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Research Article

Fuzzy comparison of drought vulnerability based on the analytical hierarchy process

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ABSTRACT

The vulnerability represents the level to which any ecosystem experiences impairment due to natural distress. One such distress is drought, a prolonged phase of deficient rainfall that causes the depletion of water resources. The possibility of the influences of drought principally depends on the vulnerability of the affected area. The predominantly arid climate of Pakistan and the dependence of its economy on agriculture make it vulnerable to climate change. Rahim Yar Khan and Tharparkar have similar environmental conditions, but Tharparkar experiences more droughts. Vulnerability factors observed by the two districts among the regions are different even with similar climate conditions. The system vulnerability to drought was observed for two districts by using the analytical hierarchy process (AHP) and drought vulnerability index (DVI). The drought vulnerability index (DVI) was used to assess the meteorological, agricultural, hydrological, and socio-economic indicators to build the hierarchy for these inconsistence factors and evaluate the most vulnerable and affecting cause among the meteorological, agricultural, hydrological, and socio-economic indicators. The selected measures specify the hypotheses and the relativity of the indicators to the overall vulnerability of the system. The evaluated weights for each variable are derived from the analytical hierarchy process by comparing the variables of the selected indicators. Due to different meteorological, agricultural, and socio-economic conditions, the weights for the DVI were not the same in both study districts, i.e., Rahim Yar Khan and Tharparkar. The classification of vulnerability depending upon the drought vulnerability index with AHP suggests that the DV indexation is favorable in assessing the regional drought vulnerability. The drought vulnerability assessment of Tharparkar indicates that Tharparkar is highly vulnerable to drought, i.e., DVI = 0.066, as it is highly dependent on irrigation resources for its agriculture and livestock. The unavailability of hydrological resources has increased the drought vulnerability of the Tharparkar, which corresponds to a high level of agricultural damage due to droughts. However, the district of Rahim Yar Khan with developed irrigation resources has a lower drought vulnerability index (DVI = 0.011). It is necessary for Tharparkar to establish countermeasures to mitigate the drought vulnerability through the development of water resources. Future studies are needed to be focused on more indicators for assessing particular drought vulnerability issues in order to reduce the drought vulnerability of Tharparkar.

Keywords: Analytical hierarchy; drought; classification; vulnerability; Rahim Yar Khan; Tharparkar.

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INTRODUCTION

Climate change is a significant variance in the statistical distribution of weather, which could induce a natural ecological threat influenced by the total GHG emissions in the atmosphere (Abbas et al., 2022; Reinhardt and Gosney, 2015; Tigkas et al., 2012).

Drought is an insidious (Hao & Singh, 2015), reoccurring (Qu et al., 2022), creepy natural hazard (Zarafshani et al., 2012), slow-onset (Vyas et al., 2015), and multi-dimensional regional phenomenon that is affecting wide areas and causing physical and socio-economic damage (Arouri et al., 2015). The intensity of the drought depends on the incidence, duration, exposures, and vulnerabilities of the population of a region (Leng et al., 2015; Hao et al., 2015). Global climate change and its impacts initiated the concept of drought vulnerability assessment to investigate and improve the climate change management, preparedness, and mitigation processes of an ecosystem (Gutiérrez et al., 2014; Dong et al., 2015). The vulnerability can be analyzed by demographic characteristics, agro-meteorological facilities, water use, land use, economic policies, and socio-economic behavior investigations (Malik et al., 2012; Singh et al., 2014; Farhangfar et al., 2015; Dong et al., 2015). Pakistan lies in a geographical region among longitudes 61° and 76° E and latitudes 24° and 37° N, primarily vulnerable to and influenced by global climate variability (Anjum et al., 2012; Rasul et al., 2012). According to the World Bank and the Asian Development Bank (ADB), Pakistan is classified as a red zone of inadequacy and a stressed country because of a decrease in groundwater, limited water storage in dams, no formalized drought vulnerability assessments, and no networks for monitoring and evaluating associated vulnerability indicators (Gutiérrez et al., 2014; Abid et al., 2016). Droughts have been observed every year in Tharparkar and southern Punjab due to low rains in the monsoon season. Tharparkar and Rahim Yar Khan districts are neighboring districts with similar climatic and physiographic characteristics, but more frequent drought spells have been witnessed in the history of Tharparkar as compared to Rahim Yar Khan (Anjum et al., 2012; Malik et al., 2012; Khan et al., 2015). The drought vulnerability assessment can be made by quantitatively evaluating a wide range of fuzzy and decision-making methods for drought preparedness and mitigation (Cheng et al., 2010). The drought vulnerability index (DVI) for a specific region is quantitatively evaluated using the analytical hierarchy process based on the nature and objective of the problem. The combination of the analytical hierarchy process (AHP), consistency test, fuzzy classification of drought vulnerability, and the drought vulnerability index allowed the study to evaluate the most vulnerable indicator to mitigate (Saha et al., 2021). The drought distribution of DVI agreed with the AHP, suggesting that DVI is a successful method for assessing regional drought vulnerability (Wu et al., 2013; Kim et al., 2015). Hence, the respective study has been designed to evaluate the vulnerability to drought of two districts, Rahim Yar Khan and Tharparkar, by comparing agricultural, hydrological, meteorological, and infrastructural variables using the analytical hierarchy process (AHP) and fuzzy classification of the drought vulnerability index for each criteria used in the AHP.

Rahim Yar Khan partially depends upon monsoon rainfall for its irrigation of agriculture, but the dependency of Tharparkar for its annual irrigation totally depends upon the monsoon rainfall (Anjum et al., 2012; Rasul et al., 2012). Hence, the mitigation of meteorological variability was selected as criteria for the study of districts Rahim Yar Khan and Tharparkar, as both districts face climate variability each year. The agriculture system needs favorable irrigation facilities for good production and yield; hence, it is necessary to investigate the hydrological resources of the region to assess the drought vulnerability. Therefore, the presence and availability of the hydrological resources selected as the criteria of selection for the hydrological indicators to assess the drought vulnerability.

MATERIALS AND METHODS

The drought vulnerability assessment in the current study encompasses the meteorological, agricultural, hydrological, and socioeconomic indicators in the system to assess the drought vulnerability of two districts, i.e., Rahim Yar Khan and Tharparkar. Figures 2 and 3 show the geographical representation of the study area. The socio-economic vulnerability was assessed by population details, education level, and the health unit providing medical facilities to the population of both districts in Rahim Yar Khan and Tharparkar. Figure (5) and (6) show the population details, i.e., male and female population, population density, and sex ratio, for each taluka in the districts of Rahim Yar Khan and Tharparkar. Figure (4) shows the health units providing the medical facilities in both the districts of Rahim Yar Khan and Tharparkar.

Variables for Drought Vulnerability by Analytical Hierarchy Process (AHP)

The study has compared the agricultural, meteorological, and infrastructure indicators to create the criteria as mitigation to meteorological variability, agricultural support systems for food security, availability of hydrological resources in a given district, and availability of socioeconomic aid to the common community, respectively. These indicators contain variables for comparison and to construct the hierarchy in the process. Mitigation to metrological vulnerability criteria include two variables: temperature and rainfall; agricultural support system for food security criteria include three variables: irrigated and unirrigated fodder area; cropping intensity of cultivated area; and equipment use for agriculture

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purposes; availability of hydrological resources criteria includes two variables: canal irrigation area and barani irrigation area. Socioeconomic vulnerability criteria include two variables: the availability of credits or insurance to farmers for agricultural production and the education level in districts. Variables from each criteria were compared to form the pair-wise matrix and the nth root, i.e., the 9th root, of the row product of the matrix. The weights were calculated by dividing the individual value of the 9th root by the sum of all the 9^{th} root values.

$w = ith\ value\ of nth\ root/\Sigma\ nth\ root$ (Torfi et al., 2010)

In order to normalize the matrix to a vector quantity, the eigenvectors (A) were calculated by using the multiplication of the matrix rule (Row × Column) of the pair-wise composite matrix. For the pair-wise comparison, the eigenvectors (A) were calculated by multiplying 1 row by the weights column, 2 rows by the weights column, and so on. The value of Wmax was calculated by using the product of the eigenvector and weights formula used in the analytical hierarchy process (A/W = λ_{max} ω). The mean λ_{max} value was required to apply the consistency test to calculate the values of CI and CR.

$\lambda max = \Sigma w \lambda max/No.of\ of variables\ in\ pairwise\ comparison\ matrix$

(Cheng et al., 2010)

$Consistency\ Index\ (CI) = (\lambda max - n)/(n-1)$ (Cheng et al., 2010)

$Consistency\ Ratio\ (CR) = CI/RI$ (Cheng et al., 2010)

The value of CR was used for the test assessment of the consistency of each given criteria; CR > 0.1 shows that the results are at the perimeter of consistency. However, CRs< 0.9 have to be accepted but CR as high than 0.9 will refer that the pairwise judgements are random and are completely untrustworthy (Saaty, 1987).

Drought Vulnerability Index (DVI)

The mathematically processed weights for each criteria were subjected to the drought vulnerability index. The drought vulnerability index (DVI) was calculated as (Leurs et al., 2003);

Where, DVI = Drought Vulnerability Index,

Wi = Weights of variables indicating drought vulnerability,

k = Upper limit of variable weights,

N = Number of variables constituting the vulnerability index.

The indexed value of each district was then processed by the allocation of the categorized classes of vulnerability (Brooks et al., 2005; Metzger et al., 2005; Wu et al., 2013; Kim et al., 2015). The districts were classified according to the DVI into four classes. That is, “slightly vulnerable” indicates that the DVI is between 0 and 0.01, “moderate vulnerable” between 0.01 and 0.02, “high vulnerable” between 0.02 and 0.04, and “severely vulnerable” values above 0.06.

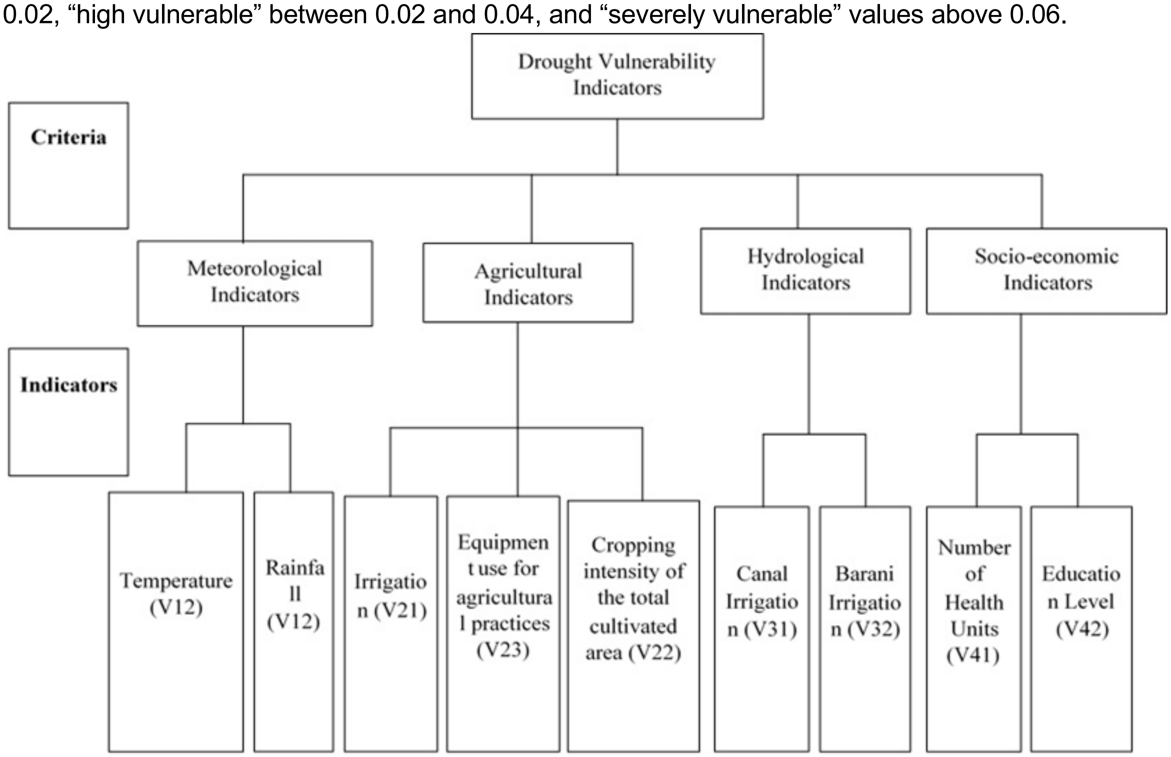

Figure 1. Hierarchy flowchart of indicators and variables used in the study.

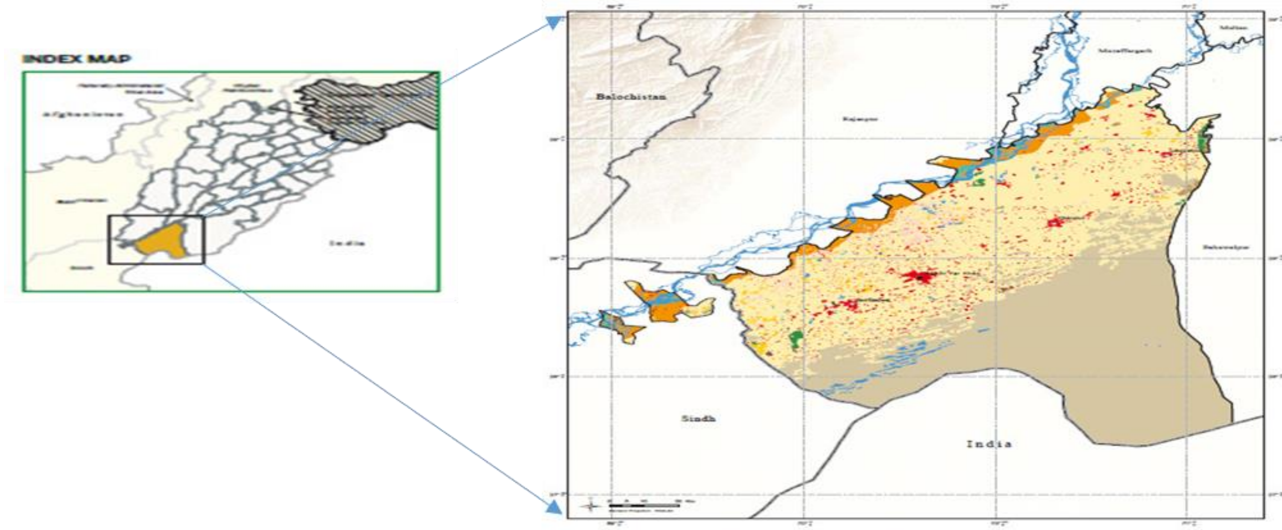

Figure 2. Land cover map of Rahim Yar Khan district.

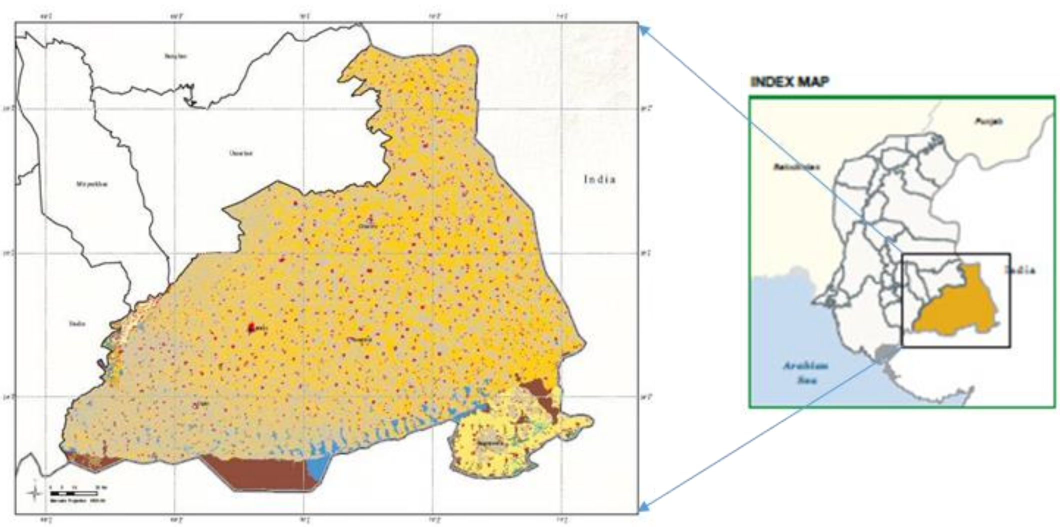

Figure 1. Land cover map of Tharparkar district.

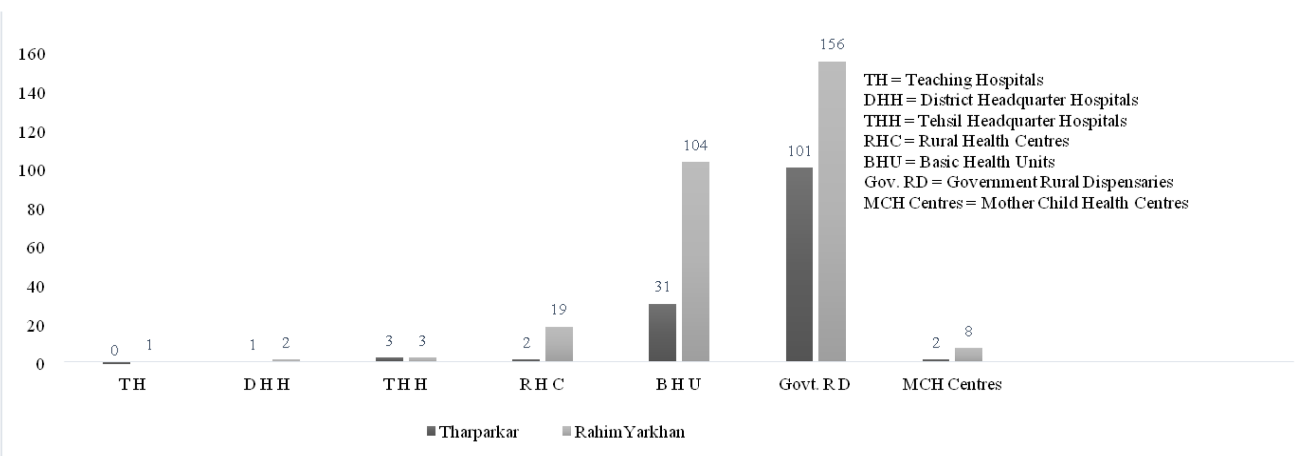

Figure 4. Number of health units of district Rahim Yar Khan and Tharparkar.

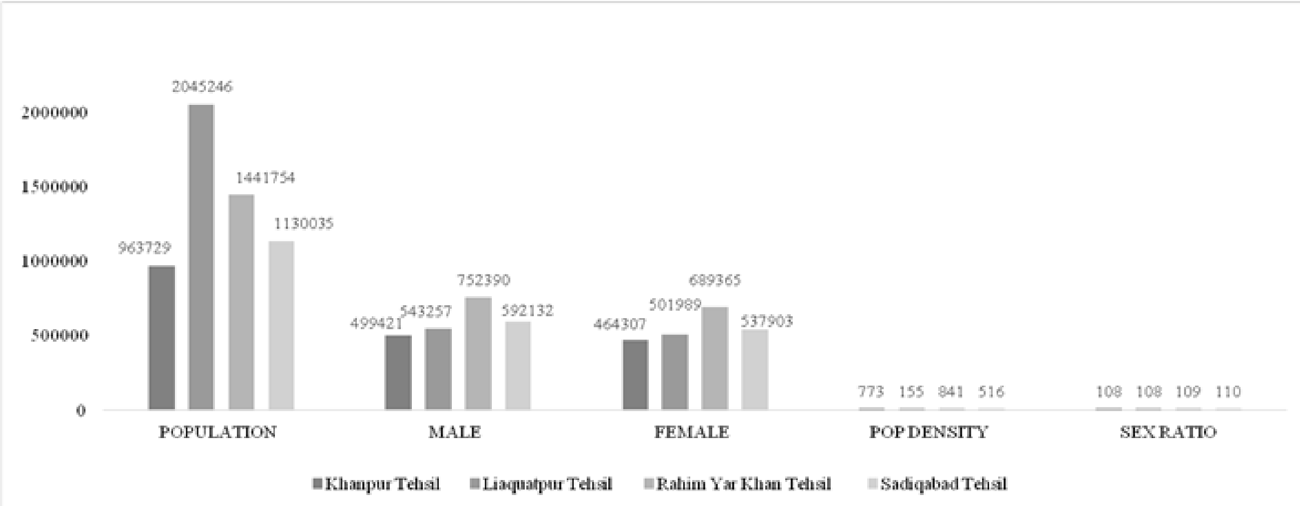

Figure 5. Population details by each Taluka of Rahim Yar Khan.

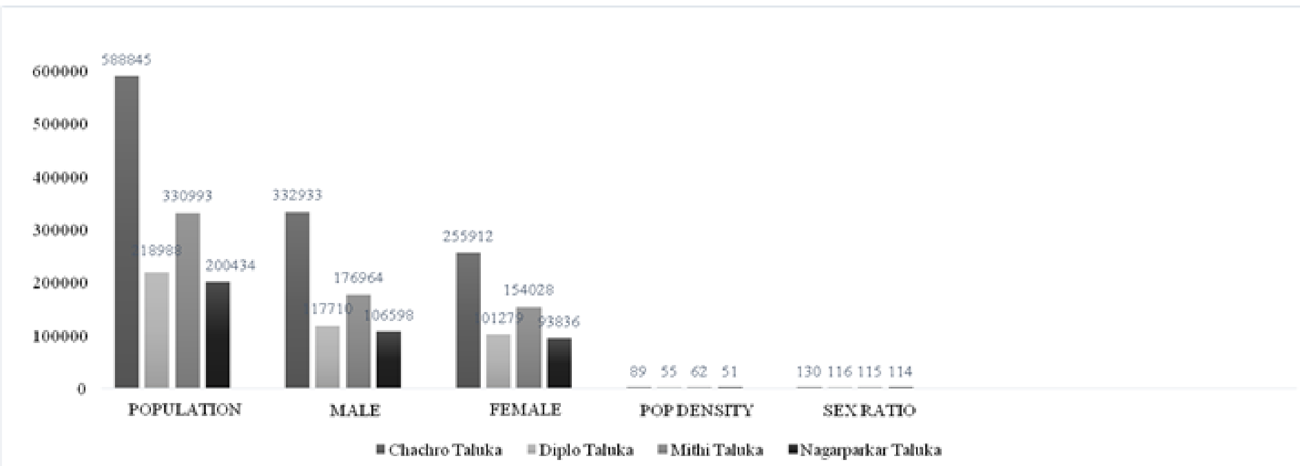

Figure 6. Population details by each Taluka of Tharparkar.

RESULTS

Analytical Hierarchy Process and Weights

We have compared the variables of four indicators to construct the pair-wise comparison matrix and the consistency test of the analytical hierarchy process for districts Rahim Yar Khan and Tharparkar. The selected variables from the four criteria mentioned in the methods are compared to each other on the respective criteria preference scale. The weights for the meteorological variables have similar values of 0.12, representing their equal significance in the criteria. The climate change will equally affect the temperature and rainfall pattern of the district. All the variables in the given criteria show similarity in weights, which represents their relativity in a pair-wise matrix. The weights for both meteorological variables have similar values of 0.12, representing their equal significance in the criteria. The climate change will equally affect the temperature and rainfall pattern of the district. All the variables in the given criteria show similarity in weights, which represents their relativity in a pair-wise matrix. Tables 1 and 2 show the pair-wise comparison matrix and the consistency test of the AHP for district Rahim Yar Khan based on criteria 2, which define the agricultural support system for food security and storage in the district. The irrigated and un-irrigated fodder area (V21) variable is given 1/2 against temperature, as temperature is the independent variable. Education is also an important factor in improving agricultural techniques to reduce drought vulnerability; therefore, it is scored 2 against temperature and rainfall, 4 against cropping intensity, and 1/2 against equipment or machinery used for agriculture purposes (V23).

Table 1. The average consistencies of random matrices; RI value used for consistency test (The Random Index values). (Ramanathan, 2001).

Size	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 2. Pair-wise comparison matrix of the meteorological variabilities of Rahim Yar Khan district.

Variables	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	1/4	2	1/3	2	2	1	2	2
V12	4	1	3	2	1/4	1/4	2	1/3	2
V21	1/2	1/3	1	2	3	1	2	1/2	1
V22	3	1/2	½	1	1/2	3	1	3	2
V23	1/2	4	1/3	2	1	1/3	1/2	4	2
V31	1/2	4	1	1/3	3	1	3	1/5	½
V32	1	1/2	½	1	2	1/3	1	6	4
V41	1/2	3	2	1/3	1/4	5	1/6	1	1
V42	1/2	1/2	1	½	1/2	2	1/4	1	1

The weights for V21 and V23, the agricultural variables, have similar values of 0.13, representing their significance in the criteria, whereas V22 has a low vulnerability weight of 0.11. Hence, the cropping intensity of the cultivated area depends on the irrigated area in the district; more canal systems will irrigate the district to support the crops in cases of less or no rainfall. Tables 3 and 4 show the pair-wise comparison matrix and the consistency test of the AHP for district Rahim Yar Khan based on criteria 3, which define the hydrological or canal system for irrigation in the district. Tables 5 and 6 show the pair-wise comparison matrix and the consistency test of AHP for district Rahim Yar Khan based on criteria 4, which define the availability of socio-economic facilities in the district.

Table 3. Consistency test of AHP to given variables of Rahim Yar Khan district with respect to meteorological variabilities.

Variables	Row Product	4^{th} Root	Weight (W)[*1]	Eigenvector[*2]	$\lambda_{max}W$[*3]	Consistency Test[*4,5]
V11	2.7	1.12	0.12	1.32	10.79	
V12	2	1.08	0.12	1.7	14.35	λ_{max}=20.15
V21	1	1	0.11	1.31	11.97	CI=1.4
V22	6.8	1.24	0.14	1.54	11.36	RI=1.45
V23	1.8	1.07	0.12	1.60	13.48	CR=0.8
V31	0.6	0.95	0.104	1.901	18.37	
V32	4	1.17	0.13	5.15	40.30	
V41	0.21	0.84	0.092	2.50	26.66	
V42	0.0313	0.68	0.08	1.713	22.90	
	Sum=9.13			Mean=20.15		

Table 4: Pair-wise comparison matrix of the agricultural support system of Rahim Yar Khan district.

Variables	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	1/8	2	1/6	1/2	2	5	1/2	1/2
V12	8	1	½	1/3	1/2	1/6	3	1/4	1/4
V21	1/2	2	1	3	5	1/7	1	3	1
V22	6	3	1/3	1	1/2	5	2	1/7	1/4
V23	2	2	1/5	2	1	2	1/4	4	2
V31	1/2	6	7	1/5	1/2	1	7	1	1/2
V32	1/5	1/2	1	1/2	4	1/7	1	6	2
V41	2	4	1/3	7	1/4	1	1/6	1	4
V42	2	4	1	4	1/2	2	½	1/4	1

The weights were subjected to judgment by applying a consistency test to the weights calculated from the matrix. The eigenvectors were calculated by linear conversion to calculate λmax, consistency index CI, random index RI, and consistency ratio CR for each given criteria for each district. The consistency test to check each of the given criteria for district Rahim Yar Khan, the consistency ratio CR, was calculated from the consistency index (CI) and random index (RI) from Saaty (1980), which is shown in Table 1. The pair-wise matrix consists of 9 variables; hence, the RI value was taken from the 9th random index matrix value, RI = 1.45. Table 3 shows the consistency test with the maximum right eigenvalue λmax=20.15 and the consistency index CI=1.4. The CR = 0.8 shows the judgment limit of the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria. Table 5 shows the consistency test with λmax=16.13 and the consistency index CI=0.8913. The CR of 0.615 indicates the judgment limit for the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria.

Table 5. Consistency test of AHP to given variables of Rahim Yar Khan district with respect to agricultural support system.

Variable	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	0.05	0.72	0.08	1.31	16.84	
V12	0.021	0.65	0.07	1.23	17.57	λ_{max}=16.13
V21	6.43	1.23	0.133	1.91	14.39	CI=0.89
V22	1.07	1.008	0.11	1.81	16.65	RI=1.45
V23	6.4	1.23	0.13	1.71	12.87	CR=0.62
V31	7.35	1.25	0.14	2.50	18.32	
V32	0.343	0.89	0.09	1.87	19.51	
V41	3.11	1.13	0.12	2.05	16.75	
V42	4	1.17	0.13	1.54	12.30	
	Sum=9.3			Mean= 16.13		

Table 6. Pair-wise comparison matrix of the hydrological resources of Rahim Yar Khan district.

Variable	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	1/3	2	1/5	1/3	1/2	1	½	1/2
V12	3	1	1/5	1/2	1/4	1/6	2	1/6	2
V21	5	5	1	1/3	1/6	1/5	2	4	1/4
V22	3	2	3	1	6	3	1	¼	1
V23	3	4	6	1/6	1	1/3	1/2	4	2

V31	2	6	1	5	3	1	1/5	1/3	4
V32	1	1/2	½	1	2	5	1	½	2
V41	2	6	¼	1/2	1/4	3	2	1	2
V42	2	1/2	4	1	1/2	1/4	1/2	½	1

Table 7. Consistency test of AHP to given variables of Rahim Yar Khan district with respect to hydrological resources.

Variable	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	0.006	0.562	0.058	0.65	11.174	
V12	0.008	0.59	0.06	0.82	13.40	λ_{max}=18.92
V21	0.56	0.94	0.09	1.54	15.91	CI=1.24
V22	81	1.63	0.17	2.30	13.70	RI=1.45
V23	16	1.40	0.14	1.93	13.73	CR=0.86
V31	48	1.54	0.16	2.40	15.06	
V32	2.5	1.11	0.11	1.72	15.04	
V41	4.5	1.18	0.12	7.31	59.98	
V42	0.125	0.79	0.08	1.01	12.32	
		Sum= 9.69			Mean=18.92	

Table (7) shows the consistency test with λmax=18.92 and the consistency index CI=1.24. The CR = 0.86 shows the judgment limit of the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria. Table 9 shows the consistency test with λmax = 15.79 and the consistency index CI = 0.85. The CR = 0.58 shows the judgment limit of the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria.

Table 8.Pair-wise comparison matrix of the socio-economic services of Rahim Yar Khan district.

Variable	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	1/4	3	1/6	4	1/2	5	2	2
V12	4	1	½	1	2	8	1/4	1/3	1/3
V21	1/3	2	1	4	1/8	1/3	1	½	2
V22	6	1	¼	1	1/3	1	2	1/3	1/4
V23	¼	1/2	8	3	1	1/4	1/6	6	1
V31	2	1/8	3	1	4	1	5	3	2
V32	1/5	4	1	1/2	6	1/5	1	2	4
V41	½	3	2	3	1/6	1/3	1/2	1	3
V42	½	3	½	4	1	1	1/4	1/3	1

Table 9. Consistency test of AHP to given variables of Rahim Yar Khan district with respect to socio-economic services.

Variable	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	5	1.19	0.13	1.94	15.12	
V12	0.89	0.99	0.11	2.5	23.25	λ_{max}=15.79
V21	0.11	0.78	0.084	1.09	13.05	CI=0.85
V22	0.08	0.76	0.08	1.50	18.38	RI=1.45

V23	0.75	0.97	0.104	1.90	18.15	CR=0.59
V31	90	1.65	0.18	2.31	13.09	
V32	3.84	1.16	0.13	1.93	15.52	
V41	0.75	0.97	0.104	1.31	12.64	
V42	0.25	0.86	0.09	1.19	12.89	
	Sum=9.3			Mean=15.79		

Drought vulnerability of Tharparkar by AHP

We have compared the variables of four indicators to construct the pair-wise comparison matrix and the consistency test of AHP for district Tharparkar based on the meteorological variabilities criteria in the district. Tables 10 and 11 show the pair-wise comparison matrix and the consistency test of AHP based on the meteorological variabilities in Tharparkar district. The temperature (V11) and rainfall (V12) variables have more significance in drought vulnerability as compared to other variables in the given criteria. The temperature (V11) scored 1/4 against canal irrigation (V31) and scored 1 with the barani irrigation system variable (V32), as there is no canal irrigation system in Tharparkar to mitigate the global climate variability by reducing the drought vulnerability of the district.

Table 10. Pair-wise comparison matrix of the meteorological variabilities of Tharparkar district.

Variables	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	1	4	6	2	¼	1	2	2
V12	1	1	1/6	4	2	3	1/4	4	1/3
V21	1/4	6	1	¼	1/5	½	2	1/6	1/2
V22	1/6	1/4	4	1	6	1/6	1/2	3	1/4
V23	1/2	1/2	5	1/6	1	9	3	1/2	4
V31	4	1/3	2	6	1/9	1	1/4	5	1/3
V32	1	4	½	2	1/3	4	1	6	1/7
V41	1/2	1/4	6	1/3	2	1/5	1/6	1	6
V42	1/2	3	2	4	1/4	3	7	1/6	1

Table 11. Consistency Test of AHP to given variables of Tharparkar district with respect to meteorological variabilities.

Variables	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	48	1.54	0.16	1.85	11.34	
V12	1.33	1.033	0.11	1.59	14.48	λ_{max}=17.11
V21	0.006	0.57	0.06	1.19	19.72	CI=1.01
V22	0.06	0.74	0.08	1.57	20.11	RI=1.45
V23	11.25	1.31	0.14	2.49	17.87	CR=0.69
V31	0.74	0.97	0.103	1.89	18.36	
V32	4.60	1.20	0.13	1.89	14.99	
V41	0.1	0.77	0.08	1.73	20.97	
V42	10.5	1.30	0.14	2.22	16.13	
	Sum=9.4			Mean=17.11		

Tables (12) and (13) show the pair-wise comparison matrix and the consistency test of AHP for district Tharparkar based on the agricultural support system for food security and storage in the district. The variables include irrigated and un-irrigated fodder area (V21), cropping intensity of the cultivated area (V22), and equipment or machinery used for agriculture purposes.

Table 12. Pair-wise comparison matrix of the agricultural support system of Tharparkar district.

Variables	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	2	¼	1/3	7	1/4	1/5	1/2	5
V12	1/2	1	1/5	1/6	4	1/8	4	1/4	2
V21	4	5	1	3	1/2	1/5	6	1/3	1/5
V22	3	6	1/3	1	1/4	6	1/7	4	2
V23	1/7	¼	2	4	1	1/5	1/4	2	1/6
V31	4	8	5	1/6	5	1	2	1/3	1/8
V32	5	¼	1/6	7	4	1/2	1	2	¼
V41	2	4	3	1/4	1/2	3	1/2	1	1
V42	1/4	½	5	1/2	6	8	4	1	1

Table 13. Consistency Test of AHP to given variables Tharparkar district with respect to agricultural support system.

Variables	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	0.15	0.81	0.09	1.65	19.34	
V12	0.017	0.64	0.07	1.21	18.05	λ_{max}=17.68
V21	2.4	1.10	0.12	1.99	17.14	CI=1.08
V22	10.29	1.30	0.14	2.52	18.44	RI=1.45
V23	0.005	0.56	0.06	1.20	20.58	CR=0.75
V31	11.11	1.31	0.14	2.19	15.90	
V32	1.46	1.04	0.11	2.12	19.30	
V41	4.5	1.18	0.13	1.61	12.90	
V42	60	1.57	0.17	2.88	17.44	
		Sum= 9.50		Mean=17.68		

(V23), which have more significance in drought vulnerability as compared to other variables in the given criteria. The weight of variable V21 shows the least value of 0.12, which shows less vulnerability in agricultural indicators as compared to V22 variable 0.14. Tables 14 and 15 show the pair-wise comparison matrix and the consistency test of AHP for district Tharparkar based on the hydrological sources in the district for agricultural irrigation. The variables, including canal irrigation area (V31) and barani irrigation area (V32), have more significance in drought vulnerability as compared to other variables in the given criteria. The weights for both variables V31 and V32 are 0.1 and 0.97, respectively, which show the vulnerability of Tharparkar district due to the lack of a canal system for the irrigation of agricultural land.

Table 14. Pair-wise comparison matrix of the hydrological resources of Tharparkar district.

Variable	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	2	3	1/4	1/2	4	1/6	5	4
V12	1/2	1	5	1/2	6	1/5	2	1/2	1/6
V21	1/3	1/5	1	3	4	6	1/3	1/5	1/2
V22	4	2	1/3	1	1/6	¼	4	2	7
V23	2	1/6	¼	6	1	4	3	1/3	1/2
V31	1/4	5	1/6	4	1/4	1	2	4	1/4
V32	6	1/2	3	1/4	1/3	½	1	1/4	3
V41	1/5	2	5	1/2	3	¼	4	1	1
V42	1/4	6	2	1/7	1/2	4	1/3	1	1

Table 15: Consistency Test of AHP to given variables Tharparkar district with respect to hydrological resources.

Variables	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	10	1.29	0.14	2.14	14.83	
V12	0.25	0.86	0.09	1.65	17.30	λ_{max}=18.62
V21	0.16	0.82	0.09	1.73	18.99	CI=1.203
V22	6.22	1.23	0.14	2.30	16.82	RI=1.45
V23	1	1	0.11	2.04	18.33	CR=0.83
V31	0.42	0.91	0.10	1.93	19.04	
V32	0.28	0.87	0.097	1.73	17.83	
V41	3	1.13	0.13	3.62	28.72	
V42	0.29	0.87	0.09	1.53	15.72	
	Sum=8.98			Mean=18.62		

Tables (16) and (17) show the pair-wise comparison matrix and the consistency test of AHP for district Tharparkar based on the socio-economic facilities in the district. The variables include variable health units for medical aid (V41) and population education numbers (V42), which have more significance in drought vulnerability as compared to other variables in the given criteria. The weight of the variable V42=0.19 shows more vulnerability than V41=0.09. The education in the area will make people in the respective area adapt various techniques to reduce their vulnerability to given environmental conditions. The pair-wise matrix of Tharparkar weights was subjected to judgment by applying the consistency test of AHP. The eigenvectors were calculated by linear conversion to calculate λmax, consistency index CI, random index RI, and consistency ratio CR for each given criteria for each district. The consistency test to check each of the given criteria for district Rahim Yar Khan, the consistency ratio CR, was calculated from the consistency index (CI) and random index (RI) from Saaty, 1980, which is shown in Table (1).

Table 16. Pair-wise comparison matrix of the socio-economic services of Tharparkar district.

Variable	V11	V12	V21	V22	V23	V31	V32	V41	V42
V11	1	2	5	1/6	1/7	1/5	3	8	1/4
V12	1/2	1	1/3	4	5	1/2	7	1/5	1/3
V21	1/5	3	1	1	1/2	4	1/6	1/4	1/2

V22	6	1/4	1	1	1/4	7	2	1/2	3
V23	7	1/5	2	4	1	3	1/4	1	6
V31	5	2	¼	1/7	1/3	1	7	3	1/3
V32	1/3	1/7	6	1/2	4	1/7	1	2	1/2
V41	1/8	5	4	2	1	1/3	1/2	1	1
V42	4	3	2	1/3	6	3	2	1	1

Table 17. Consistency Test of AHP to given variables Tharparkar district with respect to socio-economic services.

Variables	Row Product	4^{th} Root	Weight (W)*1	Eigenvector*2	$\lambda_{max}W$*3	Consistency Test*4,5
V11	0.29	0.87	0.09	1.75	19.93	
V12	0.78	0.97	0.09	2.12	21.59	λ_{max}=17.87
V21	0.025	0.66	0.07	1.11	16.59	CI=1.11
V22	7.88	1.26	0.13	2.25	17.67	RI=1.45
V23	50.4	1.55	0.16	2.98	19.07	CR=0.76
V31	0.83	0.98	0.09	1.72	17.34	
V32	0.08	0.76	0.08	1.52	19.83	
V41	0.83	0.98	0.09	1.54	15.55	
V42	288	1.87	0.19	2.50	13.26	
		Sum=9.9			Mean=17.87	

*1: $w = ith\ value\ of 4th\ root/\Sigma\ 4th\ root$
*2: $Normalization = (Row \times Colunm)$
*3: $\lambda maxW = Eigenvector/weights$
*4: $Consistency\ Ratio\ (CR) = CI/RI$
*5: $The\ consistency\ test\ would\ be\ valid\ under\ condition\ CR < 0.9$

Table (11) represents the consistency test with the maximum right eigenvalue λmax=17.12 and the consistency index CI=1.01. The CR=0.69 show the judgment limit of consistency of the given criteria. The CRs value show the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria. Table 13 shows the consistency test with λmax = 17.68 and the consistency index CI = 0.084. The CR = 0.748 shows the judgment limit of consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria. Table 15 shows the consistency test with λmax=18.62 and the consistency index CI=1.202. The CR of 0.83 indicates the judgment limit of the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria. Table (17) shows the consistency test with λmax=17.87 and the consistency index CI=1.11. The CR of 0.76 shows the judgment limit of the consistency of the given criteria. The CRs value shows the pair-wise matrix was not random or untrustworthy for the meteorological variability criteria.

Drought vulnerability indexation

The individual weights for each given criteria from both districts, i.e., Rahim Yar Khan and Tharparkar, were used to calculate the drought vulnerability index (DVI). The vulnerability of district criteria indices is classified into four classes, i.e., “slightly vulnerable” indicates the DVI between 0 and 0.01, “moderately vulnerable” indicates the DVI between 0.01 and 0.02, “highly vulnerable” indicates the DVI between 0.02 and 0.04, and “very highly vulnerable” indicates the DVI between 0.05 and 0.09.

Table 19 shows the district-wise drought vulnerability index of each of the four criteria used in the analytical hierarchy process. Tharparkar has shown a high vulnerability index for each of the criteria as compared to the district Rahim Yar Khan. The vulnerability for the criteria of the hydrological resources has shown a 0.062 index value with the class of “Very High Vulnerability” in the Tharparkar district.

Table 18. (a) Composite weights of variables for Rahim Yar Khan.

Criteria	V11	V12	V21	V22	V23	V31	V32	V41	V42	Σ Wi
Criteria 1	0.12	0.12	0.11	0.14	0.12	0.10	0.13	0.09	0.08	1.0104
Criteria 2	0.08	0.07	0.13	0.11	0.13	0.14	0.09	0.12	0.13	1.003
Criteria 3	0.06	0.06	0.09	0.17	0.14	0.16	0.11	0.12	0.08	0.99
Criteria 4	0.13	0.11	0.08	0.08	0.10	0.18	0.13	0.104	0.09	1.008

Table 18. (b) Composite weights of variables for Tharparkar.

Criteria	V11	V12	V21	V22	V23	V31	V32	V41	V42	Σ Wi
Criteria 1	0.16	0.11	0.06	0.08	0.14	0.103	0.13	0.08	0.14	1.003
Criteria 2	0.09	0.07	0.12	0.14	0.06	0.14	0.11	0.13	0.17	1.03
Criteria 3	0.014	0.09	0.09	0.14	0.11	0.10	0.97	0.13	0.09	1.86
Criteria 4	0.09	0.09	0.07	0.13	0.16	0.09	0.08	0.09	0.19	0.99

Table 19. Drought Vulnerability Index (DVI) of the given criteria for Rahim Yar Khan and Tharparkar district.

	Criteria 1	Criteria 2	Criteria 3	Criteria4	Conclusion
Index for Rahim Yar Khan	0.015	0.011	0.011	0.011	Rahim Yar Khan has low vulnerability index value for each given criteria. So it belongs to Slightly Vulnerable class of drought vulnerability.
Index for Tharparkar	0.033	0.034	0.062	0.033	Tharparkar has high vulnerability index value in each given criteria. So it belongs to highly Vulnerable class of drought vulnerability.

Table (20) shows the average monthly temperature from 1984 to 2015 in two districts, i.e., Rahim Yar Khan and Tharparkar. The 31-year average monthly temperature data of both districts was used to analyze the meteorological vulnerability. The represented data in the table shows that Tharparkar has hot summers with high temperatures from March to October, while the comparative temperature of Rahim Yar Khan district has a moderately hot summer with a high temperature of 53$^{\circ C.}$Table 21 shows the average monthly rainfall from 1984 to 2015 in two districts, i.e., Rahim Yar Khan and Tharparkar. The meteorological vulnerability criterion was observed by using the 31-year average annual rainfall data for both districts. The district of Tharparkar heavily depends on the rainfall that occurs in the months of August and September, with an average rainfall of 68.45 to 59.98. This dependency of the district for its agricultural, hydrological, and socio-economic needs will directly affect the populations in the ecosystems of the Tharparkar district. On the contrary, the district of Rahim Yar Khan faces heavy monsoon rainfall from July to September and has developed an irrigation system to reduce its drought vulnerability.

Table 20. Average monthly temperature of Rahim Yar Khan and Tharparkar (1984-2015).

Months	Rahim Yar Khan (˚C)	Tharparkar (˚C)	Months	Rahim Yar Khan (˚C)	Tharparkar (˚C)
January	28.2	34.87	July	52.9	59.43
February	34.5	41.43	August	47.44	49.67
March	46.7	35.88	September	47.33	49.47
April	47.12	33.65	October	43.54	47.21
May	48.22	52.46	November	33.9	42.03

June	53.61	58.45	December	29.14	38.28

Table 21. Average monthly rainfall of Rahim Yar Khan and Tharparkar (1984-2015).

Months	Rahim Yar Khan (˚C)	Tharparkar (˚C)	Months	Rahim Yar Khan (˚C)	Tharparkar (˚C)
January	4.91	0.764	July	64.52	32.51
February	10.58	4.9	August	89.527	68.45
March	6.871	1.47	September	68.92	59.98
April	9.762	2.38	October	10.8	8.71
May	9.57	4.76	November	1.04	0.613
June	26.58	14.41	December	5.37	1.23

The agricultural vulnerability was assessed by using the land use for cultivation, cropping intensity, and machinery used for agriculture. Tables (24) and (25) show the agricultural machinery used to improve agricultural practices and enhance productivity. Tables (22) and (23) show the total cultivated area, net sown area, and cropping intensity of the total cultivated area in the districts of Rahim Yar Khan and Tharparkar. The cultivated area is further divided according to the size of the land cultivated, i.e., 12 to 25 acres of farm with a large cultivated area of 255814 and net sown land in the same farm range of 250536. The Rahim Yar Khan district has shown more land cultivated in the range of 25- to 50-acre cultivated farms, which shows a large cultivated area in the district with a reduced vulnerable cropping intensity percent of the total cultivated area. This range of farm area shows a higher cropping intensity of the total cultivated area (102.11, 103.27, and 104.09), which means the district has a high portion of land farms from 12.5 to 25, 25 to 50, and 50 to 100 acres of agricultural productivity during one agricultural season. The district of Rahim Yar Khan shows a maximum cropping intensity of 113.78 from 106825 acres of 100 to 150 acres of land, while the Tharparkar district shows a maximum cropping intensity of 108.81 from 16683 acres of 100 to 150 acres of land. The Tharparkar district has shown more land cultivated in the range of 2.5- to 7.5-acre cultivated farms, which shows the maximum cultivated area in the district with increased vulnerable cropping intensity of 100.72 percent of the total cultivated area.

Table 1**.** Total cultivated and uncultivated area (Acres) of Rahim Yar Khan.

Size of Farm (Acres)	Total Cultivated Area (Acres)	Net Sown Area (Acres)	Cropping intensity of cultivated area (Acres)
0-1	57526	57457	100.12
1-2.5	162963	162552	100.25
2.5-5.0	201693	200353	100.67
5.0-7.5	181860	179977	101.05
7.5-12.5	245262	241692	101.48
12.5-25.0	255814	250536	102.11
25.0-50.0	176078	170506	103.27
50.0-100	116399	111830	104.09
100-150	44210	42153	104.88
150 Above	106825	93888	113.78

Table (26) depicts the hydrological resources in the districts via canals in different ranges of farm size, number of tube wells, number of tanks, and barani sources. The district of Rahim Yar Khan has more agricultural land with irrigation facilities like canals and tube wells in each of the chakk divisions. The more cultivated farm size, from 25.0 to 50.0, has more canal area (55326), and the least cultivated range of 1 canal farm has 833 acres of area under the canal system in the district. There is no developed canal irrigation system in district Tharparkar, but a few canals with extensions from the “Nara canal” in the province of Sindh irrigate the agricultural land of ‘Mithi’ and ‘Diplo’ Talukas in the district.

Table 2. Total cultivated and uncultivated area (Acres) of Tharparkar.

Size of Farm (Acres)	Total Cultivated Area (Acres)	Net Sown Area (Acres)	Cropping intensity of cultivated area (Acres)
0-1	871	1810	48.12
1-2.5	6779	6777	100.03
2.5-5.0	20204	19315	104.60
5.0-7.5	57083	56713	100.65
7.5-12.5	68738	68240	100.73
12.5-25.0	18867	104864	17.99
25.0-50.0	87367	85015	102.77
50.0-100	49732	49160	101.16
100-150	16683	15332	108.81
150 Above	6989	6868	101.76

Table 3. Agricultural Machinery use in Rahim Yar Khan.

Size of Farm (Acres)	Tractor	Thresher	Sheilder	Drills	Spray Machine	Reaper	Harvesters
0-1	42791	31258	1863	8297	16982	2767	898
1-2.5	64934	62846	3386	29594	32814	8066	1618
2.5-5.0	44085	45359	3452	22219	19152	6664	1493
5.0-7.5	23012	25360	1161	13083	10877	3896	292
7.5-12.5	16215	21313	1648	11333	7666	4400	975
12.5-25.0	7821	12192	722	6331	4634	3007	703
25.0-50.0	1890	3591	277	1531	1056	1026	324
50.0-100	368	1096	89	322	407	388	175
100-150	73	296	20	45	67	58	101
150 Above	103	319	81	61	132	38	57

Table 25. Agricultural machinery use in Tharparkar.

Size of Farm (Acres)	Tractor	Thresher	Sheilder	Drills	Spray Machine	Reaper	Harvester
0-1	86	0	0	0	0	0	0
1-2.5	2350	0	81	0	0	0	0
2.5-5.0	5735	2385	2471	1630	2000	124	2247
5.0-7.5	9153	494	858	124	371	0	371
7.5-12.5	7059	741	1232	494	494	124	742
12.5-25.0	853	1248	2498	988	1112	124	1112
25.0-50.0	993	13	646	0	0	0	0
50.0-100	113	125	195	1	0	1	1
100-150	48	0	30	0	0	0	0
150 Above	39	0	11	0	0	0	1

The Tharparkar district has shown more agricultural land in the range of 2.5 to 7.5 acres of cultivated farms, which shows the maximum irrigated area (1574) for the canals in the district. The district of Rahim Yar Khan has more tube wells in each size of agricultural farm, but with a low water table, the Tharparkar district has few tube wells in its agricultural farms. There are 265 and 376 tube wells in 12.5 to 25 acres of farms and 25 to 50 acres of farms, respectively. Table 27 presents the irrigated and non-irrigated areas for the cultivation of fodder for the livestock The fodder cultivation and irrigation area are high in Rahim Yar Khan district, as it has more agricultural land and livestock. The highest fodder-irrigated area is 27319 acres of land found in the range of 7.5 to 12.5 acres of farm size. The farm in sizes 12.5 to 25.0 and 25.0 to 50.0 shows a large area of irrigation, more cultivation, and higher cropping intensity, with 25244 and 13579 acres of fodder to support the livestock and agricultural activities. Talukas in Tharparkar district with nearby canals support the irrigation for the fodder, and agricultural farms in the range of 7.5 to 12.5 acres of farm size have 4048 acres for the fodder. The area for fodder in Tharparkar is 2.74 percent of the total cultivated area in the district, which increases the livestock vulnerability.

Table 26. Number of irrigation facilities in Rahim Yar Khan and Tharparkar.

Size of Farm (Acres)	Canals in Rahim Yar Khan	Canals in Tharparkar	Number of Tube well in Rahim Yar Khan	Number of Tube well in Tharparkar
0-1	833	0	2044	0
1-2.5	12638	29	7613	0
2.5-5.0	28707	176	9226	0
5.0-7.5	28663	390	10996	0
7.5-12.5	55326	1574	10369	0
12.5-25.0	56500	751	10472	265
25.0-50.0	46233	361	8854	376
50.0-100	29707	0	7024	0
100-150	12173	0	3574	0
150 Above	23039	0	5878	0

Table 27. Irrigated area of Fodders in Rahim Yar Khan and Tharparkar.

Farm size (Acres)	Irrigated area of fodder in Rahim Yar Khan	Irrigated area of fodder in Tharparkar	Non-irrigated area of fodder in Rahim Yar Khan	Non-irrigated area of fodder in Tharparkar
0-1	8112	0	317	0
1-2.5	18461	0	930	2011
2.5-5.0	26600	536	1474	4368
5.0-7.5	20351	374	1248	15560
7.5-12.5	27319	4048	998	22099
12.5-25.0	25244	863	1808	31551
25.0-50.0	13579	1712	1003	26427
50.0-100	5970	672	321	15879
100-150	1378	1029	77	3353
150 Above	4977	19	111	1742

DISCUSSION

Climate-sensitive regions in Pakistan are most vulnerable to drought as its agricultural economy is reliant on climate change and requires more capacity to survive the risks (Farooqi et al., 2005; Rasul et al., 2012; Malik et al., 2012). Drought is one of the most complex climate-sensitive natural hazards that has economic, environmental, and social impacts, affecting the natural resources and human development of vulnerable territorial boundaries (Smakhtin & Schipper, 2008; Mishra & Singh, 2010). According to the World Bank and the Asian Development Bank (ADB), Pakistan has been classified as a water-stressed country and placed in a red zone of scarcity owing to the anticipated critical water shortage. The Tharparkar district faces severe droughts every year since the whole district is desert-like and there is no regular irrigation system. However, the monsoon rains play an important role in the irrigation of agricultural land in the Tharparkar district (Wandel & Smit, 2000; Adger et al., 2005; Gutiérrez et al., 2014; Abid et al., 2015; Abid et al., 2016). Rahim Yar Khan and Tharparkar are neighboring districts with similar climatic conditions, but differences in infrastructure and demographic vulnerability factors make Tharparkar more vulnerable to drought (Rajar et al., 2007). Hence, Tharparkar district experiences drought conditions every year with a high infant mortality rate and agricultural loss as compared to neighboring district Rahim Yar Khan.For drought vulnerability assessment, the meteorological, agricultural, hydrological, and socio-economic data can show inconsistency with respect to time and region. In order to build the hierarchy for these inconsistence factors, the assessment of the drought vulnerability index (DVI) is necessary to represent and evaluate the most vulnerable and affecting cause among the meteorological, agricultural, hydrological, and socio-economic factors (Serkendiz et al., 2023). The meteorological vulnerability was assessed by using the mitigation and availability of irrigation facilities to address accessibility and shortage challenges. The agricultural vulnerability was evaluated by using the agricultural support system, modes of irrigation, and agricultural practices used to cope with shortage challenges and improve productivity over the agricultural year. The hydrological vulnerability was weighed with the ways of irrigation in agriculture and the total irrigated area of fodder to support the livestock and reduce the vulnerability to drought. The socio-economic vulnerability was considered through the health units available in each of the districts and the education level in the district (Nyatuame et al., 2014; Dong et al., 2015).

Drought vulnerability of Rahim Yar Khan and Tharparkar

Rahim Yar Khan and Tharparkar have same meteorological conditions but there are many other factors which are involved in the making one region more vulnerable to drought than the other neighboring areas. Hence, these factors i.e. agricultural, irrigation and socio-economic, were used as indicators to assess the drought vulnerability of both the districts. Each indicator was assessed by using variables relating to each of the indicator through analytical hierarchy process and drought **Vulnerability index (DVI).**

The climate change will equally affect the temperature and rainfall patterns in both the districts but a well-defined irrigation support to agricultural sector can reduce the scarcity in less rainfall. The barrages followed by the canal networks linked with neighboring district in Punjab, Rahim Yar Khan district was found less vulnerable with the 0.011 DVI index of hydrological resources. Whereas the major Talukas of Tharparkar district has no irrigation resource availability and deserted area with less cultivation land (Jethoo et al., 2012). The areas with no canals and tube wells are fully depending upon the monsoon rains, are considered more vulnerable to drought due to the meteorological variabilities causing insufficient rains. This scarce condition has increased the drought vulnerability index of Tharparkar district to highly vulnerable class.

The agriculture sector in Rahim Yar Khan district mainly depends upon the canal irrigation, however, the modes of land irrigation like pumps and tube wells are also used in the assessment of drought vulnerability index and analytical hierarchy process. The meteorological variabilities are supported by the agricultural modifications and availability of canal system, which has reduced the meteorological and hydrological drought vulnerability of the Rahim Yar Khan. The agricultural modifications have improved the system and enhanced the agricultural and livestock productivity by reducing the agriculture vulnerability to drought. The socio-economic conditions can be managed by availability of education and health services to the population of the region (Rasul et al*.,* 2012). In Tharparkar, the population migration is a substantial problem which places pressure on the social infrastructure of the urban areas and increased their social vulnerability. Unequal distribution of natural resources and services have aggravated the drought vulnerability, increased the social-unjust and social vulnerability of Tharparkar districts (Rasul et al., 2012; Tahir, 2007; Depietri et al., 2013). Underdeveloped infrastructure and lack of life-saving facilities make the region more vulnerable to drought (Rasul et al., 2012). Most of the areas have low agricultural productivity and no storage and food security due to high drought vulnerability index (DVI) of 0.346 and 0.062 for agricultural and hydrological indicators. Hence the absence of hydrological and irrigation facilities has provoked the hydrological and agricultural vulnerability of the Tharparkar district to the alarming situations.

Analytical Hierarchy Process

The drought vulnerability assessment for meteorological, agricultural, hydrological, and socio-economic development is a hotspot method to evaluate the synthetic drought vulnerability index (DVI) (Dong et al., 2015). It is difficult to compare different regions with different indicators and weights; hence, regions with similar environmental conditions can be compared to each other using similar indicators. Hence, the drought vulnerability of Rahim Yar Khan and Tharparkar was assessed based on the hierarchy process. The consistency test was used to remove the uncertainty in the selection of criteria and score for each matrix of AHP. The consistency ratio CR signifies the result that lies within the limit of consistency, though CRs > 0.1 are believed to be conventionally accepted. The CR value should not exceed the limit of 1.0; a value greater than l would mean that the pairwise judgments are unbiased, random, and completely untrustworthy (Serkendiz & Tatli, 2023).

Drought Vulnerability Indexation

The study proposed optimized drought vulnerability indices (DVI) from an analytical hierarchy process. Weights for each variable are derived from the analytical hierarchy process by comparing the variables of the selected indicators. Due to different meteorological, agricultural, and socio-economic conditions, the weights for the DVI were not the same in both study districts, i.e., Rahim Yar Khan and Tharparkar. The classification of vulnerability depending on the drought vulnerability index with AHP suggests that the DV indexation is favorable in assessing regional drought vulnerability.

CONCLUSION

The drought vulnerability assessment results indicate that Tharparkar is the most vulnerable district to drought as compared to Rahim Yar Khan, which is affected by hydrological droughts with the highest vulnerability degree of 0.066. However, agriculture in these moderately vulnerable regions is significantly affected by droughts, with a DV index of 0.033. The drought vulnerability assessment of Tharparkar indicates that the district is highly vulnerable to drought as it is highly dependent on irrigation resources for its agriculture and livestock. The unavailability of hydrological resources has increased the drought vulnerability of the district, which corresponds to a high level of agricultural damage due to droughts. It is necessary for Tharparkar to establish countermeasures to mitigate the drought vulnerability through the development of water resources.Future studies are needed to be focused on reducing the drought vulnerability of Tharparkar. However, efforts have so far been inadequate for the district to be able to achieve DVI. Furthermore, there are many other indicators to assess particular vulnerability issues in the education and health sectors in Tharparkar district.

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