International Journal of Academic and Applied Research (IJAAR)
ISSN: 2000-005X
Vol. 2 Issue 10, October – 2018, Pages:40-45

Water Requirement of Rice in Different Agro-Potential Zones Based on Aridity Indices by Using Geographic Information System

Sahrish Anwar[1] and Mr. Muhammad Amin[2]
1Institute of Geo-Information & Earth Observation, Arid Agriculture University Rawalpindi, Pakistan
2Faculty of Institute of Geo-Information & Earth Observation, Arid Agriculture University Rawalpindi, Pakistan

Abstract: *Aridity indices are widely used as an indicator of moisture availability for crop's growth. Our main objective is to determine spatial variability of aridity in Punjab, Pakistan by using different aridity indices to calculate water requirement for Rice. Climate data of eighteen weather stations in all over Punjab were collected for 25 years (1991-2016). Reference evapotranspiration (ETo) was calculated by using Modified Penman Monteith method. Annual rainfall and annual ETo was interpolated by using Inverse distance weighted method in Arc GIS 10.3 software. Interpolated data were validated by Geo-statistical analysis, presented results with 99 % accuracy and Root mean square error was -0.00024. All aridity indices were calculated by using Raster calculations and mapped in GIS environment. Agro-potential zone maps based on aridity indices were developed by using Geographic Information System (GIS). Daily and monthly water requirement for Rice crop in all zones were calculated by multiplying ETo with Crop factor (Kc) values. Monthly water requirements for rice in Zone1, 2, 3, 4, 5, 6 were 816, 857, 798, 772, 770, 642 mm respectively. Optimum Seasonal water requirement for rice was 887 mm. This study will be helpful in predicting moisture availability and water need for Rice in all zones for farmers, field activity planners and policy makers.*

Keywords— Reference evapotranspiration, Geographic information system, Aridity indices, Agro-potential zones, Water requirement of rice

1. INTRODUCTION

Rice (*Oryza sateva)* is one of the important cereal crops in Pakistan (Timsina and Connor, 2001). It is grown in May-June and harvested in October-November (Aselmann and Crutzen, 1989). Aridity is the major environmental constraint in sustainable agriculture (Haider and Adnan, 2014). About 70 to 75 % area of Pakistan consists on arid and semi-arid climatic (Chaudhry and Rasul, 2004). Two-third part of Punjab receives most of rainfall in summer *season* (Ahmad et al., 2015). Rice is a tropical plant, requires about average temperature of 30°*C* to maximum 45°*C* temperature and 45 to 50 inches rainfall with 15 to 16 times irrigations throughout its vegetative growth. Temperature is rising with the rate of 0.64°C annually (Afzaal *et al.*, 2009) that's an alarming situation in country. Average annual rainfall in Punjab is about less than 10 inches (Treydte *et al.*, 2006) which can't fulfill the requirement of water-intensive crops like rice.

1.1 Objectives of the study

Our main objective of the study is to calculate different aridity indices and to delineate Agro-potential zones by using Geographic Information System. The second objective of the study is to calculate water requirements of Rice crop in all agro-potential zones.

2. MATERIALS AND METHODS

2.1 Study Area and Meteorological Data

Geographical location of Punjab contributed to the possibility of Rice crop growth in arid and semi arid conditions by utilizing water for irrigation.

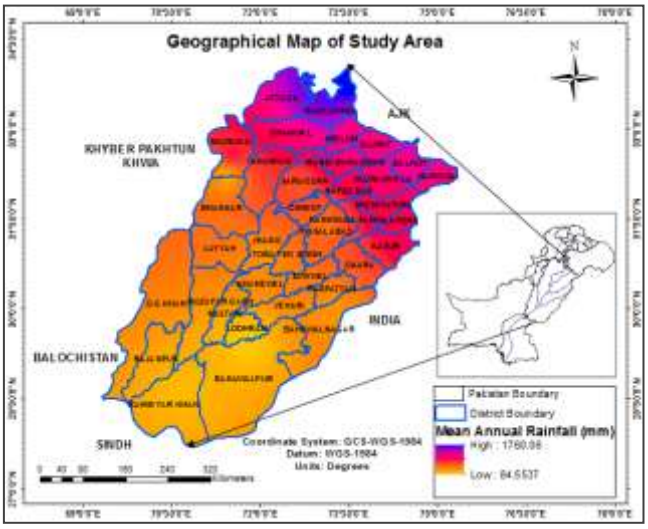

Figure1. Map showing Geographical extent of study area

It lies between 31.17° N latitudinal and 72.70° E longitudinal extent of 31.17° N and 72.70° E. Its total area is about 205,34400 hectares. Overall it falls in arid and semi-arid type of climate. Maximum and minimum annual temperature of Punjab varies between 27°C to 32°C and 15°C to 19.5°C. Average annual rainfall ranges between 39 inches in upper part to 10 inches in southern districts. Relative humidity fluctuates from 50% to 63% in all over Punjab. Wind speed varies from north to south. Sunshine

hours are long in summer and short in winter. Meteorological data of 18 weather stations were acquired from Punjab meteorological department (PMD).

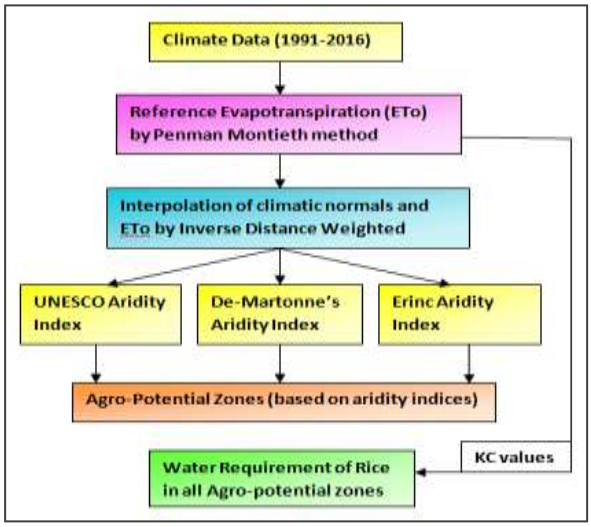

Figure2. Methodology chart of study area

2.2 Reference Evapotranspiration (ETo)

Modified Penman Monteith method is a widely used method by world renowned researchers for calculating reference evapotranspiration. It gives best results in arid and semi-arid type of environment (Rasul and Mahmood, 2009). Assessment of ETo by using climatic parameters (18 weather stations) of rainfall (mm), maximum and minimum temperature (°C), relative humidity (%), wind speed (km/day), sunshine (hours) was done by using CropWAT 8.0 software It is a software based on FAO (Food and Agricultural Organization) computation method of ETo (Piticar et al., 2016). Reference Et was calculated by using equation used by (Allen *et al.*, 1998).

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

Where,

ET_o is the reference evapotranspiration (mm/day); Rn means net radiation at the crop surface (MJ/m^2/day); G is the soil heat flux density (MJ/m^2/day); T is the mean daily air temperature at 2 m height (°C); u2 means wind speed at 2 m height (m/s); es is the saturation vapour pressure (kPa) ; ea is the actual vapour pressure (kPa); es - ea means saturation vapour pressure deficit (kPa); Δ stands for slope vapour pressure curve (kPa/°C) and γ is the psychrometric constant (kPa/°C).

2.3 Interpolation of Meteorological Data

Inverse distance weighted method was used to interpolate climatic normals by using IDW spatial analyst tool in Arc GIS 10.3 software. This method creates a raster surface characterize by similar extent of cells (Childs, 2004) and widely used for climatic parameters. Interpolated data was tested by using Geo-statistical analysis and results presented with 99% accuracy and Root mean square error was -0.00024.

2.4 Aridity Indices

UNESCO Aridity Index

A method of aridity computing is based on ratio of precipitation to reference evapotranspiration proposed by United Nations Educational Scientific and Cultural Organization (1979) and It was calculated by using a very simple equation used by (Dixon et al., 2013).

$$AI = P/ETo \quad (2)$$

Where,
AI stands for Aridity index;
P is the precipitation (mm)
ETo is the reference evapotranspiration (mm)

Table2. Scaling of UNESCO Aridity Index

Climate scaling	AI values	Zone ID
Hyper Arid	< 0.03	1
Arid	0.03-0.2	2
Semi-arid	0.2-0.5	3
Wet Sub-humid	0.5-0.65	4
Humid	>0.65	5

De-Martonne's Aridity Index

This aridity index was anticipated to distribute areas of different moisture characteristics. It was calculated by using equation presented by (de Martonne, 1926).

$$AI = [P/ (T+10) + 12p/ (t+10)]/2 \quad (3)$$

Where,
P stands for average annual rainfall in mm;
T = mean annual temperature (°C);
p= rainfall of the driest month in mm
t = the temperature of the driest month (°C)

Table1. Scaling of De Martonne's Index

Climate scaling	AI values	Zone ID
Arid	< 5	1
Semi-arid	5-12	2
Dry Sub-humid	12-20	3

Wet Sub-humid	20-30	4
Humid	30-60	5
Very Humid	>60	6

Erinc Aridity Index

It is simple aridity index calculated by using very simple parameters. Its scaling limits are same like Thornthwaite's moisture index but parameters are simple. Following equation was adopted by (Erinç, 1996) used for calculating arid classification of study area.

$$Im = P/ Tmax \quad (4)$$

Where,
Im stands for Aridity index; P is the annual precipitation (mm) and Tmax is the maximum annual temperature (°C).

Table3. Scaling of Erinc Index

Climate scaling	Im values	Zone ID
Hyper Arid	< 8	1
Arid	8-15	2
Semi-arid	15-23	3
Wet Sub-humid	23-40	4
Humid	40-55	5
Very Humid	>55	6

2.5 Water Requirement of Rice

After calculation of ETo, Kc values were derived from (available literature of FAO). Crop Et was calculated by using equation adopted by (Allen *et al.*, 1998).

$$ETc/ CWR = ETo * Kc \quad (5)$$

Where,
CWR = crop water requirement
ETo= reference evapotranspiration (mm)
Kc= crop factor

3. Results and Discussion

3.1 Distribution of Aridity Indices

Firstly ETo was calculated by using Eq. (1) in CropWAt 8.0 software. Interpolation maps of Climatic variable were prepared in GIS environment. Further, Aridity indices were calculated by using Eq. (2), (3) and (4) in Map Algebra (Raster calculations) and mapped in Arc GIS 10.3 software. Geographic information system was used to mark the limits of arid zones.

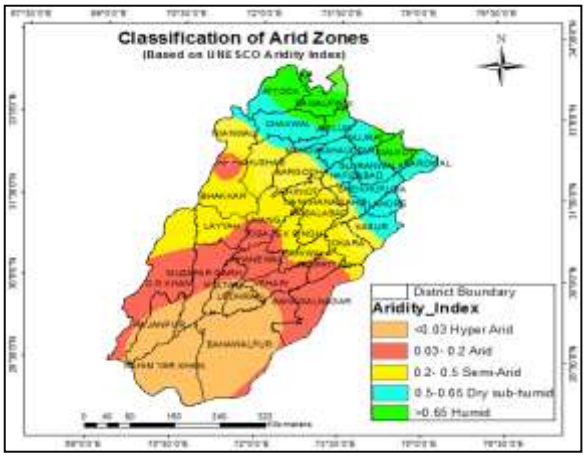

Figure3. Arid zones based on UNESCO aridity index

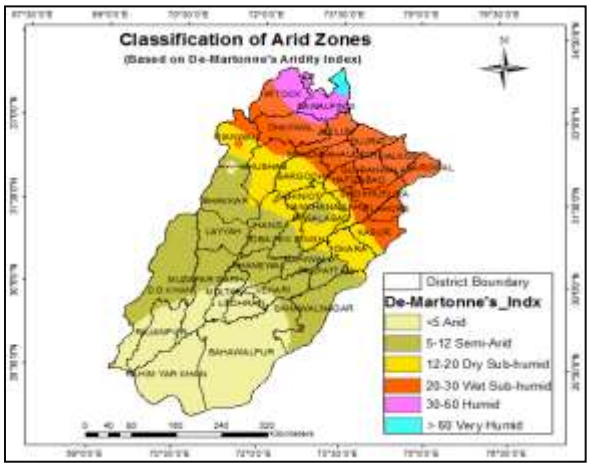

Figure4. Arid zones based on Martonne's aridity index

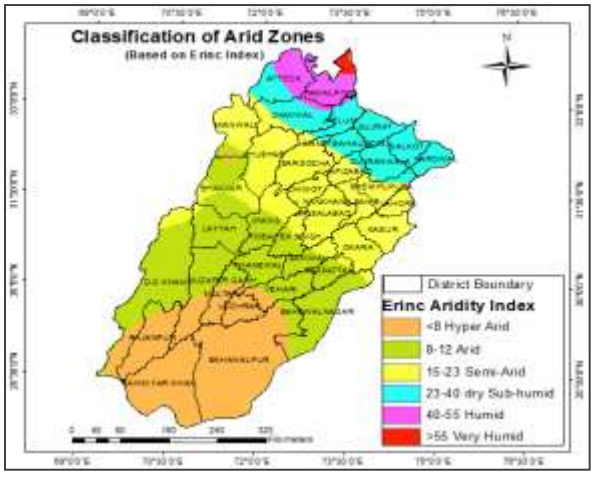

Figure4. Arid zones based on Erinc aridity index

International Journal of Academic and Applied Research (IJAAR)
ISSN: 2000-005X
Vol. 2 Issue 10, October – 2018, Pages:40-45

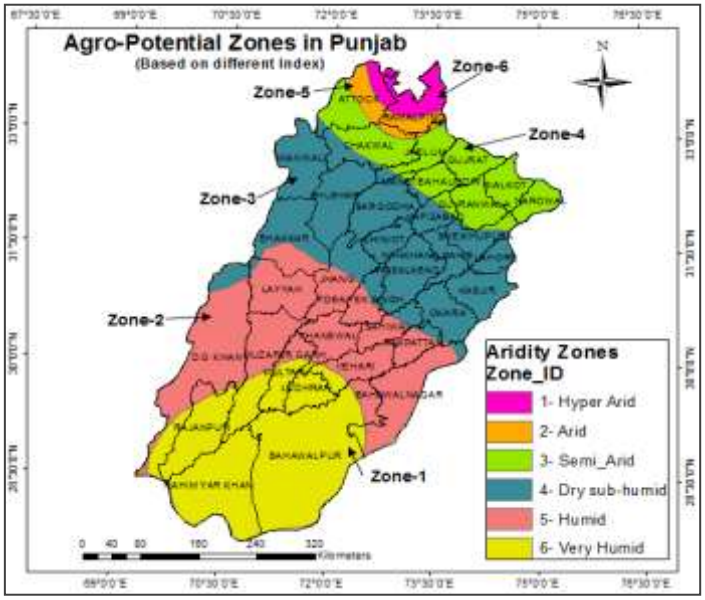

Figure5. Agro-potential zones based on all aridity indices

About six Agro-potential zones having homogenous moisture characteristics were delineated and marked to calculate water requirements of Rice in all zones.

Fig.5. Showing suitable zones having same agro-characteristics. Rice is cultivated almost in all agro-potential zones of Punjab from minor to higher level. Cultivation of rice is critical in zone-1 due to hyper- arid climatic conditions, so it is cultivated on small scale here with more irrigations. In Zone 2 and 3, supplement irrigations are required due to hot and arid conditions. Zone 4 is very ideal for rice cultivation due to available soil moisture, especially Sialkot, Narowal, Gujranwala, Gujrat and Hafizabad districts. Because this zone receives more monsoon rainfall in summer as compared to others. Rice is grown here with slight irrigations. In, Zone 5 and 6 varieties of rice, can be grown in such type of climate are cultivated at very small scale.

3.2 Daily and Monthly Water Requirements

Daily water requirements (mm/day) for Rice crop in all agro-potential zones were calculated by using Eq. (5). And monthly water requirements were calculated as mean over thirty days.

Table4. Daily water requirements of Rice in all agro-potential zones

	Water requirements of Rice (mm/day)						
MONTHS	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Date**
May	4.02	4.01	3.78	3.91	3.79	3.69	15-May-2016
Jun	4.67	4.97	4.83	4.60	4.82	4.30	15-June-2016
July	5.30	5.50	6.16	4.65	4.90	3.96	15-July-2016
Aug	5.07	5.19	4.80	5.01	4.86	3.55	15-Aug-2016
Sep	4.10	5.21	3.52	3.92	3.80	2.96	15-Sep-2016
Oct	2.66	2.37	2.29	2.47	2.45	1.95	15-Oct-2016
Nov	1.37	1.33	1.21	1.18	1.05	0.98	15-Nov-2016

As Table 4. Shows daily water requirement is calculated for every 15th date of the months in millimeters. CWR for rice is high in the zone 1, 2 and 3 in the months of June, July and August. As Table.5.shows supplemented irrigations are required in zone 1 and 2 as CWR varies from 39.9 mm in Nov to 165 mm in July. CWR is high in the months of May, June, July and August due to hot temperature and less rainfall. Even that July and August are the rainiest months in Punjab but due to long sunshine period evaporation becomes high. Seasonal requirement of Rice is 887 mm/year.

Table5. Monthly water requirements in all Agro-potential zones

MONTHS	Water requirements of Rice (mm/month)						
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Optimum CWR (mm)
May	120.6	120.3	113.4	117.3	113.7	110.7	120.6
Jun	140.1	149.1	144.9	138	144.6	129	149.1
July	159	165	184.8	139.5	147	118.8	184.4
Aug	152.1	155.7	144	150.3	145.8	106.5	155.7
Sep	123	156.3	105.6	117.6	114	88.8	156.3
Oct	79.8	71.1	68.7	74.1	73.5	58.5	79.8
Nov	41.1	39.9	36.3	35.4	31.5	29.4	41.1
Annual/ Total	**815.7**	**857.4**	**797.7**	**772.2**	**770.1**	**641.7**	**887**

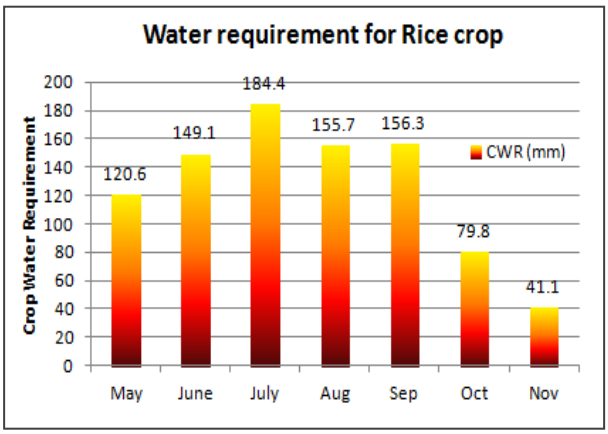

Figure6. Optimum CWR of Rice

Recent study showed slight shift of aridity zones from the study presented by (Haider and Adnan, 2014). The uniqueness of the study to add water requirements of Rice crop in these zones delineated from aridity indices.

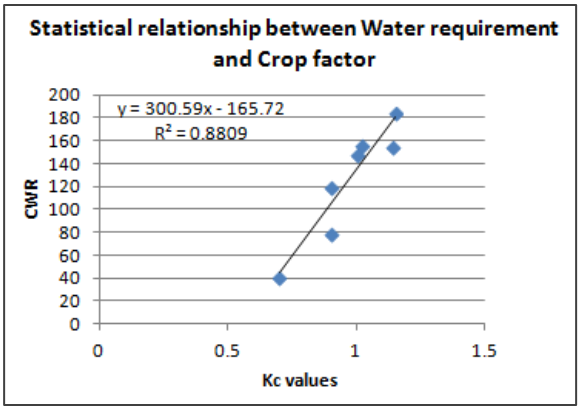

Figure7. Statistical relationship of Kc and CWR

Strong statistical relationship R^2= 0.88 of Kc with water requirement shows water requirement increase at its different stages of growth.

Conclusion

Geographic information system is a best technology for delineating and mapping of spatial variability of aridity over Punjab. ETo is climatic parameter helpful in determining water requirement of crops in arid and semi-arid regions. Aridity indices are best indicator for availability of soil moisture and agro-potential zones based on these indices are helpful in determining variations in water requirement of rice in all zones. This study will be helpful for farmers and field activity planners in irrigation scheduling for rice in all zones at its different stages of growth. Further studies should be occurred by using satellite based moisture indices for other crop.

[1] Afzaal, M., Haroon, M. A., and ul Zaman, Q. (2009). Interdecadal oscillations and the warming trend in the area-weighted annual mean temperature of Pakistan. *Pakistan Journal of Meteorology* **6**.

[2] Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S. A., Khaliq, T., Rasul, F., Saeed, U., Rahman, M. H. u., Hussain, J., and Ahmad Baig, I. (2015). Impact of climate change on the rice–wheat cropping system of Pakistan. *In* "HANDBOOK OF CLIMATE CHANGE AND AGROECOSYSTEMS: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments, Part 2", pp. 219-258. World Scientific.

[3] Allen, R., Pereira, L., Raes, D., and Smith, M. (1998). Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO-Food and Agriculture Organisation of the United Nations, Rome (http://www. fao. org/docrep) ARPAV (2000), La caratterizzazione climatica della Regione Veneto, Quaderni per. *Geophysics* **156**, 178.

[4] Aselmann, I., and Crutzen, P. (1989). Global distribution of natural freshwater wetlands and rice paddies, their net primary productivity, seasonality and possible methane emissions. *Journal of Atmospheric chemistry* **8**, 307-358.

[5] Chaudhry, Q., and Rasul, G. (2004). Agroclimatic classification of Pakistan. *Science Vision* **9**, 59-66.

[6] Childs, C. (2004). Interpolating surfaces in ArcGIS spatial analyst. *ArcUser, July-September* **3235**, 569.

[7] De Martonne, E. (1926). Areisme et indice d'aridite, comptes rendus de L'Academie des Sciences de Paris. 182: 1393-1 398. *English: Regions of Interior Basin Drainage. Geogr. Rev* **17**, 397-414.

[8] Dixon, J. A., James, D. E., and Sherman, P. B. (2013). "Economics of dryland management," Routledge.

[9] Erinç, S. (1996). Klimatoloji ve Metodlari (Climatology and Methods). *Alfa Basim Yayim IV. Basim, Istanbul*.

[10] Haider, S., and Adnan, S. (2014). Classification and assessment of aridity over Pakistan provinces (1960-2009). *International Journal of Environment* **3**, 24-35.

[11] Piticar, A., Mihăilă, D., Lazurca, L. G., Bistricean, P.-I., Puţuntică, A., and Briciu, A.-E. (2016). Spatiotemporal distribution of reference evapotranspiration in the Republic of Moldova. *Theoretical and applied climatology* **124**, 1133-1144.

[12] Rasul, G., and Mahmood, A. (2009). Performance evaluation of different methods for estimation of evapotranspiration in Pakistan's climate. *Pakistan Journal of Meteorology* **5**.

[13] Timsina, J., and Connor, D. J. (2001). Productivity and management of rice–wheat cropping systems: issues and challenges. *Field crops research* **69**, 93-132.

[14] Treydte, K. S., Schleser, G. H., Helle, G., Frank, D. C., Winiger, M., Haug, G. H., and Esper, J. (2006). The twentieth century was the wettest period in northern Pakistan over the past millennium. *Nature* **440**, 1179.