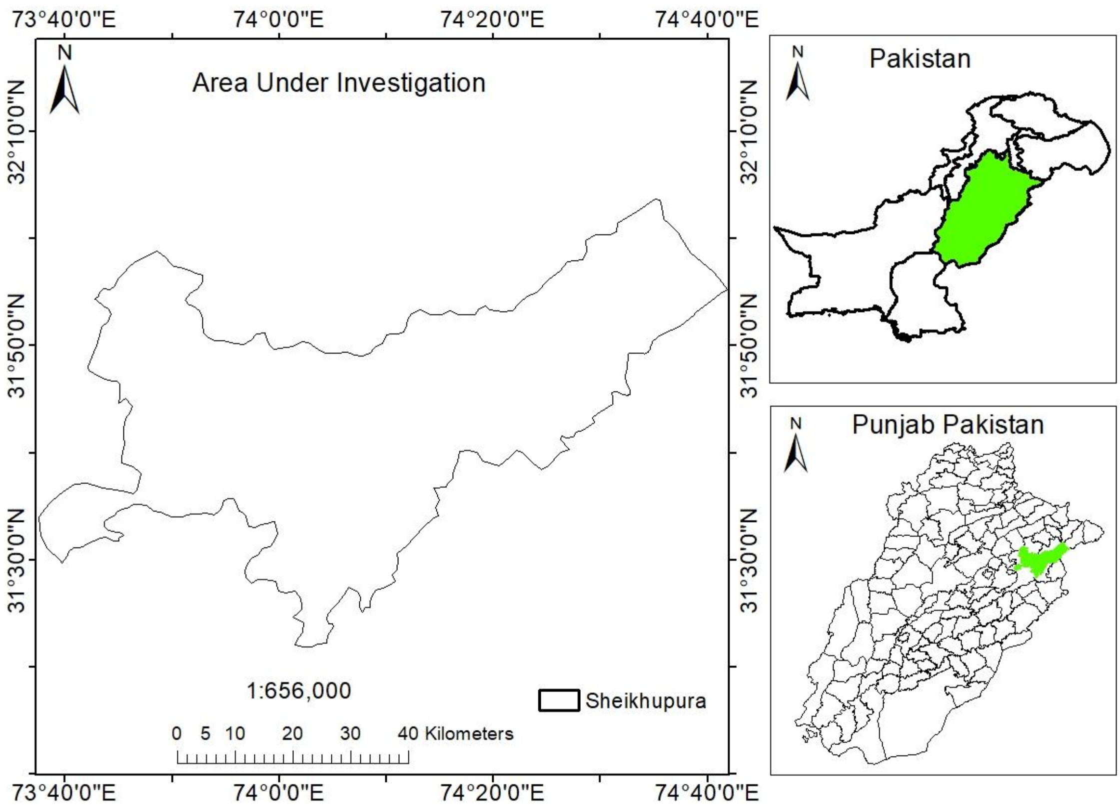

Figure 1. Spatial extent of the study site.

Methodology.

Flow of methodology to estimate water stress is described in the Figure 2 as below:

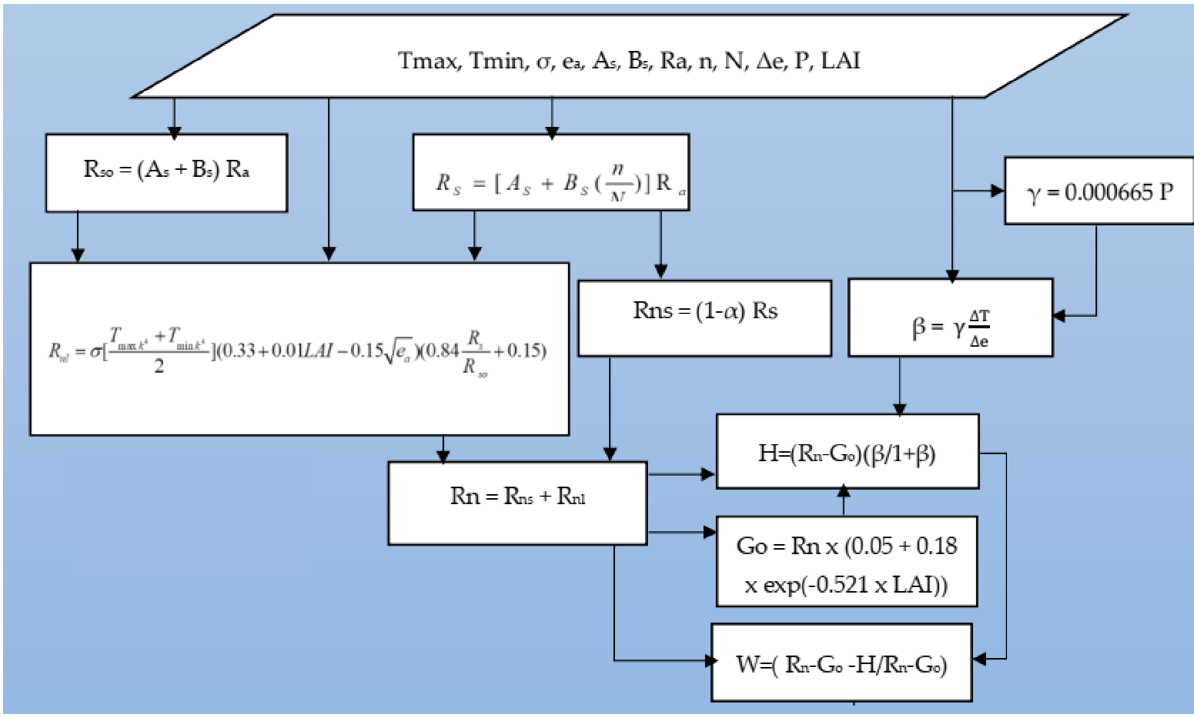

Figure 2. Flow of methodology used in this research to estimate water stress on rice crop.

Various parameters are significant to evaluate the water stress on rice crop. These parameters include the variations in temperature on daily basis, pressure, Leaf Area Index (LAI) actual sunshine hours in comparison to total sunshine hours and the actual vapor pressure.

Net Radiations (R_n)

R_n describes the energy balance of earth which is signification to determine the physical nature of features laying on the surface of earth. It is the ratio of incoming to outgoing solar radiations. Evapo-transpiration in plants is affected by this energy balance, therefore it is significant to estimate R_n to investigate agro-climatic interactions [14]. All the physical & chemical reactions occurring in plants are derived by solar radiations [15]. Net radiations can be computed by integrated impact of incoming and outgoing radiations. Incoming radiation are called net shortwave (R_{ns}) and outgoing are known as net long wave (R_{nl}) radiations [16, 17, 18].

$$Rn = R_{ns} + R_{nl} \qquad (1)$$

R_{ns} can be computed by the interaction of actual incoming radiations with albedo of rice crop canopy.

$$Rns = (1-\alpha)R_s \qquad (2)$$

Where α represents albedo by rice plant and R_s is actual incoming solar radiations. According to Stephen Boltzmann Law, R_{nl} is four times proportional to earth's surface temperature, as below [19].

$$R_{nl} = \sigma\left[\frac{T_{\max k^4} + T_{\min k^4}}{2}\right](0.33 + 0.01LAI - 0.15\sqrt{e_a})(0.84\frac{R_s}{R_{so}} + 0.15) \qquad (3)$$

Where σ is Boltzman constant ($\sigma = 4.903 \times 10^{-9} MJK^{-4}M^{-2}Day^{-1}$), T_{max} and T_{min} represents the maximum and minimum temperatures, R_{so} and R_s are incoming radiations in comparison to actual incoming radiations respectively and e_a is the actual vapor pressure. We collected T_{max}, T_{min} and e_a by Local Weather Station (L W S) for the complete Rice Growth Period (R G P) and averaged. R_a is extraterrestrial radiations which strike on the Top of Atmosphere (T O A) before entering in to earth's atmosphere [20]. Considerable variations can be measured in Ra due to change in solar angle [21]. R_a can be computed using the website

http://www.engr.scu.edu/~emaurer/tools/calc_solar_cgi.pl.

Radiations that actually strike the surface of earth after interaction with atmospheric gases are called actual incoming radiations that can be computed according to [16, 20, 21, 22, 23, 24, 25].

$$Rs = [A_s + B_s (n/N)] R_a \qquad (4)$$

Where A_s and B_s represents calibration constants, n and N are actual sunshine hours in comparison to possible sunshine hours on daily basis. We obtained the data about n, N through LWS. It is observed that 75% of extraterrestrial radiations approach the earth's surface in a cloud free day. Remaining 25% are scattered due to atmospheric interactions. R_{so} can be computed using Angstrom's formula [20, 22].

$$R_{so} = (A_s + B_s) R_a \qquad (5)$$

Soil heat flux (G_o)

G_o is related to heat conduction in to the soil due to variations in temperature which depends upon the soil composition. Penetration of heat into the soil is more if it has high concentration of elements that can conduct heat. All the biochemical reactions happening in soil are controlled by G_o. The contribution of G_o in energy balance is smallest therefore this factor is often ignored but this ignorance may lead to considerable errors. G_o can be computed as follows [25].

$$Go = Rn \times (0.05 + 0.18 \times \exp(-0.521 \times LAI)) \qquad (6)$$

Where LAI is leaf area index of rice crop that varies from germination to ripening. G_o largely depends upon LAI because the density of leaves influences the heat penetration into the soil. We obtained 21 field observations with a temporal window of five days from rice fields to estimate the variations in leaf area, e.g., leaf area was observed 0.23 m^2m^{-2} on July 13, 2017 that was assumed same for the next five days (13-17) July 2017. Variations in LAI throughout the RGP are mapped in figure 3 as below.

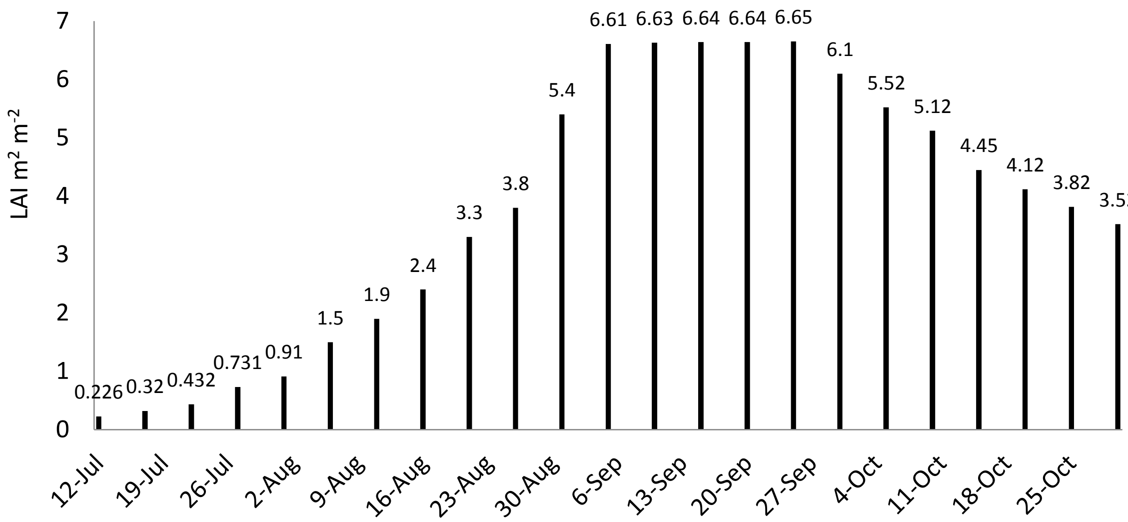

Figure 3. Variations in leaf area throughout the RGP.

Sensible and latent heat flux (H)

The exchange of heat in plant's body without changing its state is called sensible heat flux. Bowen ratio (β) is an important indicator to estimate H. To evaluate β, we need daily variations in temperature with actual vapor pressure as below [26, 27, 28].

$$\beta = \gamma \frac{\Delta T}{\Delta e} \quad (7)$$

Where γ is known as psychometric constant which is 0.000665th portion of atmospheric pressure [29]. Δe and Δt represents the actual vapor pressure and temperature gradients respectively. The expression to evaluate γ is as follows

$$\gamma = 0.000665 x P \quad (8)$$

We obtained the variation in atmospheric pressure, temperature and actual vapor pressure from LWS and averaged. The expression to estimate H is as follows [27]

$$H = \left(\frac{\beta}{1+\beta}\right)(R_n - G_o) \quad (9)$$

Where R_n, G_o and H are the basic input factors to evaluate water stress (W) on the rice crop. W determines the amount of moisture in the soil. A range of 0 to 1 is used for determination of W where 0 indicates oven dry soil and 1 as penalty of water. W can be compute using the following expression [11].

$$W = \frac{R_n - G_o - H}{R_n - G_o} \quad (10)$$

Results and discussion.

We used equations 1-5 to compute R_a, R_{so}, R_{ns}, R_{nl}, R_n and mapped the results in Figure 4.

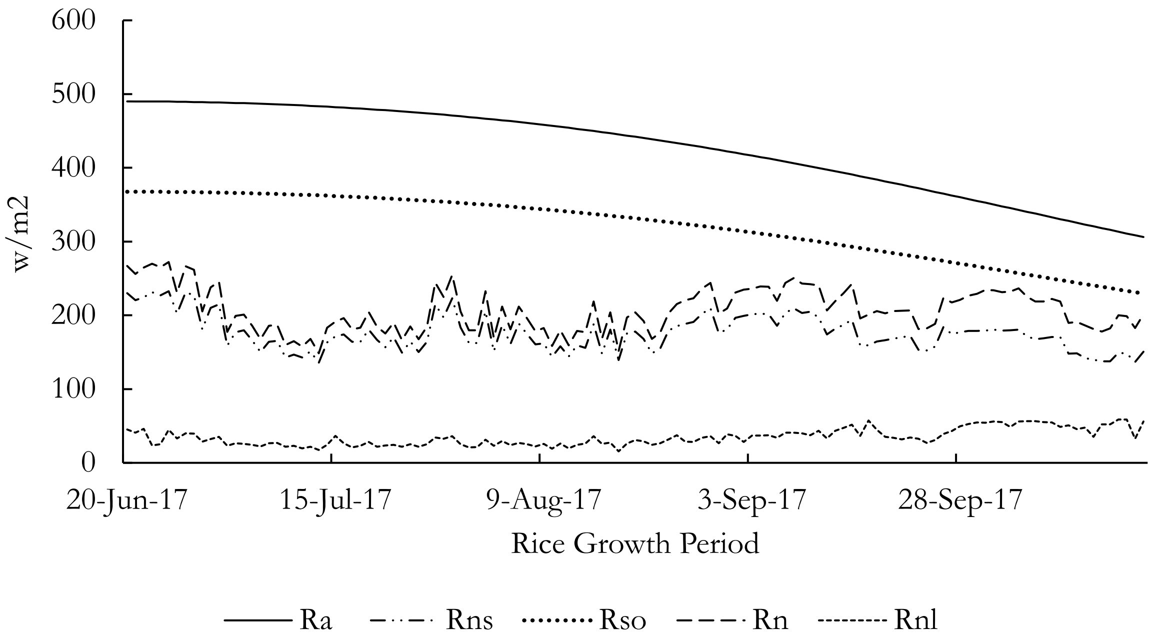

Figure 4. Variations in various fluxes throughout the RGP.

Figure 4 shows the variations in various fluxes throughout the RGP. Extraterrestrial radiations are showing a decline to flux which is due to the change in solar angle throughout the RGP. Figure 4 determines that a total flux of 55625 w/m^2 was received as extraterrestrial radiations and 415 w/m^2 as average. A fraction of about 25% of Ra was scattered/reflected into the atmosphere due to interaction with gases and 41718 w/m^2 was available to approach the surface of earth. A flux of about 27474 w/m^2 could approach the crop canopy throughout the RGP including 23087 w/m^2 as R_{ns} and 4387 as R_{nl} radiations. Peaks and dips in Rn, Rns and Rnl resemble with the variation in n/N ratio in figure 5. It determines that more flux was received by the crop canopy on the day where n/N ratio approached 1 and vice versa.

Figure 5 describes the cloud activity throughout the RGP. Cloud activity is essential for various growth stages of rice crop e.g., cumulus clouds with heavy rainfall provides a large quantity of water to the rice fields which is a nice addition in germination, leaf emergence and panicle primordia development, however, rain free clouds are considered good in ripening process of rice crop. The peaks and dips in figure 5 determine the dense cloud activity at dips and clear sky on peaks throughout the RGP

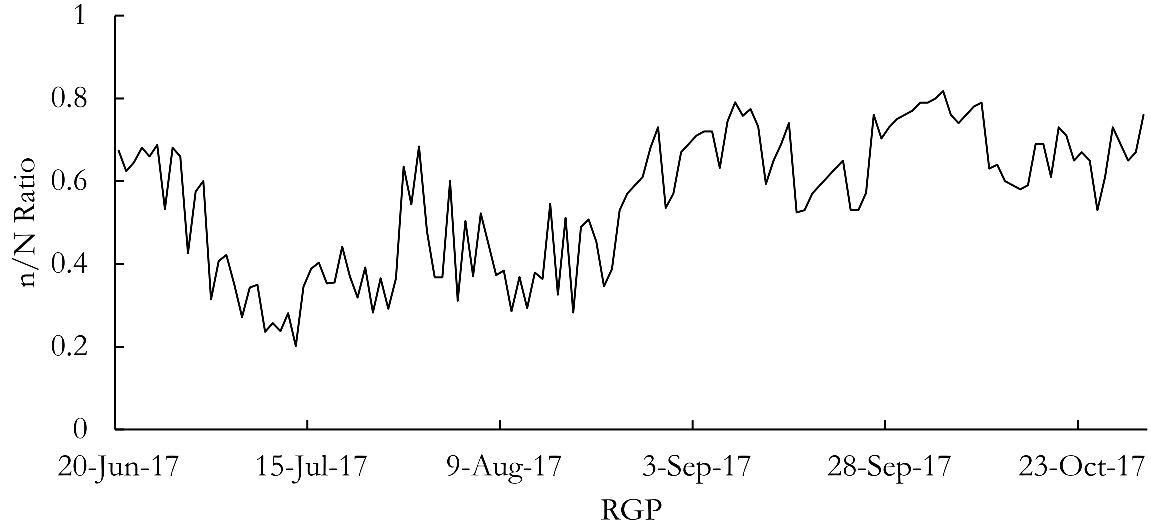

Figure 5. Cloud activity throughout the RGP.

Variations in G_o throughout the RGP were estimated using equation (6) as below.

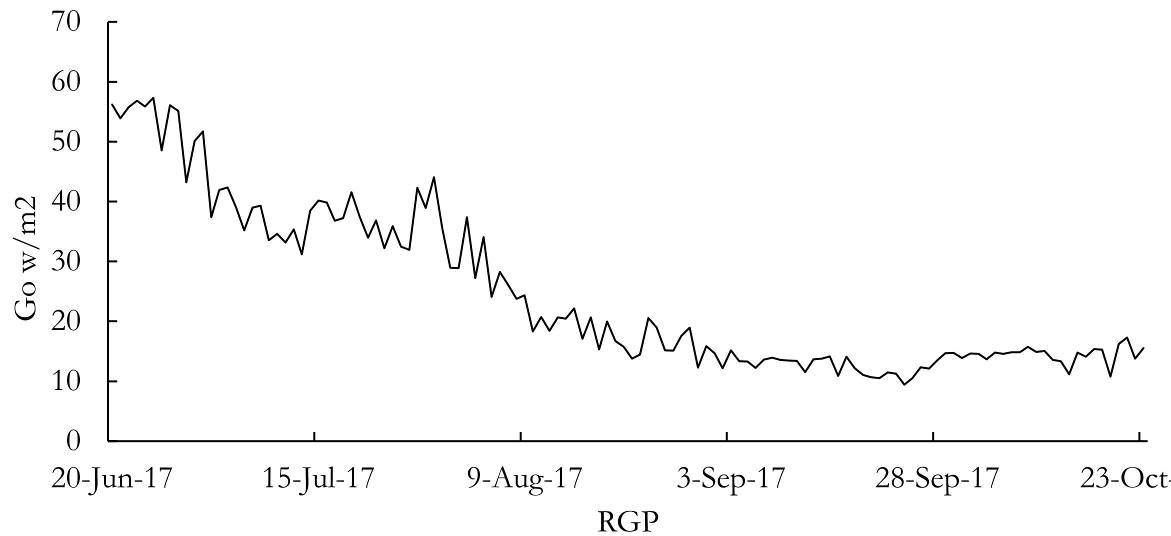

Figure 6. Variations in Go throughout the RGP.

Figure 6 is showing the variations in ground heat flux which is showing a decreasing trend from start to the end of growth period. This decline in G_o is due to inverse relationship of G_o with LAI. The increment in LAI stops the sunlight to approach the earth's surface. This trend shows that LAI of rice crop increase hence G_o declined. Go again increased in the end of rice season due to decrease in LAI. A total G_o was recorded as 3104 w/m^2 throughout the RGP.

Variations in sensible heat flux for the complete growth period of rice crop were estimated using equations 7-9 and mapped the results in Figure 7.

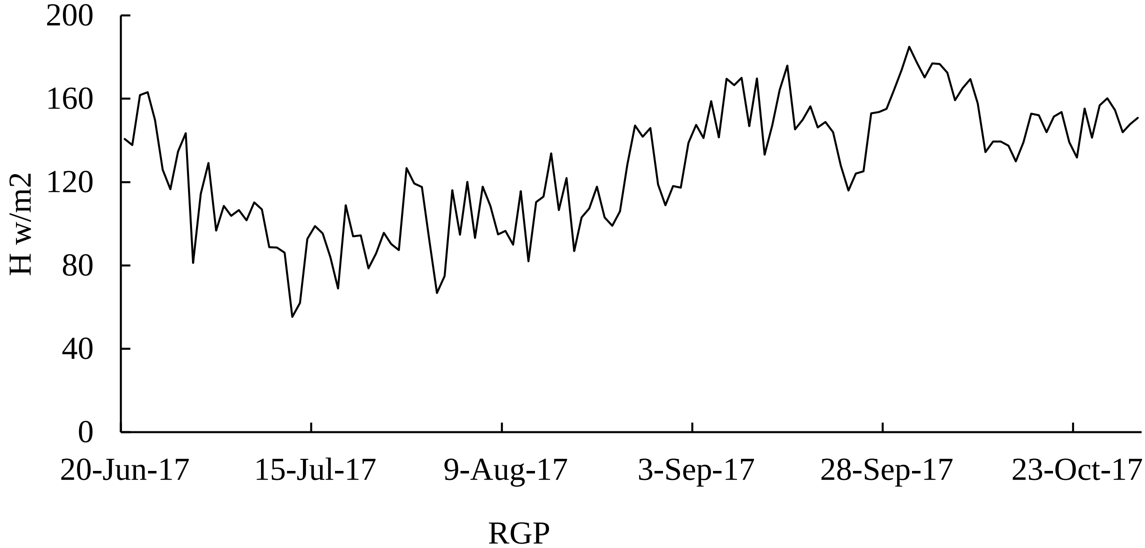

Figure 7. Variations in sensible heat flux throughout the RGP.

Figure 7 is showing the same trend as R_n in Figure 4. Sensible heat is required to maintain the plant bloody temperature in comparison to its surroundings. The resemblance of both figures describes that more H is required on the day where a high value of R_n is recorded and vice versa. Sensible heat was recorded as 1771 w/m^2 and 127 w/m^2 as average on the rice crop canopy throughout its growth period.

We used equation 10 to compute the variations in water stress and mapped the results in Figure 8.

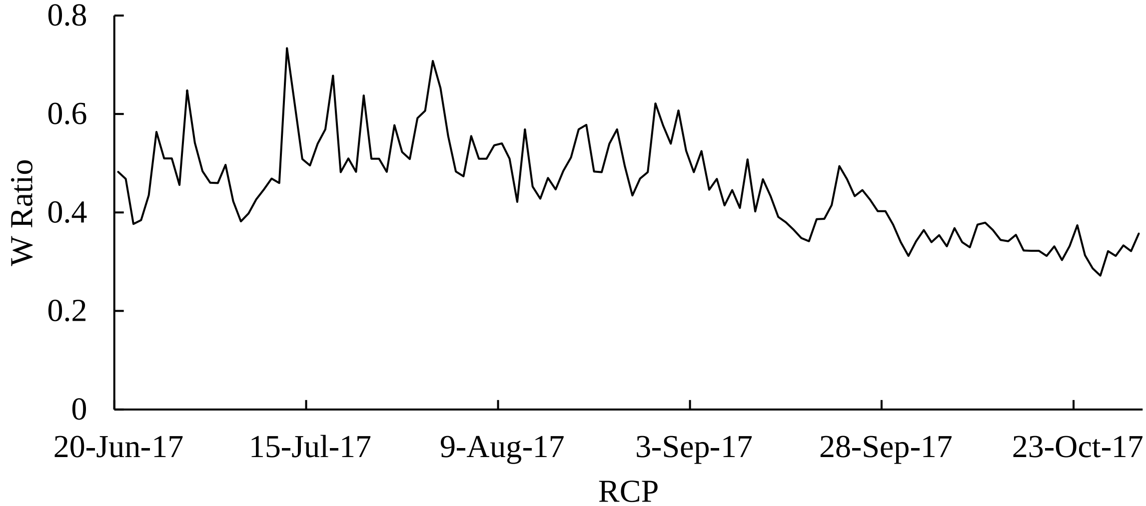

Figure 8. Estimation of water stress throughout the RGP.

Figure 8 shows that the rice crop in the study site had surplus of water in early stages of growth. Rice crop was observed in stress toward the end of rice crop season. On ground validation it was observed that ripening period don't need much water however, initial stages require a big quantity of water for full fledge growth. On comparison of Figure 8 with Figures 5, it was observed that cloud activity (n/N) effects the solar fluxes e.g., R_n, R_{ns}, R_{nl}, H, G_o and finally W. If (n/N) ratio approaches to 0, it shows that it is a complete cloudy day with less flux in term of Rn, hence a little H is required, this situation leads to the values of W greater than 0.5. Finally, we concluded that the initial stages of rice crop were observed in clouds with n/N ration near to zero and less amount of water was required as H therefore, it was not water stress in early stages however there was water stress in the end of rice season with $W<0.5$. Our results corroborate with Raza.S.M.H 2018 [11,12].

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Conclusion.

Ecological parameters are of great importance to monitor the physical changes within a plant. Optimum range of these parameters will lead to enhance the capacity of a plant for generation of fruitful yield with reduced water. The research methodology is easy and handy to apply in rice fields at domestic level because it is significant to ensure the availability of water in rice fields to get much of yield.

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Author's Contribution. All the authors contributed equally.

Conflict of interest. We declare no conflict of interest to publish this research in IJASD

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