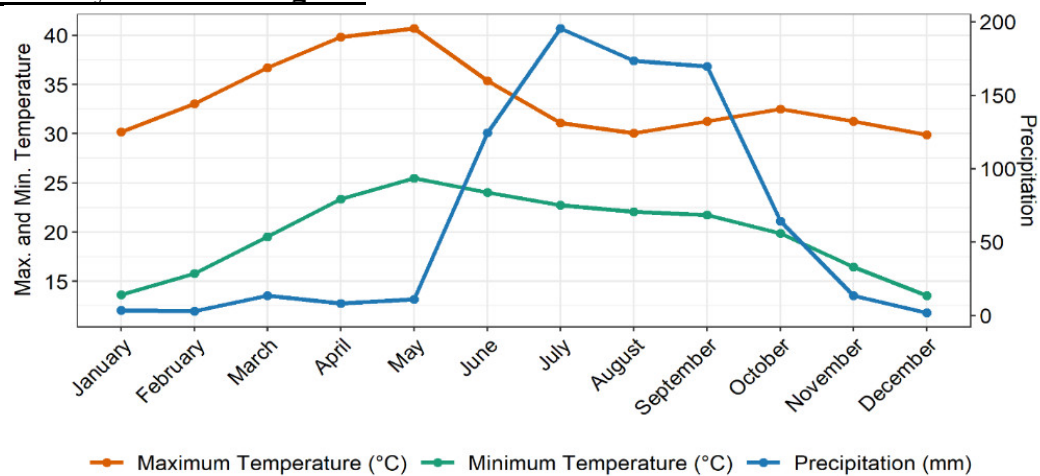
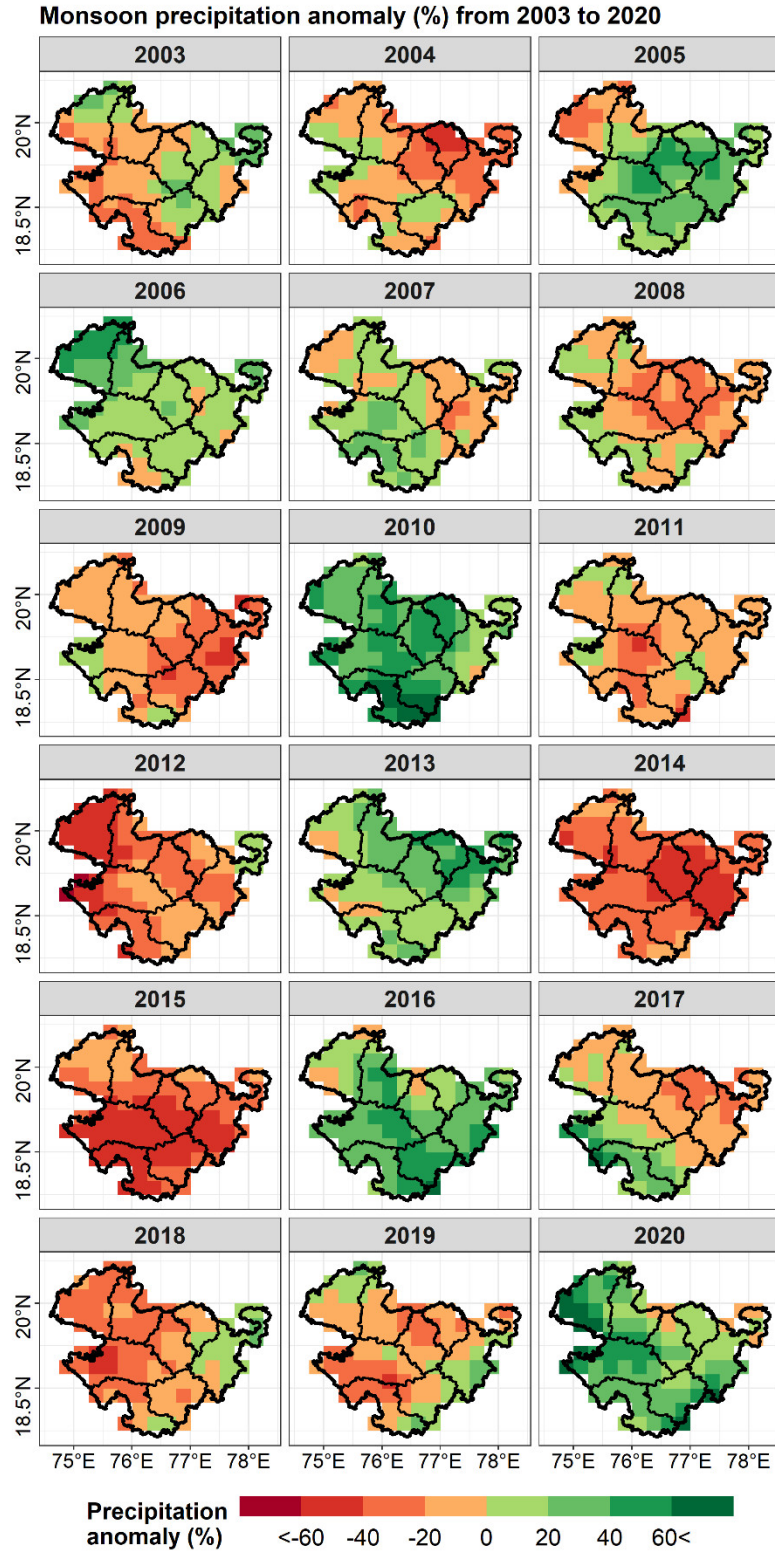


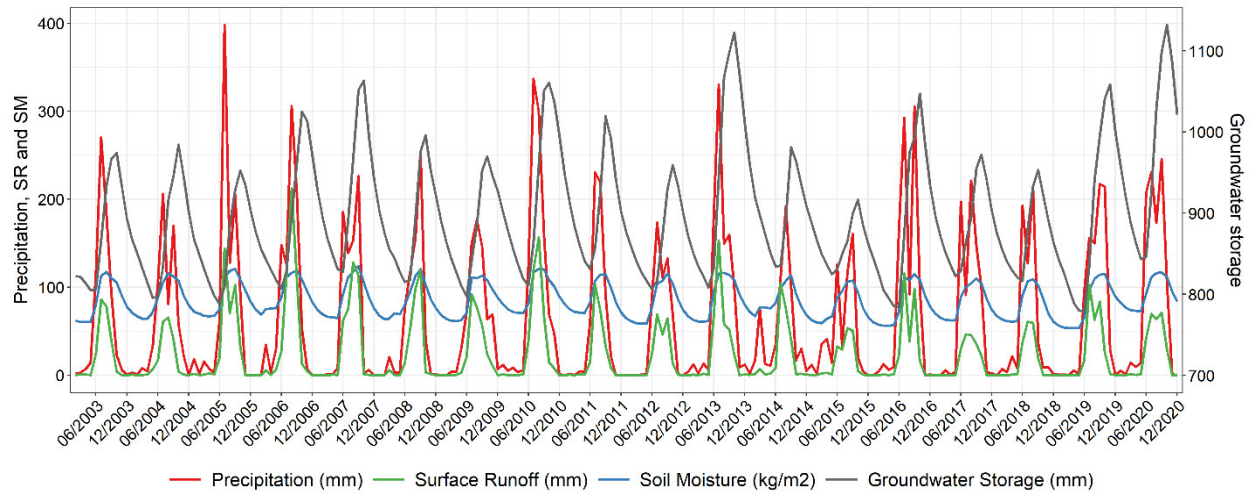
### **Supplimentary Material : Figures**



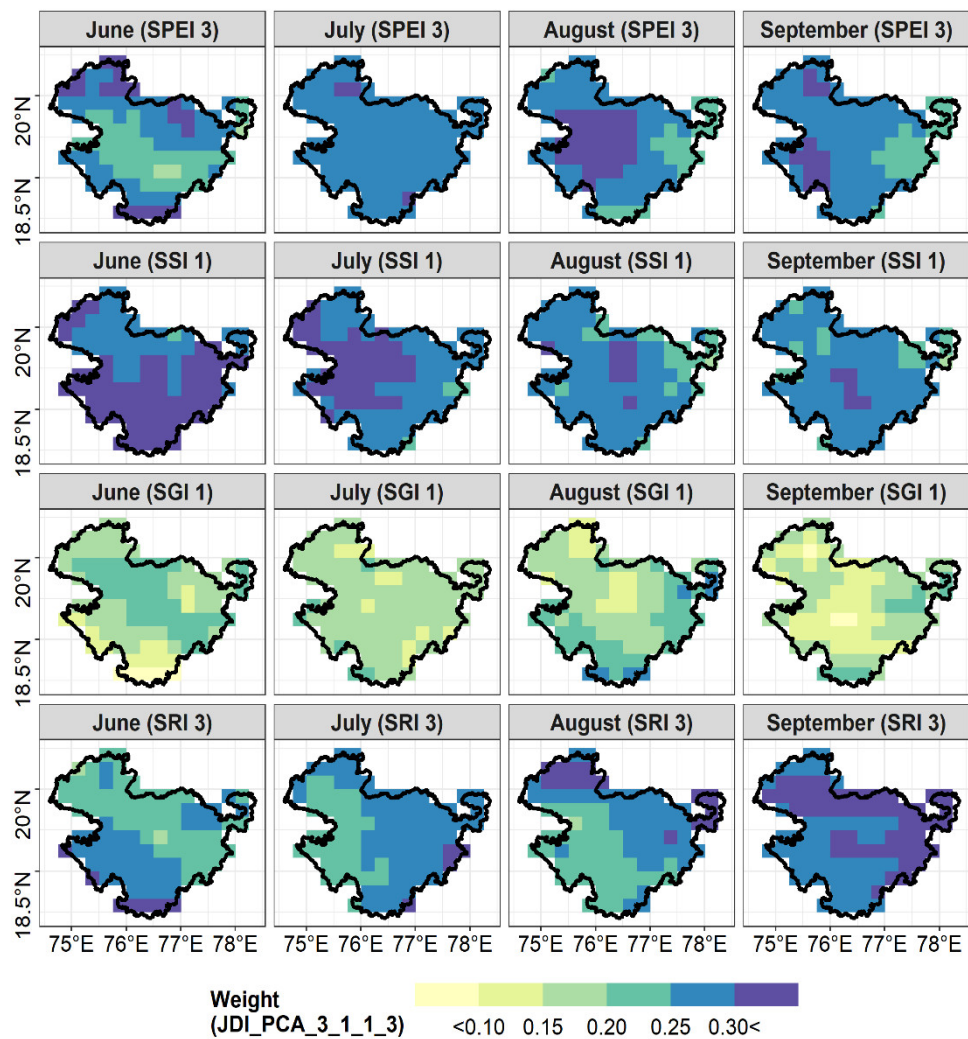
**Figure S1:** Long term (1989-2020) mean monthly precipitation and minimum and maximum temperature in Marathwada.



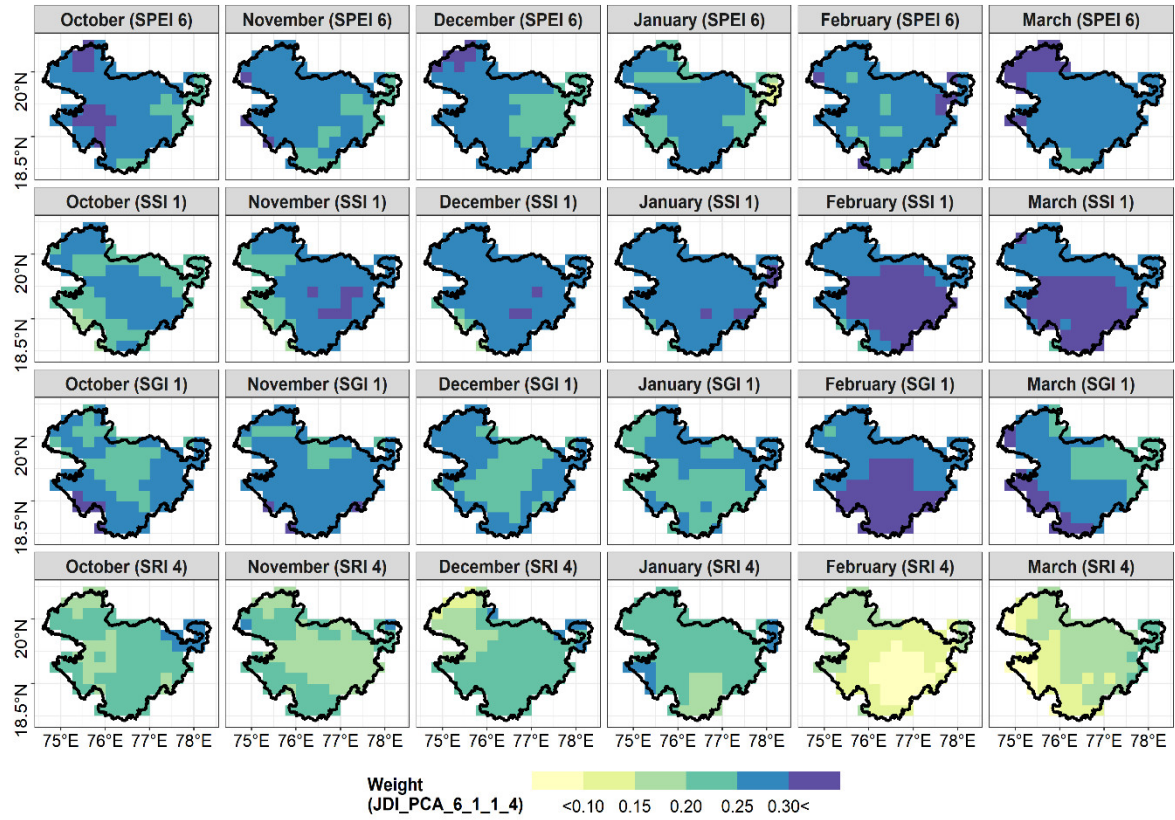
**Figure S2:** Monsoon precipitation anomaly over Marathwada from 2003 to 2020.



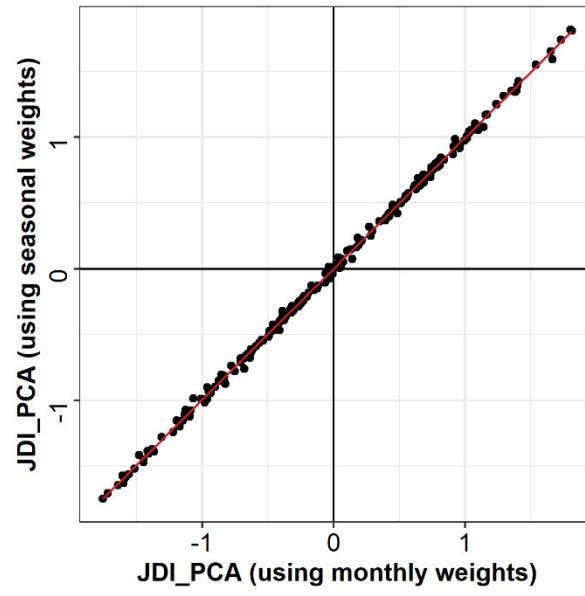
**Figure S3:** Mean monthly precipitation, surface runoff, soil moisture and groundwater storage over Marathwada region from 2003 to 2020.



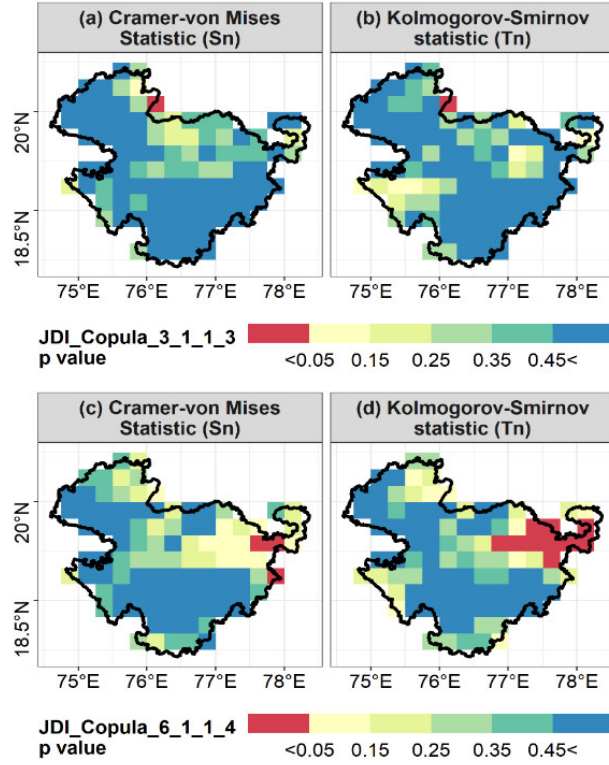
**Figure S4:** Weight allocation to each hydroclimatic variable in each month by PCA in Kharif season (JDI\_PCA\_3\_1\_1\_3).



**Figure S5:** Weight allocation to each hydroclimatic variable in each month by PCA in Rabi season (JDI\_PCA\_6\_1\_1\_4).

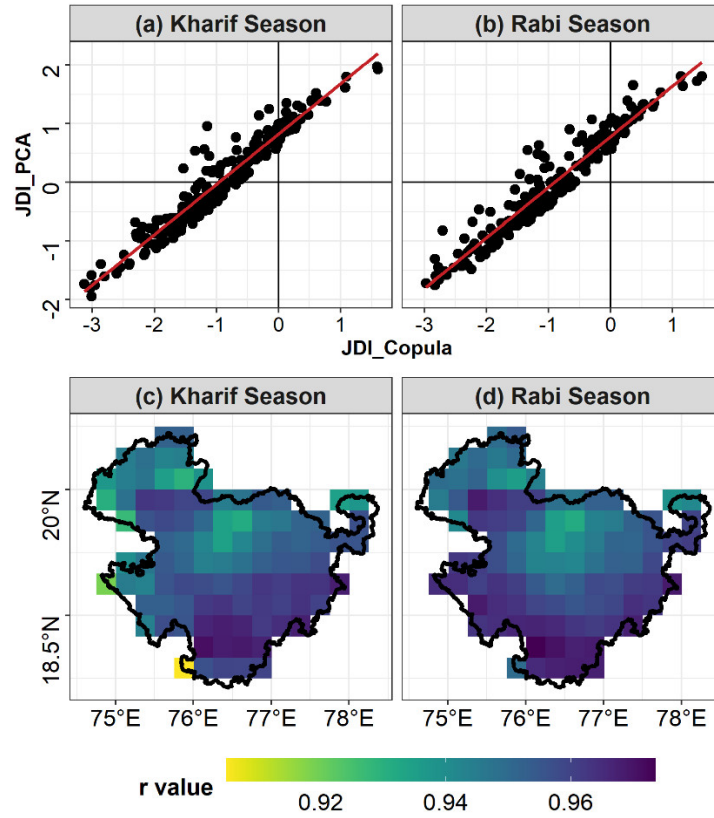


**Figure S6:** Scatterplot of JDI\_PCA intensities using monthly weights and seasonal weights obtained by process discussed in section 2.2.1 on monthly data and seasonal data of each year during 2003-2020.



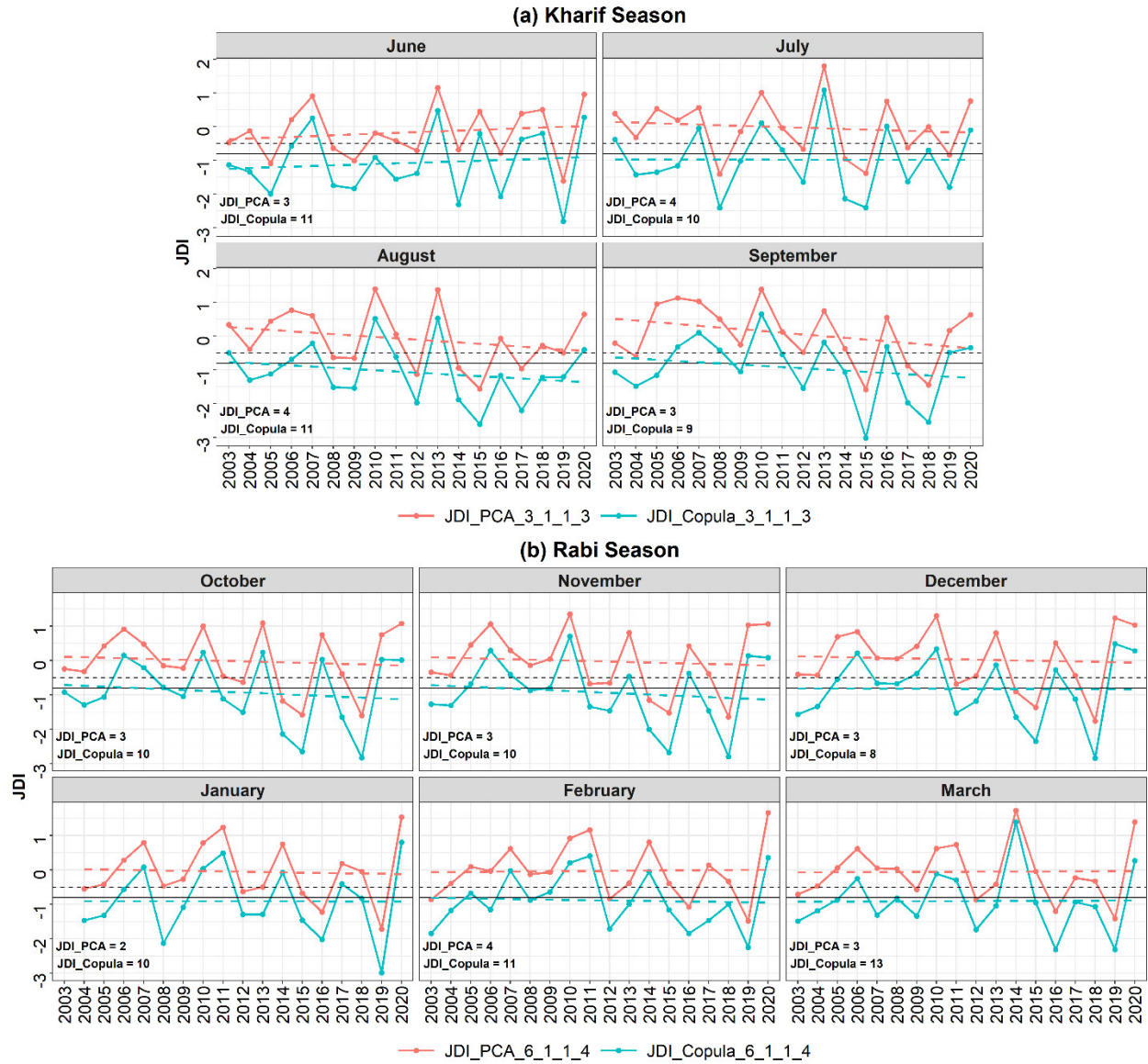
**Figure S7:** Significance value (p value) for Cramer-von Mises statistic (Sn) and Kolmogorov-Smirnov statistic (Tn) for gaussian copula in Kharif season (a & b; JDI\_Copula\_3\_1\_1\_3) and Rabi season (c & d; JDI\_Copula\_6\_1\_1\_4).



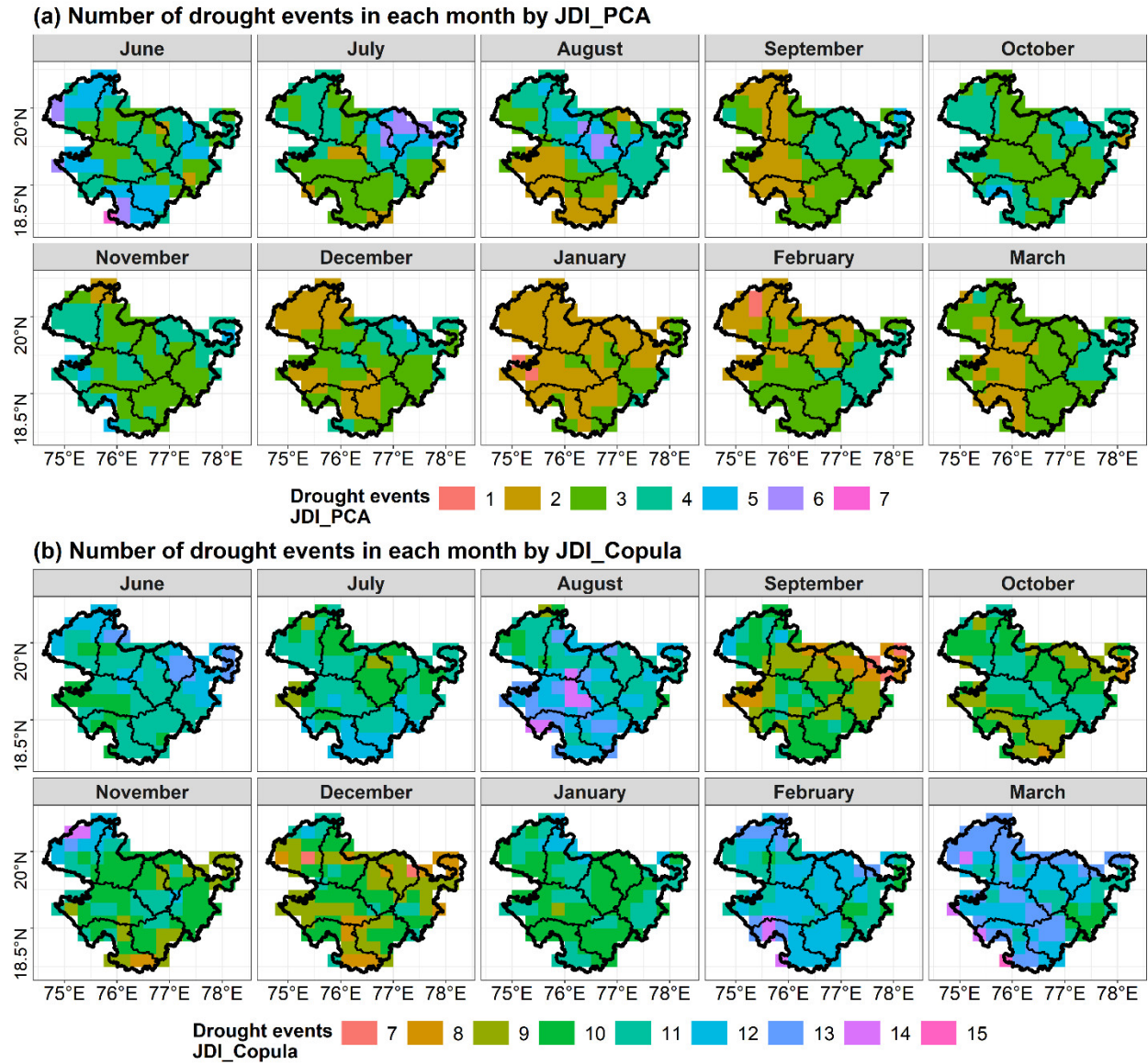


**Figure S8:** Scatterplot showing correlation between JDI\_PCA and JDI\_Copula for Kharif (scale 3\_1\_1\_3) and Rabi (scale 6\_1\_1\_4) season for average Marathwada (a & b,  $r \sim 0.95$ ) and spatial correlation of the same in each season (c & d).

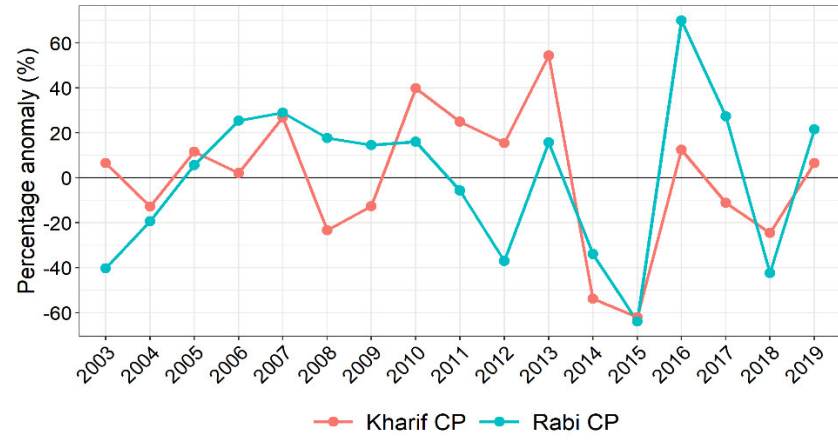




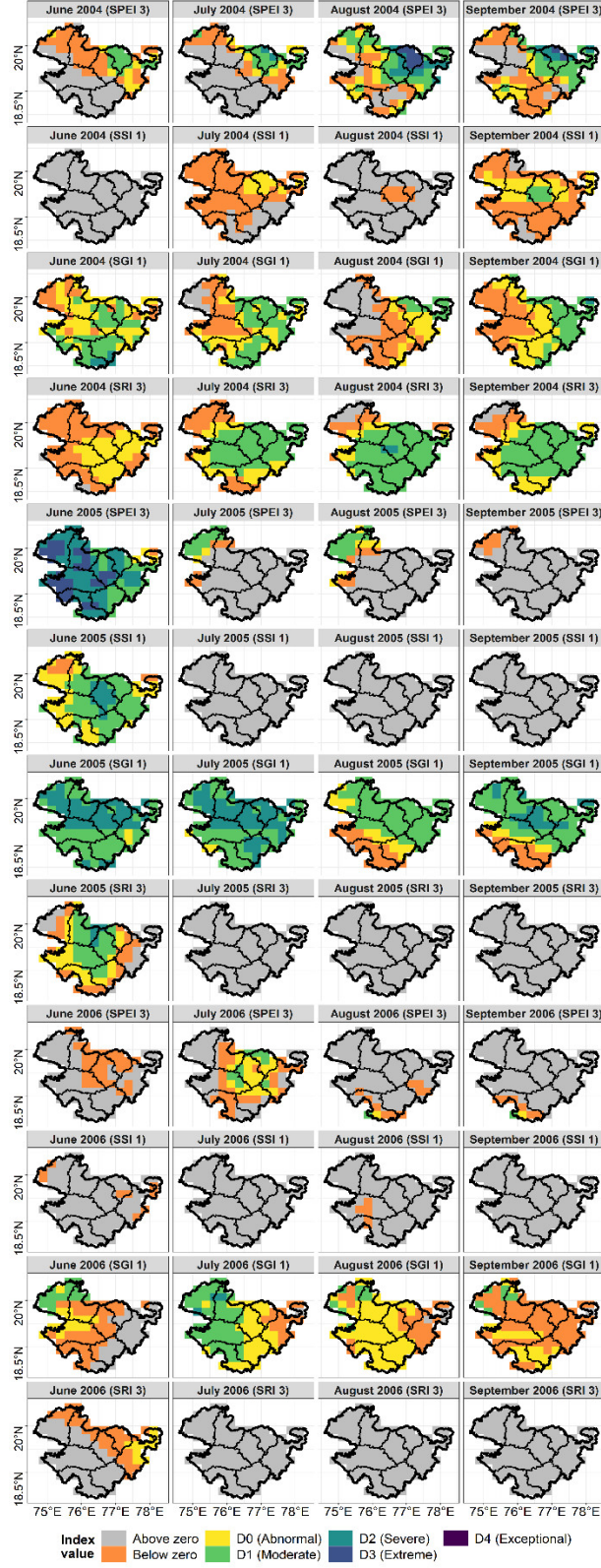
**Figure S9:** Time series of JDI\_PCA and JDI\_Copula in each month of (a) Kharif (June to September) and (b) Rabi (October to March) season during 2003 to 2020. Number of moderate to exceptional drought events captured by JDI\_PCA and JDI\_Copula are noted in bottom left of each panel. Colored dashed lines represent linear trend in each variable while black dashed and solid lines represent abnormally dry ( $JDI = -0.5$ ) and moderate drought ( $JDI = -0.8$ ), respectively.



**Figure S10:** Number of moderate to exceptional drought events in each month of Kharif and Rabi season during 2003 to 2020 using (a) JDI\_PCA and (b) JDI\_Copula.

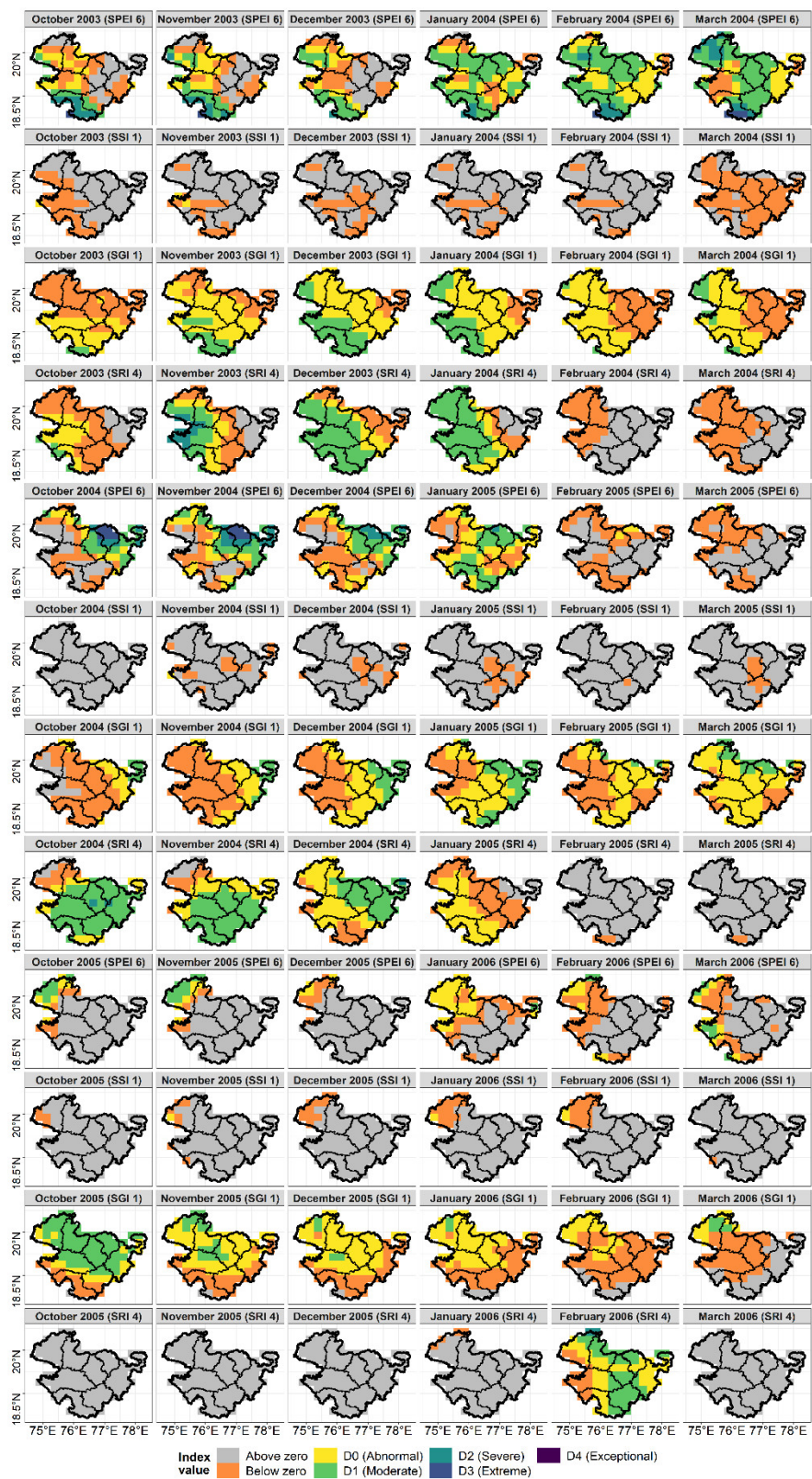


**Figure S11:** Crop production (CP) anomaly in Kharif and Rabi season during 2003-2019.

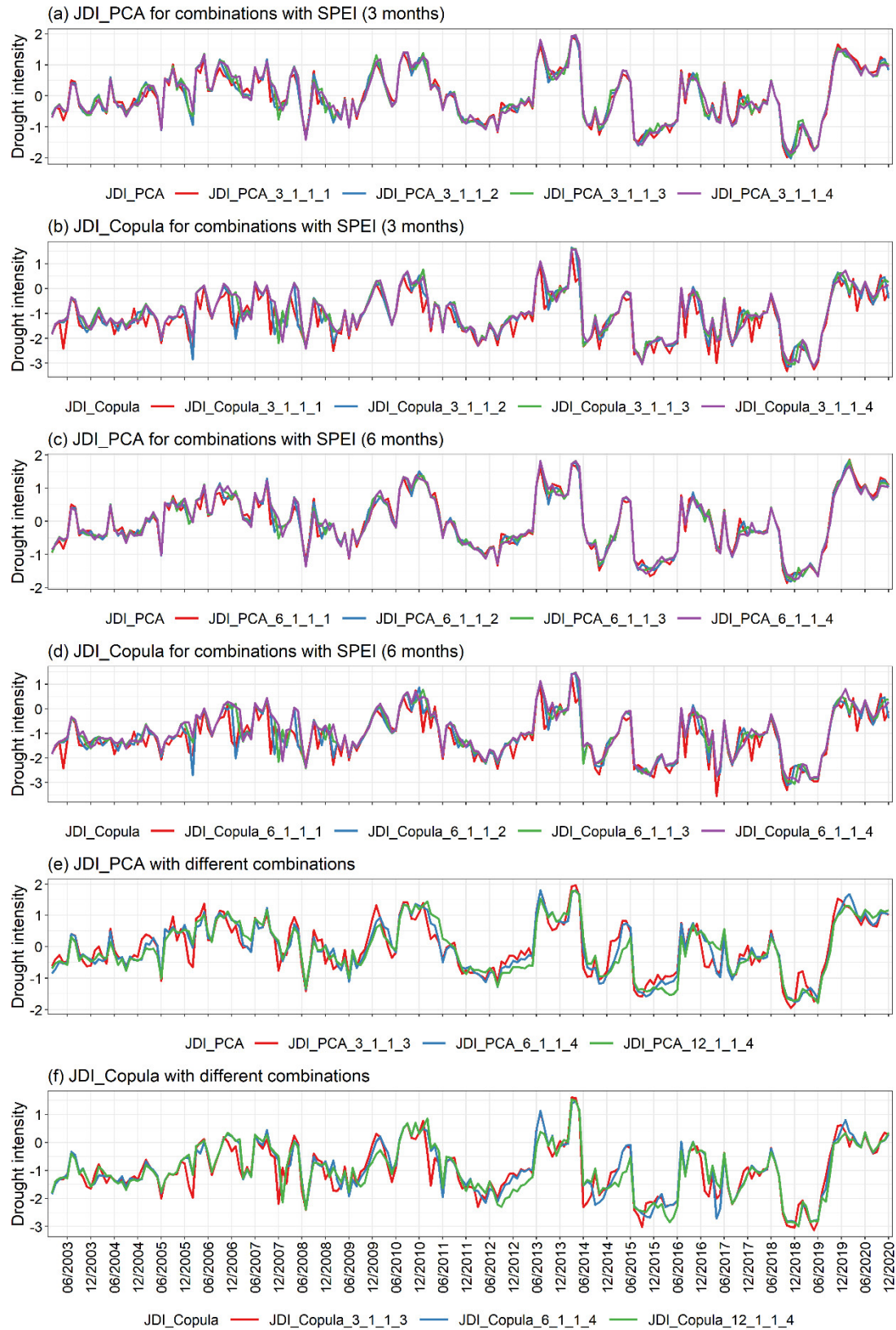


**Figure S12:** Spatial drought severity over Marathwada in Kharif season in each index i.e., SPEI (3 months), SSI (1 month), SGI (1 month) and SRI (3 months) for the year 2004, 2005 and 2006.

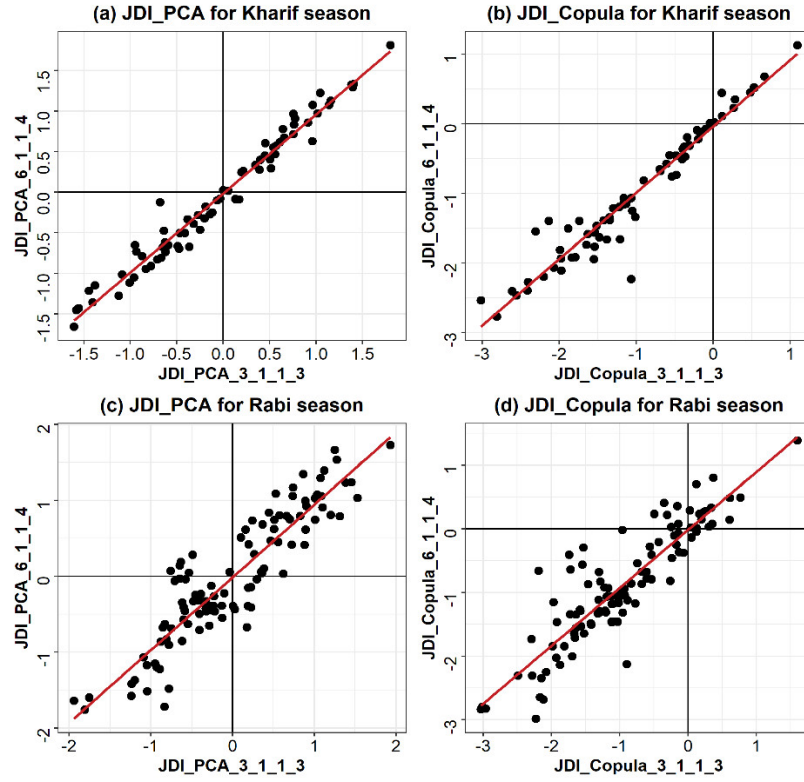




**Figure S13:** Spatial drought severity in Rabi season in each index i.e., SPEI (6 months), SSI (1 month), SGI (1 month) and SRI (4 months) for the year 2003-04, 2004-05 and 2005-06.

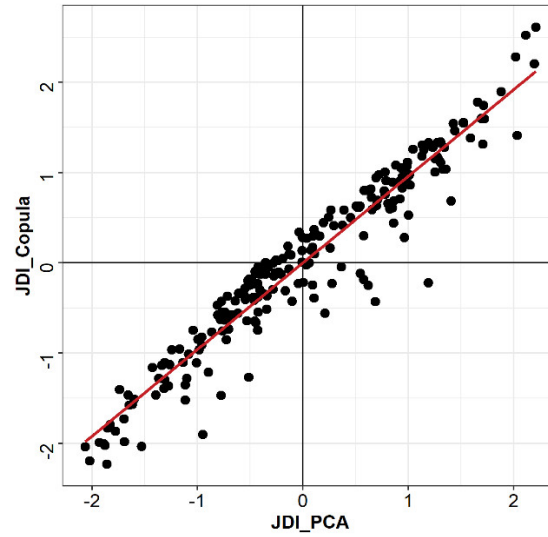


**Figure S14:** Time series of JDI\_PCA and JDI\_Copula with different combinations.



**Figure S15:** Scatterplot of JDI\_PCA and JDI\_Copula for scales 3\_1\_1\_3 and 6\_1\_1\_4 analyzed for Kharif months (a & b) and Rabi months (c and d).





**Figure S16:** Scatterplot of standardized JDI\_PCA and standardized JDI\_Copula obtained by removing the mean and dividing by standard deviation. Scale of the integrated indices from June-September is 3\_1\_1\_3 and for October-May is 6\_1\_1\_4 (order of the variables: SPEI, SSI, SGI, and SRI).

### **Supplimentary Material : Tables**

**Table S1:** Correlation of mean drought intensities by JDI\_PCA and JDI\_Copula with standardized crop productions in Kharif and Rabi seasons for different combinations of the integrated indices (First column represents the scales of the indices integrated within JDI in the order as mentioned. For e.g., 3\_1\_1\_1 represents combination of SPEI (3 months), SSI (1 month), SGI (1 month) and SRI (1 month) for construction of JDI).

SPEI_SSI_SGI_SRI	JDI_PCA		JDI_Copula	
	Kharif CP	Rabi CP	Kharif CP	Rabi CP
3_1_1_1	0.80	0.59	0.80	0.54
3_1_1_2	0.79	0.58	0.80	0.56
<b>3_1_1_3</b>	<b>0.79</b>	0.59	<b>0.82</b>	0.60
3_1_1_4	0.78	0.63	0.80	0.62
4_1_1_1	0.76	0.62	0.77	0.57
4_1_1_2	0.75	0.62	0.78	0.59
4_1_1_3	0.76	0.62	0.80	0.61
4_1_1_4	0.75	0.64	0.78	0.65
6_1_1_1	0.70	0.70	0.71	0.63
6_1_1_2	0.70	0.70	0.73	0.65
6_1_1_3	0.71	0.70	0.75	0.68
<b>6_1_1_4</b>	0.70	<b>0.70</b>	0.73	<b>0.71</b>
12_1_1_1	0.64	0.71	0.63	0.66
12_1_1_2	0.65	0.72	0.66	0.68
12_1_1_3	0.66	0.71	0.69	0.70
12_1_1_4	0.66	0.72	0.66	0.73

**Table S2:** Correlation of JDI\_PCA and JDI\_Copula with their integrated indices for different combinations.

Index	JDI_PCA combination (SPEI_SSI_SGI_SRI)							
	3_1_1_1	3_1_1_2	3_1_1_3	3_1_1_4	4_1_1_1	4_1_1_2	4_1_1_3	4_1_1_4
<b>SPEI</b>	0.85	0.86	<b>0.88</b>	0.84	0.87	0.87	0.88	0.89
<b>SSI</b>	0.90	0.89	<b>0.88</b>	0.90	0.91	0.90	0.90	0.89
<b>SGI</b>	0.77	0.74	<b>0.74</b>	0.76	0.79	0.77	0.77	0.77
<b>SRI</b>	0.55	0.74	<b>0.84</b>	0.83	0.52	0.70	0.79	0.84
<b>Index</b>	6_1_1_1	6_1_1_2	6_1_1_3	<b>6_1_1_4</b>	12_1_1_1	12_1_1_2	12_1_1_3	12_1_1_4
<b>SPEI</b>	0.90	0.89	0.90	<b>0.90</b>	0.89	0.88	0.88	0.88
<b>SSI</b>	0.92	0.92	0.91	<b>0.91</b>	0.90	0.90	0.90	0.89
<b>SGI</b>	0.81	0.80	0.80	<b>0.80</b>	0.86	0.85	0.85	0.85
<b>SRI</b>	0.44	0.60	0.73	<b>0.79</b>	0.36	0.53	0.66	0.73
Index	JDI_Copula combination (SPEI_SSI_SGI_SRI)							
	3_1_1_1	3_1_1_2	3_1_1_3	3_1_1_4	4_1_1_1	4_1_1_2	4_1_1_3	4_1_1_4
<b>SPEI</b>	0.79	0.82	<b>0.83</b>	0.81	0.80	0.82	0.83	0.84
<b>SSI</b>	0.81	0.82	<b>0.84</b>	0.85	0.81	0.83	0.85	0.85
<b>SGI</b>	0.71	0.74	<b>0.77</b>	0.78	0.72	0.75	0.77	0.79
<b>SRI</b>	0.68	0.75	<b>0.80</b>	0.79	0.67	0.75	0.79	0.81
<b>Index</b>	6_1_1_1	6_1_1_2	6_1_1_3	<b>6_1_1_4</b>	12_1_1_1	12_1_1_2	12_1_1_3	12_1_1_4
<b>SPEI</b>	0.77	0.79	0.83	<b>0.84</b>	0.74	0.76	0.79	0.80
<b>SSI</b>	0.81	0.83	0.85	<b>0.86</b>	0.81	0.83	0.85	0.85
<b>SGI</b>	0.73	0.76	0.79	<b>0.80</b>	0.75	0.78	0.81	0.82
<b>SRI</b>	0.67	0.73	0.77	<b>0.79</b>	0.63	0.70	0.74	0.76

**Table S3:** Seasonal weights of indices for JDI\_PCA in Kharif (scale 3\_1\_1\_3) and Rabi (scale 6\_1\_1\_4) season. For each season, weights were obtained by applying PCA separately over seasonal data points (June-September of each year for Kharif and October to March for Rabi), where 4 weights per season (1 for each variable) were generated (total 8)

<b>Scale of variables for each season</b>	<b>SPEI</b>	<b>SSI</b>	<b>SGI</b>	<b>SRI</b>
<b>3_1_1_3 (June-September)</b>	0.29	0.28	0.17	0.26
<b>6_1_1_4 (October-March)</b>	0.28	0.28	0.26	0.19

**Table S4:** Correlation between JDI\_PCAs having different combinations of the integrated indices.

JDI_PCA	3_1_1_1	3_1_1_2	3_1_1_3	3_1_1_4	4_1_1_1	4_1_1_2	4_1_1_3	4_1_1_4	6_1_1_1	6_1_1_2	6_1_1_3	6_1_1_4	12_1_1_1	12_1_1_2	12_1_1_3	12_1_1_4
3_1_1_1	1.00	0.99	0.98	0.98	0.99	0.98	0.98	0.96	0.96	0.95	0.95	0.95	0.92	0.92	0.92	0.92
3_1_1_2	0.99	1.00	0.99	0.98	0.97	0.99	0.98	0.96	0.93	0.95	0.95	0.94	0.89	0.91	0.91	0.91
3_1_1_3	0.98	0.99	1.00	0.98	0.96	0.97	0.99	0.96	0.93	0.94	0.96	0.94	0.88	0.90	0.92	0.91
3_1_1_4	0.98	0.98	0.98	1.00	0.98	0.98	0.99	0.99	0.95	0.96	0.97	0.97	0.90	0.92	0.93	0.94
4_1_1_1	0.99	0.97	0.96	0.98	1.00	0.99	0.98	0.98	0.97	0.97	0.96	0.97	0.93	0.93	0.93	0.94
4_1_1_2	0.98	0.99	0.97	0.98	0.99	1.00	0.99	0.99	0.95	0.97	0.96	0.97	0.91	0.93	0.93	0.93
4_1_1_3	0.98	0.98	0.99	0.99	0.98	0.99	1.00	0.99	0.95	0.96	0.97	0.97	0.90	0.92	0.94	0.94
4_1_1_4	0.96	0.96	0.96	0.99	0.98	0.99	0.99	1.00	0.95	0.96	0.96	0.98	0.90	0.92	0.93	0.94
6_1_1_1	0.96	0.93	0.93	0.95	0.97	0.95	0.95	0.95	1.00	0.99	0.99	0.98	0.96	0.95	0.96	0.95
6_1_1_2	0.95	0.95	0.94	0.96	0.97	0.97	0.96	0.96	0.99	1.00	0.99	0.99	0.95	0.96	0.96	0.96
6_1_1_3	0.95	0.95	0.96	0.97	0.96	0.96	0.97	0.96	0.99	0.99	1.00	0.99	0.94	0.95	0.97	0.96
6_1_1_4	0.95	0.94	0.94	0.97	0.97	0.97	0.97	0.98	0.98	0.99	0.99	1.00	0.94	0.95	0.96	0.97
12_1_1_1	0.92	0.89	0.88	0.90	0.93	0.91	0.90	0.90	0.96	0.95	0.94	0.94	1.00	0.99	0.99	0.98
12_1_1_2	0.92	0.91	0.90	0.92	0.93	0.93	0.92	0.92	0.95	0.96	0.95	0.95	0.99	1.00	0.99	0.99
12_1_1_3	0.92	0.91	0.92	0.93	0.93	0.93	0.94	0.93	0.96	0.96	0.97	0.96	0.99	0.99	1.00	0.99
12_1_1_4	0.92	0.91	0.91	0.94	0.94	0.93	0.94	0.94	0.95	0.96	0.96	0.97	0.98	0.99	0.99	1.00

**Table S5:** Correlation between JDI\_Copulas having different combinations of the integrated indices.

JDI_Co pula	3_1_ 1_1	3_1_ 1_2	3_1_ 1_3	3_1_ 1_4	4_1_ 1_1	4_1_ 1_2	4_1_ 1_3	4_1_ 1_4	6_1_ 1_1	6_1_ 1_2	6_1_ 1_3	6_1_ 1_4	12_1_ 1_1	12_1_ 1_2	12_1_ 1_3	12_1_ 1_4
3_1_1_ 1	1.00	0.93	0.92	0.91	0.99	0.92	0.91	0.89	0.97	0.90	0.89	0.87	0.94	0.87	0.85	0.83
3_1_1_ 2	0.93	1.00	0.96	0.95	0.92	0.99	0.95	0.93	0.89	0.97	0.92	0.89	0.87	0.94	0.89	0.86
3_1_1_ 3	0.92	0.96	1.00	0.98	0.90	0.94	0.99	0.95	0.88	0.92	0.97	0.93	0.85	0.90	0.95	0.90
3_1_1_ 4	0.91	0.95	0.98	1.00	0.91	0.94	0.98	0.98	0.88	0.92	0.96	0.96	0.85	0.89	0.93	0.93
4_1_1_ 1	0.99	0.92	0.90	0.91	1.00	0.93	0.91	0.92	0.98	0.92	0.89	0.89	0.95	0.87	0.85	0.85
4_1_1_ 2	0.92	0.99	0.94	0.94	0.93	1.00	0.95	0.95	0.90	0.98	0.92	0.92	0.87	0.95	0.89	0.88
4_1_1_ 3	0.91	0.95	0.99	0.98	0.91	0.95	1.00	0.98	0.89	0.94	0.98	0.95	0.86	0.90	0.95	0.92
4_1_1_ 4	0.89	0.93	0.95	0.98	0.92	0.95	0.98	1.00	0.89	0.93	0.95	0.98	0.85	0.90	0.92	0.95
6_1_1_ 1	0.97	0.89	0.88	0.88	0.98	0.90	0.89	0.89	1.00	0.92	0.90	0.90	0.96	0.87	0.85	0.85
6_1_1_ 2	0.90	0.97	0.92	0.92	0.92	0.98	0.94	0.93	0.92	1.00	0.94	0.93	0.88	0.96	0.90	0.89
6_1_1_ 3	0.89	0.92	0.97	0.96	0.89	0.92	0.98	0.95	0.90	0.94	1.00	0.97	0.86	0.90	0.96	0.93
6_1_1_ 4	0.87	0.89	0.93	0.96	0.89	0.92	0.95	0.98	0.90	0.93	0.97	1.00	0.86	0.89	0.93	0.96
12_1_1_ 1	0.94	0.87	0.85	0.85	0.95	0.87	0.86	0.85	0.96	0.88	0.86	0.86	1.00	0.91	0.89	0.89
12_1_1_ 2	0.87	0.94	0.90	0.89	0.87	0.95	0.90	0.90	0.87	0.96	0.90	0.89	0.91	1.00	0.94	0.93
12_1_1_ 3	0.85	0.89	0.95	0.93	0.85	0.89	0.95	0.92	0.85	0.90	0.96	0.93	0.89	0.94	1.00	0.97
12_1_1_ 4	0.83	0.86	0.90	0.93	0.85	0.88	0.92	0.95	0.85	0.89	0.93	0.96	0.89	0.93	0.97	1.00