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SEASONAL (KHARIF, RABI AND ZAID) PRECIPITATION, POTENTIAL EVAPOTRANSPIRATION AND ARIDITY INDEX WITH RESPECT TO VARIOUS AGRO ECOLOGICAL ZONES OF INDIA

Laxmi GOPARAJU
goparajulaxmi@yahoo.com

Firoz AHMAD
adfiroz@yahoo.com

VINDHYAN ECOLOGY AND NATURAL HISTORY FOUNDATION, MIRZAPUR, INDIA

ABSTRACT

Climate change has very significant impact on livelihoods and food security. The geospatial technology provides a better understanding of various themes related to climate change. This study examined the seasonal (kharif, rabi and zaid) long term (1970-2000) monthly climatic parameters such as precipitation, potential evapotranspiration over the country of India. The seasonal Aridity Index was computed and analyzed with respect to various agro-ecological zones of India. The analysis of long term mean precipitation (mm) during kharif, rabi and zaid season was found to be in the range of (14-7463), (0-914) and (0-1722) respectively. The analyses of the long term mean potential evapotranspiration in all seasons was found notable high in arid/semiarid zones. The Aridity Index during kharif, rabi and zaid seasons was found to be in the range of (0.19-4.27), (0.03-0.73) and (0.01-1.48) respectively. The seasonal Aridity Index in some of the agro-ecological zones of the central India in the arid and semiarid regions was found to be notably low. A concrete plan with synergic approach including integrated watershed management and traditional ecological practices will help to fulfill crop water demand and maintain adequate soil moisture for the present and future crops.

KEYWORDS:

Remote sensing/GIS, precipitation, potential evapotranspiration, aridity index, agro ecological zones, India.

1. Introduction

Climate change and associated risk have significant direct/indirect impact on crop production and food security (Reynolds et al. 2018) and a big challenge for the scientists/researchers/policymakers. The geospatial technology and recent free online weather data sets provide great scope

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which offer tangible solutions in term of resilience to farmers/cultivators (Jimenez & Ramirez-Villegas, 2018). The seasonal/ monthly precipitation patterns in India were studied by several researchers (Mooley & Parthasarathy, 1983, 1984; Guhathakurta & Rajeevan, 2008) and their variations impacts the food grain production (Srinivasa Rao et al. 2016). The potential evapotranspiration (PET) is the amount of transfer of water to the atmosphere from land surfaces by evaporation (e.g. from the soil and plant canopy) and via plant transpiration which increases during the summer season due to increase in temperature/solar radiation. The aridity is evaluated by comparing the long-term average of water supply or precipitation to the long-term average of climatic water demand (known as potential evapotranspiration) and an indicator of long-term seasonal climatic water deficits (European Commission, 2018).

The agriculture crops and their growths vary significantly due to seasonal soil moisture and aridity (Spinoni et al. 2015; Salem, 1989). The cultivated agriculture crops during these seasons (kharif, rabi and zaid) varies in water need (supply/demand) across regions (Stefan & Zhao, 2014; Ashaolu & Iroye, 2018) due to seasonal change in precipitation and potential evapotranspiration. Such evaluation highlights the need of adequate strategies/ planning for the water conservation for seasonal rainfall/precipitation which is found surplus during the monsoon season and can be used for subsequent dry months. Such arrangement can meet the crop soil moisture demand and boost agricultural production significantly (Killeen & Solorzano, 2008). The aim of this paper is to investigate the seasonal (kharif, rabi and zaid) long term (1970-2000) monthly climatic parameters such as precipitation, potential evapotranspiration over the country of India and examine the aridity index (AI) (UNESCO, 1979) with respect to various agro ecological zones of India in GIS environment for better understanding of climate-resilience practices against the climate-related risk.

2. Materials and methods

2.1. The study area

The study area includes the entire land area of India (excluding islands). The geoponic practices are quite common among the rural people and support the livelihood/food chain supply to the majority of people of India. The climate stress in term of variation of precipitation, temperature, and drought are quite common these days in India which impact the agriculture, environmental and social sustainability.

2.2. Data acquisition and processing

Here we have systematically evaluated the precipitation and potential evapotranspiration data for kharif (June to October), rabi (November to February) and zaid (March to May) seasons which are strong parameters delicately linked to seasonal crop water supply/demand (Zhao & Siebert, 2015). These data were used to determine the Aridity Index (UNESCO, 1979) in different agro-ecological zones of India which are highly important to boost agriculture/agroforestry production.

Mean monthly (1970-2000) precipitation, data was with spatial resolutions of 30 seconds (~1 km^2) was downloaded (http://worldclim.org/version2) for every 12 months (Fick and Hijmans, 2017). Similarly, the Mean monthly (1970-2000) potential evapotranspiration (PET) dataset also have the same spatial resolution of precipitation was also be downloaded (Trabucco & Zomer, 2019) for 12 months. The potential-evapotranspiration was calculated based on the Penman-Monteith Evapotranspiration equation (Trabucco & Zomer, 2019).

The monthly data sets such as precipitation and potential evapotranspiration were arranged based on kharif, rabi and zaid season in GIS domain using ARC/GIS software (Version 10.1). The sub-module such as map algebra/zonal of Spatial

Analyst toolsets were used significantly for making it seasonal clusters. The vector files of agro-ecosystem of India (Bandyopadhyay et al., 2009) were brought in the GIS domain (Ahmad et al., 2018). The precipitation and potential evapotranspiration data were brought in vector file. The Aridity Index of kharif, rabi and zaid season were calculated based on the ratio of the mean precipitation value to mean potential evapotranspiration value. The above-mentioned data were analyzed and their spatial pattern was examined with GIS queries which give a better understanding of the climate (precipitation, potential evapotranspiration, and AI) distribution pattern of India.

3. Result and discussion

The agriculture/forest/agroforestry practices are vital for our life because they satisfy the social, environmental, economic goals and vary significantly in term of distribution pattern with the variation in topography/temperature/precipitation pattern. Agro-ecological zones of India are steered by inter-related geographic factors such as climate/soil/physiographic environment which manifested in term of the diversity of agriculture/forest/trees/livestock dominance (Balasubramanian 2013). The agro-ecological zones of India used here are delineated based on the growing period as integrated criteria of effective rainfall, soil groups, with twenty major agro-ecological zones (Bandyopadhyay et al. 2009). These various agro-ecological zones and their seasonal (kharif, rabi and zaid) changes of precipitation, potential evaporation and aridity index are important for farmers/cultivators for better understanding of existing/future water requirements for crops in achieving sustainability due to climate change impact.

3.1. Precipitation pattern analysis

The various crops/trees activity practiced by farmers/cultivators of India is delicately connected to seasonal precipitation distribution pattern. Their variation impacts the crops due to water supply/demand which is essential for their metabolic activity and growth. The long term (1970-2000) seasonal (kharif, rabi and zaid) precipitation maps produced were given in Figure no. 1-3 which shows huge spatial variation. The agro-ecosystem zones wise mean precipitation and potential evaporation were also computed which are given in Table no. 1.

Table no. 1

The long term (1970-2000) mean of precipitation and potential evapotranspiration in various agro ecological zones of India

Agro-ecological region of India	Kharif season		Rabi season		Zaid season	
	Mean precipitation (mm)	Mean potential evaporation (mm)	Mean precipitation (mm)	Mean potential evaporation (mm)	Mean precipitation (mm)	Mean potential evaporation (mm)
1. Western Himalayas (Cold region)	114.132	599.136	28.9338	155.209	40.2536	219.52
2.Western Plain and Kachchh Peninsula	334.797	1052.76	13.699	542.574	13.4297	762.983
3. Deccan Plateau (Hot Arid)	459.707	804.53	38.5279	631.455	94.1505	699.554
4. Northern Plain and Central Highlands	708.651	897.121	31.8918	483.791	18.91	735.388
5. Central Malwa Highlands and Kathiawar Peninsula	845.276	882.471	16.5426	614.128	10.0021	806.496
6. Deccan Plateau	820.005	823.031	33.4526	630.168	55.3653	772.58

Agro-ecological region of India	Kharif season		Rabi season		Zaid season	
	Mean precipitation (mm)	Mean potential evaporation (mm)	Mean precipitation (mm)	Mean potential evaporation (mm)	Mean precipitation (mm)	Mean potential evaporation (mm)
(Hot semi-arid region)						
7. Deccan (Telengana) Plateau and Eastern Ghats	697.727	851.495	56.0726	586.399	65.0886	720.676
8. Eastern Ghats (Tamil Nadu Uplands) and Deccan Plateau (Karnataka)	497.255	837.612	188.255	572.174	131.495	625.84
9. Northern Plain	922.842	800.803	56.7331	425.608	37.2198	682.776
10. Central Highlands (Malwas and Budelkhand)	1093.29	835.155	37.5005	546.937	18.946	795.941
11. Deccan Plateau and Central Highlands (Budelkhand)	1104.86	780.706	45.1777	512.374	33.6588	751.201
12. Eastern Plateau (Chhattisgarh)	1203.92	726.774	40.1126	495.65	50.8245	728.511
13. Eastern (Chotanagpur) Plateau and Eastern Ghats	1250.64	720.35	48.3215	511.061	100.49	687.941
14. Eastern Plain	1109.43	740.328	36.8407	427.523	64.9269	647.474
15. Western Himalayas	670.257	690.232	185.165	253.86	179.245	385.11
16. Bengal and Assam plains	1698.69	643.4559	85.1064	427.8565	566.863	495.651
17. Eastern Himalayas	1360.03	547.1575	66.7246	325.1055	307.885	362.839
18. North Eastern Hills (Purvanchal)	1980.44	582.778	90.2862	397.886	504.714	450.916
19. Eastern Coastal Plain	910.384	816.267	199.854	540.917	93.4074	612.796
20. Western Ghats and Coastal Plain	2792.01	653.736	113.42	605.255	201.637	582.013

The analysis of long term mean precipitation (mm) during kharif, rabi and zaid season in India was found to be in the range of (14-7463), (0-914) and (0-1722) respectively. The evaluation of long term mean precipitation with respect of various agro-ecological zone during kharif season was found highest (2792 mm) in the categories of “Western Ghats and Coastal Plain” followed by “North Eastern Hills (Purvanchal): 1980 mm”, “Bengal and Assam plains: 1699 mm” (Table no. 1). The lowest was found in category of “Western Himalayas (Cold region): 114 mm) during the same base season. Similarly, during the rabi season the mean precipitation (mm) were found significantly high in the categories of “Eastern Coastal Plain: 200 mm”, “Eastern Ghats (Tamil Nadu Uplands) and Deccan Plateau (Karnataka):188 mm” and “Western Himalayas: 185 mm”. During the zaid season the mean precipitation (mm) were found significantly high in the categories of “Bengal and Assam plains: 567 mm”, “North Eastern Hills (Purvanchal): 505 mm” and “Eastern Himalayas: 308 mm”. A similar observation was found by Rajeevan et al. 2012 and Birthal et al. 2014.

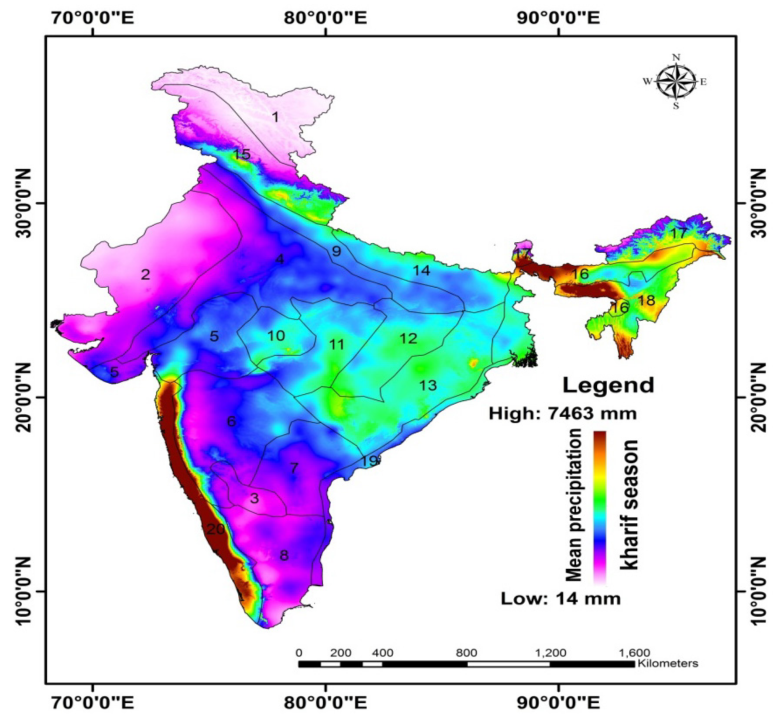

Figure no. 1. Mean long-term (1970-2000) kharif season precipitation overlaid by agro ecological zone of India

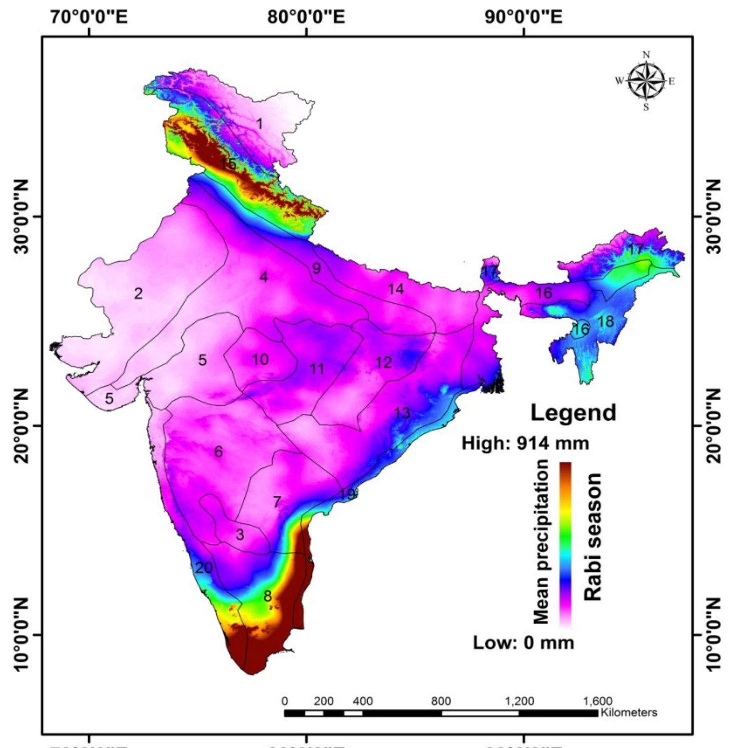

Figure no. 2. Mean long-term (1970-2000) rabi season precipitation overlaid by agro ecological zone of India

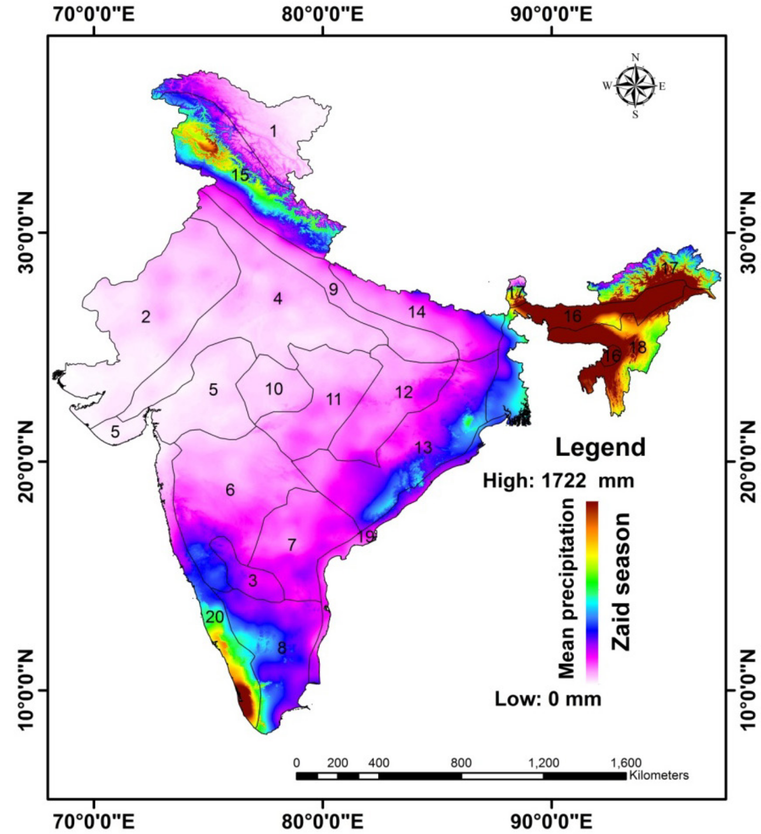

Figure no. 3. Mean long-term (1970-2000) zaid season precipitation overlaid by agro ecological zone of India

3.2. Potential evapotranspiration pattern analysis

The seasonal potential evapotranspiration and their variability play a crucial role which influence the hydrological arrangement thus impact the vegetation health including seasonal crops water demand (Liu et al., 2015). The evaluations significantly help in various applications including irrigation management and in climate change impacts (Lang et al., 2017). The long-term (1970-2000) PET maps were generated for kharif, rabi and zaid seasons of India were given in Figure 4-6. The long-term PET pattern in all three seasons are found more pronounce and significantly high in various agro eco region of arid and semi-arid regions of India. These regions are significantly high climate severity/ limitations (Tewari et al., 2014). The analysis of long term mean PET (mm) during kharif, rabi and zaid season in India are found to be in the range of (34-1291), (11-742) and (6-903) respectively. The investigation of long term mean PET with respect of various agro-ecological zone during kharif season is found to be highest (1053 mm) in the categories of "Western Plain and Kachchh Peninsula" followed by "Northern Plain and Central Highlands: 897 mm", "Deccan (Telengana) Plateau and Eastern Ghats: 852 mm" (Table no. 1). The analysis revealed all arid zones shows high mean PET in all seasons whereas the agro ecological zone category "Deccan Plateau (Hot Arid)" is the only category retain the highest mean PET > 600 mm in all three seasons (Table no. 1).

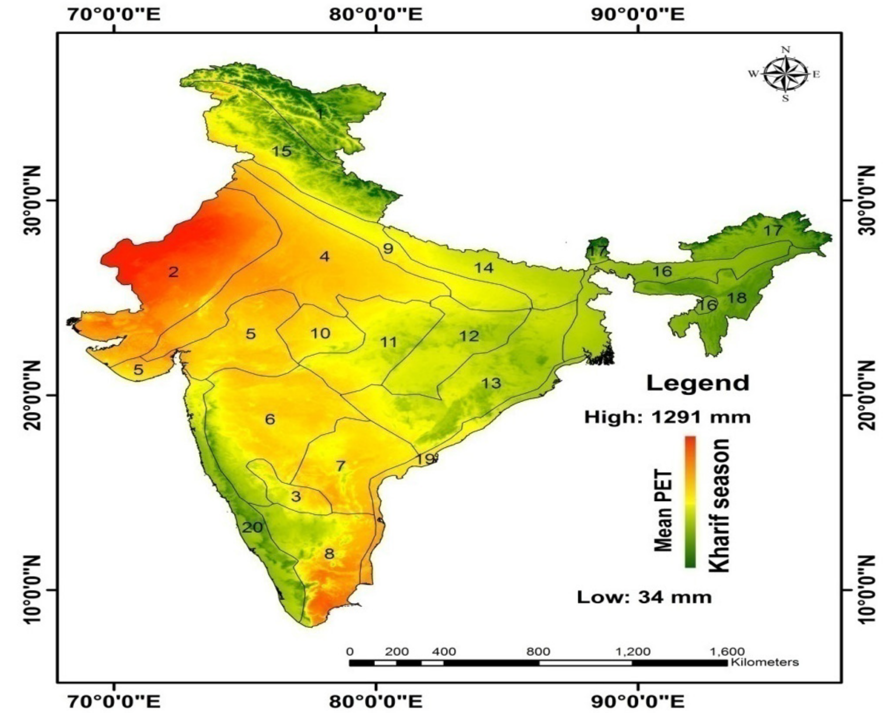

Figure no. 4. Mean long-term (1970-2000) kharif season potential evapotranspiration overlaid by agro ecological zone of India

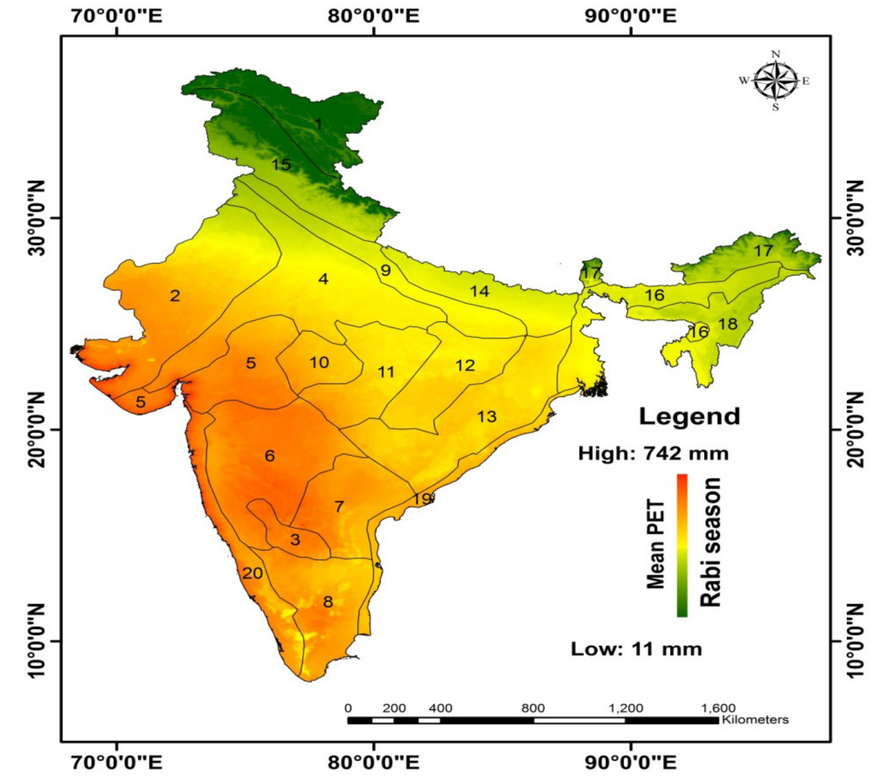

Figure no. 5. Mean long-term (1970-2000) rabi season potential evapotranspiration overlaid by agro ecological zone of India

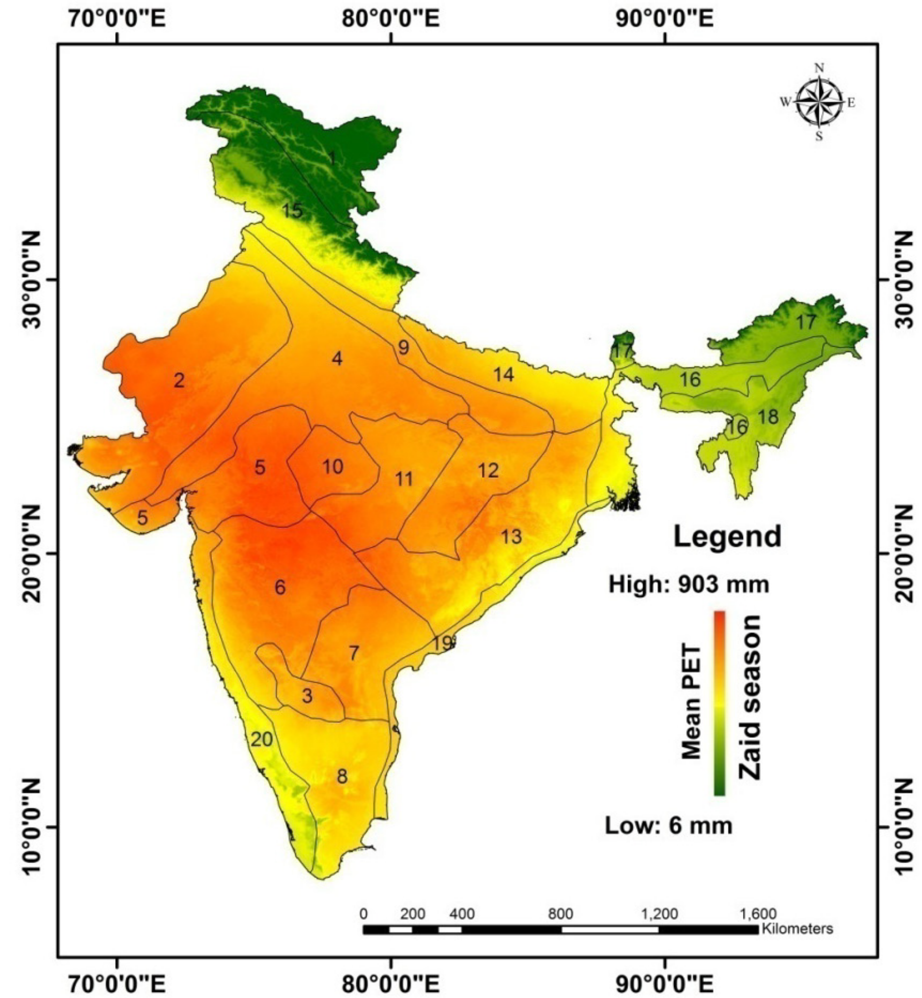

Figure no. 6. Mean long-term (1970-2000) zaid season potential evapotranspiration overlaid by agro ecological zone of India

3.3. Aridity index pattern analysis

Aridity indexes are quantitative measure of the degree of water shortage and are very usually related to distributions of natural vegetation and crops (Stephen, 2005). In this computation, we have used the aridity index formula (ratio of precipitation to potential evapotranspiration) (UNESCO, 1979) which is globally documented (Maliva & Missimer, 2012; Trabucco & Zomer, 2019). The AI for the seasons (kharif, rabi and zaid) were analyzed with respect to 20 agro ecological zones of India are given in Figure no. 7-9. The two zones categories 16 and 17 are found in two geographical locations were analyzed separately (for AI). In the present study, we have addressed one the critical research gaps such as seasonal evaluations of AI with respect to agro ecological zones of India. These analyses significantly help in geoponic sustainability as an adaptation to climate change (Zomer et al., 2007, 2008).

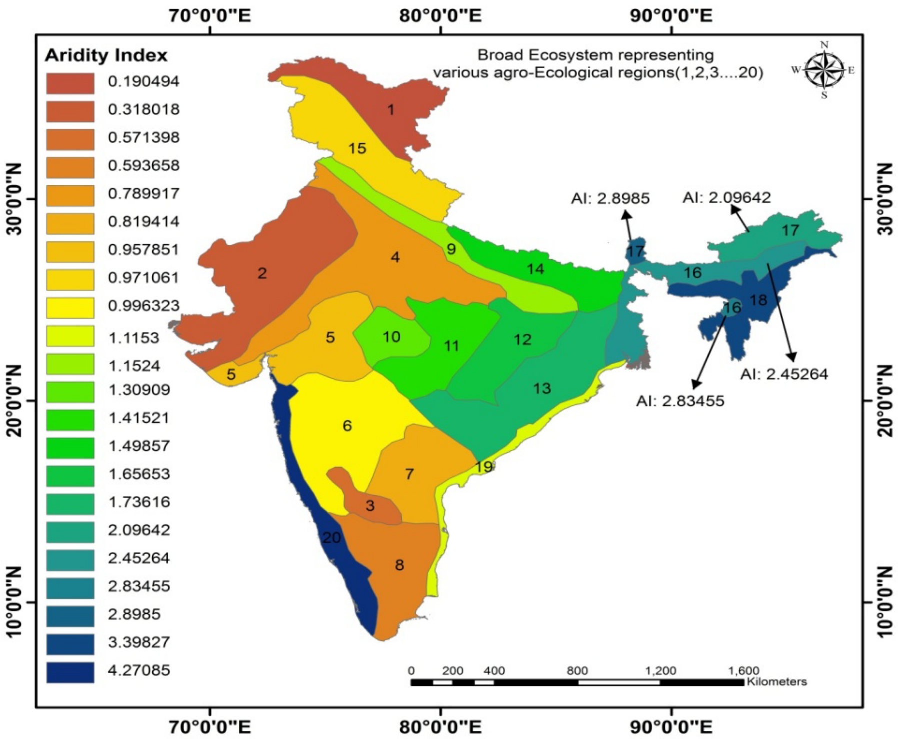

Figure no. 7. Aridity Index of various agro ecological zones in kharif season of India

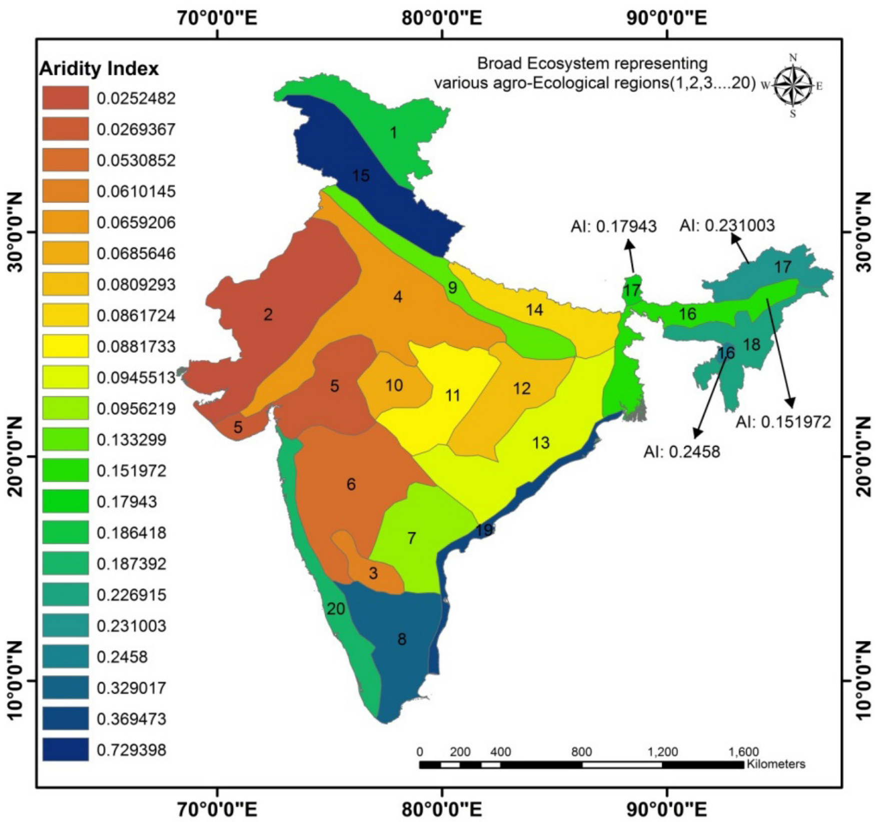

Figure no. 8. Aridity Index of various agro ecological zones in rabi season of India

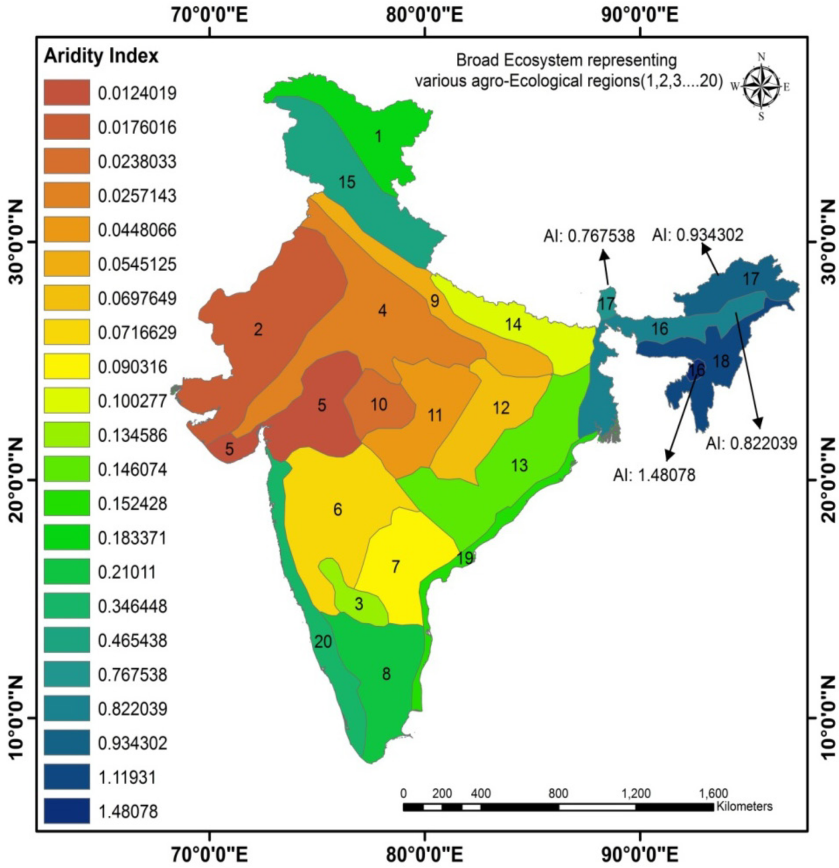

Figure no. 9. Aridity Index of various agro ecological zones in zaid season of India

The higher values AI manifest more humid condition whereas the lowest value for more xeric condition (Zomer et al., 2008). The AI during kharif, rabi and zaid seasons in India are found to be in the range of (0.19-4.27), (0.03-0.73) and (0.01-1.48) respectively (Figure no. 7-9). The AI greater than 1 during kharif season is found in 11 agro ecological regions (Figure no. 7). These zones during the kharif season have significantly high soil moisture and largely utilized for rice cultivation. The AI during rabi season are found significantly low in major of the agro ecological zones except the categories "Western Himalayas", "Eastern Coastal Plain" and "Eastern Ghats (Tamil Nadu Uplands) and Deccan Plateau (Karnataka)". The majority of these areas where the AI is found significantly high are due to adequate precipitation during returning northeast monsoon (Rajeevan et al., 2012). In the category "Western Himalayas" the AI during the rabi season was found to be highest because of the significantly low potential evapotranspiration specially due to low temperature occurrence in hilly/mountain tracks of Himalayas (Figure no. 8 and Table no. 1). The majority of the central Indian agro ecological zones showed low AI during the zaid season due to high stress of weather severity in terms of high temperature, potential evapotranspiration (Figure no. 6) and low precipitation (Figure no. 3). The rise of mean annual temperature was found to be very significant these days which continuously magnifies the drying phenomenon (Ramachandran et al., 2015). Such phenomenon increases the seasonal PET and decrease the aridity index significantly which leads to more water crop demand. It was also observed that several agro ecological zones receive adequate precipitation during the kharif season (Figure no. 1). These zones can be utilized for water conservation practices at watershed level which will help significantly to support crop water demand and maintain adequate soil moisture. Such action will boost the agriculture crop production in present climate change scenario (Wani et al., 2003). The seasonal AI in some of the agro ecosystem zones of the central India such as the states Andhra Pradesh, Telangana, Karnataka and Madhya Pradesh in the arid and semiarid regions were found notably low and well known for farmer's suicide hot spot (Carleton, 2017). These areas are also suffering from poverty (Lewis, 2013). There is a need develop a concrete plan with synergic approach which includes integrated watershed management strategies with traditional ecological practices for achieving long-term sustainable goals (Goparaju & Ahmad, 2019; James et al., 2018).

4. Conclusion

In the present study, we have used long term (1970-2000) datasets such as seasonal precipitation, potential evapotranspiration of India. Furthermore, we have compiled the seasonal AI to address one of the critical research gaps with respect to various agro ecological zones of India. In our study, we found several agro ecological zones of India which receive adequate precipitation during kharif season and manifested with low aridity index in the rabi and the zaid season. These agro ecological zones with low AI need to be addressed by synergic approach/strategies of rainwater conservation at the watershed level with suitable technologies (Sivanappan). Such measures/approach with integrated watershed management will enhance the soil moisture to support adequately various agriculture/agroforestry/horticulture crops at regional level (Ahmad & Goparaju, 2017). These types of practices when integrated with various ancillary data sets of various agro ecosystem zones will improve the farmers/cultivators socio economic condition and support significantly as an adaptation of climate change. Furthermore, the evaluation of present study highlights the need of synergic approaches/strategies especially in arid and semi-arid regions to mitigate the climate change impact on farmer's suicidal hotspot as long term goal to obtain sustainability in food security, enhancing the livelihood and magnifying the farm household (Goparaju & Ahmad, 2019). The potentialities of geospatial technology have the enormous capability and will support significantly when integrated with *in situ* ancillary datasets to address the cultivator's issues.

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