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Analysis of Drought in the Northern Region of Bangladesh Using Standardized Precipitation Index (SPI)

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Abstract

Drought is an extended period when a region notes a deficiency in its water supply. The Standardized Precipitation Index (SPI) method was used in this study to analyze drought. Northern region of Bangladesh was the area of study. Monthly rainfall data of northern region of Bangladesh was obtained from the Meteorological Department of Bangladesh. Obtained rainfall data was from 1991 to 2011 and values from 2012 to 2026 were generated using Markov model. Then SPI values from 1991 to 2026 were calculated by using SPI formula for analyzing drought. Analysis with SPI method showed that droughts in northern region of Bangladesh varied from moderately dry to severely dry conditions and it may vary from moderately dry to severely dry conditions normally in future but in some cases extreme drought may also take place. From the study, it is observed that the northern region of Bangladesh has already experienced severe drought in 1991, 1992, 1994, 1995, 1997, 1998, 2000, 2003, 2005, 2007, 2009 and 2010. The region may experience severe drought in 2012, 2015, 2016, 2018, 2019, 2021, 2022, 2023, 2024, 2025 and 2026 and extreme drought in 2012, 2014, 2016, 2023 and 2024.

Key words: Drought, Markov model, Rainfall data

Introduction

A drought is an extended period when a region notes a deficiency in its water supply (Beran and Rodier, 1985). Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the affected regions. Although droughts can persist for several years, even a short, intense drought can cause significant damage (Daniel, 2008). Many people in Bangladesh as well as the government perceive floods and cyclones as recurrent environmental hazards in the country. They also view that these two hazards are the main contributors to crop loss in the country. But in reality, droughts afflict the country at least as frequently as do major floods and cyclones, averaging about once in 2.5 years (Adnan, 1993; Ericksen, 1993; Hossain, 1990). Drought was the lone environmental factor to cause severe crop damage in Bangladesh in 1994. The northwestern region of the country, popularly known as North Bengal, experienced one of the most severe droughts of the century, which started in October 1994 and was broken in July 1995 with the onset of monsoon rain (Rahman, 1995). The continued drought in the northwestern districts of Bangladesh led to a shortfall of rice production of 3.5 million tons (Rahman and Biswas, 1995).

It is not possible to avoid drought but drought preparedness can be developed and drought impacts can be managed. The success of both depends, amongst others, on how well the droughts are defined and drought characteristics quantified (Smakhtin and Hughes, 2004). Droughts have often resulted in famine, displacement of people, homelessness, ill health, social disorder and in advance stages death (Odongkara, 2002). Most parts of Bangladesh depend on rain fed agriculture. But the amounts of rainfall and their duration time throughout the year are decreasing day by day. So drought has become a curse in many regions now-a-days. It is thus important to carry out drought studies so that when the disaster (drought) strikes, the occupants of the area are not caught unaware. Northern region of Bangladesh is taken as a case study area in this observation because it is considered as the most drought prone area of Bangladesh. The objective of the study is to generate future precipitation values using the Multi-period Markov model and analyze drought using the Standardized Precipitation Index (SPI).

Materials and Methods

Study area

The Meteorological Department of Bangladesh has six stations in the northern part of Bangladesh and they were selected for the study (Table 1).

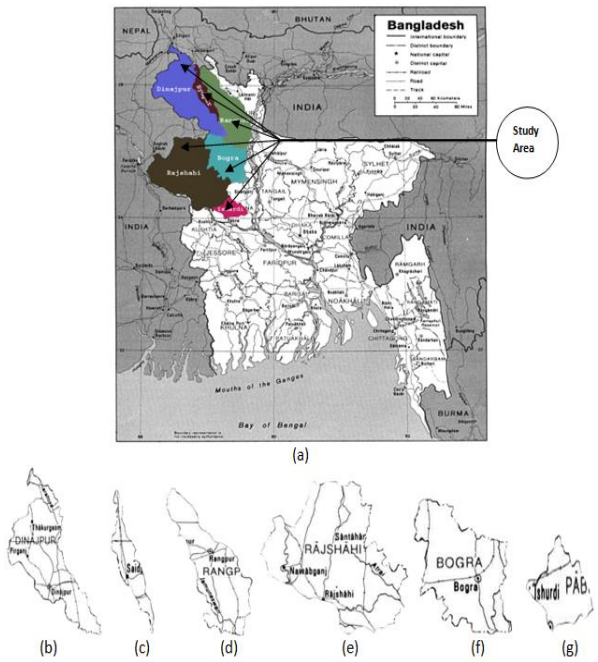

Fig. 1. Map showing the geographic position of the study area- (a) Bangladesh, (b) Dinajpur, (c) Sydpur, (d) Rangpur, (e) Rajshahi, (f) Bogra and (g) Ishurdi

Table 1. Names and locations of the selected stations

Station No.	Name of the Station	Latitude	Longitude
1.	Dinajpur	25° 39´N	88° 41´E
2.	Rangpur	25° 44´N	89° 14´E
3.	Rajshahi	24° 22´N	88° 42´E
4.	Bogra	24° 51´N	89° 22´E
5.	Sydpur	25° 47´N	88° 53´E
6.	Ishurdi	24° 08´N	89° 03´E

Data collection

Monthly rainfall data records for the selected regions were obtained from the Meteorological Department, Agargaon, Dhaka.

Generation of rainfall data

Markov generation technique was used to generate and extend the rainfall data to the year 2042 for the northern region of Bangladesh. The formula is given below:

$$Q_{ij} = \bar{Q}_j + b_j(Q_{i-1,j-1} - \bar{Q}_{j-1}) + \sigma_j\sqrt{1 - r_j^2}\,\varepsilon$$

where, i is the periodic index (years),

j is the annual index (months),

Q_{ij} is the generated precipitation value (which will be set to zero, in case it is negative, but only after all the subsequent rainfall values have been generated),

$\bar{Q}_j$ is the mean precipitation in month j. It is given by:

$$\bar{Q}_j = \frac{\sum Q_j}{n}$$

where, Q_j is the precipitation in month j and n is the number of years,

b_j is a parameter given by

$$r_j\left(\frac{\sigma_{j+1}}{\sigma_j}\right)$$

$Q_{i-1, j-1}$ is the final recorded monthly precipitation from the preceding year or the generated value from the preceding year,

$\bar{Q}_{j-1}$ is the preceding mean monthly rainfall,

t_i is a random number selected from a normal distribution having a zero mean and unit variance. The random number is given by = *RAND()* in Microsoft Excel. Using *NORMINV(RAND(),0,1)* in Microsoft Excel generates t_i.

σ_j is the standard deviation of observed precipitation values for the month j given by:

$$\sigma_j = \sqrt{\frac{n\sum Q_j^2 - \left(\sum Q_j\right)^2}{n(n-1)}}$$

r_j is the correlation coefficient for the relation of values in the period $j+1$ and period j. It is given by:

$$r_j = \frac{cov\left(Q_j, Q_{j+1}\right)}{\sigma_j \cdot \sigma_{j+1}}$$

where,

$$cov\left(Q_j, Q_{j+1}\right) = \frac{1}{n}\sum_{m=1}^{n}\left(Q_{j_m} - \bar{Q}_j\right)\left(Q_{j+1_m} - \bar{Q}_{j+1}\right)$$

Analysis of drought

Analysis in terms of rainfall: The Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a way of measuring drought and the SPI value is defined as the ratio of the difference between the measured rainfall and the long term mean to the standard deviation for any month (Table 2).

$SPI = \frac{Q_j - Q_j}{\sigma_j}$ where, σ_j is the standard deviation for the month, Qj and are the measured monthly and long term mean monthly rainfall respectively.

Table 2: The SPI scales

SPI values	Weather condition
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Results and Discussions

Analysis of the collected rainfall data (1991-2011)

Station No. 1 (Dinajpur) had experienced the highest rainfall in 2005 and the lowest in 1994. June, July, August and September were considered as the wettest periods having the highest rainfall amount over the study period. January, February, March, November and December were regarded as the driest periods having the lowest rainfall amount. April, May and October had moderate rainfall amount over the study periods (SI Table 1).

SI Table 1. Monthly rainfall data records (mm) for Station No. 1 (Dinajpur) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	27	4	1	18	400	376	184	282	647	29	0	44
1992	6	6	1	5	87	212	535	228	483	76	6	4
1993	42	0	29	82	308	495	218	565	361	64	15	0
1994	23	22	0	50	146	294	148	122	248	89	0	0
1995	3	12	10	0	54	287	472	593	1026	77	74	5
1996	16	4	0	29	76	320	428	353	744	75	0	0
1997	21	11	3	64	90	501	461	330	289	3	0	36
1998	2	17	24	148	152	237	566	548	317	380	0	0
1999	0	0	0	68	367	283	403	587	589	234	5	0
2000	0	30	1	147	325	399	197	195	196	25	0	0
2001	0	0	0	5	222	573	158	318	462	382	53	0
2002	8	18	13	168	104	658	795	246	481	56	6	0
2003	11	34	53	105	147	337	532	197	230	380	0	31
2004	7	0	12	163	278	517	602	128	253	330	0	3
2005	9	15	37	89	255	474	507	597	222	770	0	0
2006	0	0	1	67	259	222	218	126	340	21	23	8
2007	0	30	2	33	121	474	401	233	234	51	0	0
2008	33	1	19	27	220	363	437	385	242	45	0	0
2009	0	0	10	41	369	457	281	471	128	267	1	0
2010	0	0	0	84	206	515	356	290	107	82	1	0
2011	0	28	27	61	250	348	285	381	261	0	3	0

Station No. 2 (Rangpur) had faced the highest rainfall in 2002 and the lowest rainfall in 1994. May, June, July, August and September had the highest rainfalls and January, February, March, November and December had the lowest rainfalls over the study periods. April and October had moderate rainfalls (SI Table 2).

SI Table 2. Monthly rainfall data records (mm) for Station No. 2 (Rangpur) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	38	1	1	41	302	593	162	264	726	106	2	27
1992	13	10	0	89	245	348	248	367	552	129	4	2
1993	49	0	30	62	190	633	499	572	358	91	26	0
1994	16	29	28	49	212	427	202	97	135	106	0	0
1995	3	3	4	1	158	369	568	388	804	51	109	3
1996	13	0	0	39	232	396	479	353	333	159	0	0
1997	19	14	3	113	230	276	523	338	410	16	2	27
1998	0	12	50	173	202	333	473	458	255	409	0	0
1999	0	0	7	228	336	447	436	829	337	303	8	0
2000	1	15	3	283	416	438	166	232	172	19	0	0
2001	0	1	23	38	235	481	341	346	550	470	7	0
2002	8	6	38	376	290	913	582	287	521	99	7	0
2003	8	23	109	143	160	573	633	183	206	340	0	24
2004	9	0	39	196	347	352	653	133	464	484	0	3
2005	11	9	61	93	271	428	671	400	328	581	0	0
2006	0	1	2	85	367	472	271	96	235	120	8	25
2007	0	47	16	39	233	568	558	149	277	138	12	0
2008	36	1	49	74	273	444	232	396	227	175	0	0
2009	0	0	9	158	270	336	304	832	77	231	0	0
2010	0	0	0	169	237	650	346	240	332	122	4	2
2011	0	20	13	28	261	306	389	542	366	6	1	0

Station No. 3 (Rajshahi) had experienced the highest rainfalls in 1997 and the lowest in 1992. June, July, August, September and October were the wettest months over the study period. January, February, March, November and December were considered as the driest months. April and May had moderate rainfalls (SI Table 3).

SI Table 3. Monthly rainfall data records (mm) for Station No. 3 (Rajshahi) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	6	0	19	25	157	211	286	96	484	122	0	92
1992	1	33	0	16	121	85	244	185	124	29	5	0
1993	0	5	55	70	65	477	247	177	316	157	54	0
1994	18	36	5	31	115	237	171	206	171	130	22	0
1995	17	31	9	8	91	291	287	270	370	13	44	1
1996	0	21	4	73	95	284	106	270	298	118	0	0
1997	8	35	19	56	53	242	763	468	348	4	44	22
1998	16	5	52	33	129	92	404	268	310	198	33	0
1999	0	0	0	9	144	348	349	354	502	155	1	0
2000	4	47	27	136	198	244	115	190	644	85	0	0
2001	0	0	9	13	209	324	338	209	95	184	1	0
2002	10	1	20	96	196	222	316	238	281	48	17	0
2003	3	18	64	45	84	280	230	128	262	292	0	6
2004	10	0	0	61	92	507	339	275	349	153	0	0
2005	14	1	104	27	108	92	492	161	131	275	0	0
2006	0	0	7	36	189	188	130	247	302	36	10	0
2007	0	27	59	13	260	313	364	236	309	76	1	0
2008	26	0	0	30	144	247	373	245	129	121	0	0
2009	1	7	28	0	131	126	183	240	282	45	0	0
2010	0	2	2	37	75	211	94	101	101	127	3	39
2011	6	0	10	94	187	341	144	454	203	35	1	0

Station No. 4 (Bogra) had experienced the highest rainfalls in 1998 and the lowest rainfalls in 2006 over the last 21 years. May, June, July, August and September were the months having the highest rainfalls. January, February, March, November and December had the lowest rainfalls over the study periods. April and October had moderate rainfalls (SI Table 4).

SI Table 4. Monthly rainfall data records (mm) for Station No. 4 (Bogra) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	4	14	8	48	416	240	404	207	733	105	0	112
1992	0	14	0	30	140	202	289	159	424	108	3	0
1993	65	8	14	58	268	466	432	266	240	95	2	0
1994	14	26	4	32	156	305	165	208	268	199	5	0
1995	16	18	14	0	111	462	524	438	477	117	70	1
1996	3	28	7	104	184	283	338	185	366	176	0	0
1997	10	11	9	140	102	199	298	245	220	29	2	27
1998	10	13	26	84	143	367	749	563	283	353	10	0
1999	0	0	0	9	261	283	343	397	145	133	17	0
2000	18	37	76	158	272	250	190	289	466	84	0	0
2001	0	0	0	22	223	299	185	115	344	203	8	0
2002	7	0	13	284	132	254	476	496	326	27	21	0
2003	4	53	72	113	214	364	219	220	156	264	0	13
2004	0	0	45	90	137	638	529	261	206	251	0	0
2005	5	9	58	72	138	130	471	328	356	523	0	1
2006	0	0	12	143	193	184	192	138	174	69	1	0
2007	0	18	25	28	92	732	320	256	302	131	15	0
2008	27	0	22	20	213	393	474	374	109	159	0	0
2009	0	3	3	49	205	128	194	570	169	89	0	0
2010	0	0	0	26	185	286	92	225	244	190	3	20
2011	1	0	7	145	194	193	175	606	389	0	11	0

Station No. 5 (Sydpur) had experienced the highest rainfalls in 1999 and the lowest rainfalls in 1994. June, July, August and September were the months having the highest rainfalls. January, February, March, November and December had the lowest rainfalls. April, May and October had moderate rainfalls over the last 21 years (SI Table 5).

SI Table 5. Monthly rainfall data records (mm) for Station No. 5 (Sydpur) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	13	0	16	4	245	497	81	183	748	20	0	29
1992	16	5	0	0	133	219	318	317	498	74	2	12
1993	38	0	45	58	201	700	293	360	383	86	38	0
1994	19	40	21	49	143	224	176	75	255	242	0	0
1995	5	11	3	0	46	576	431	325	890	80	81	4
1996	18	0	0	10	195	259	501	227	468	101	0	0
1997	25	10	0	77	214	396	640	257	272	44	2	26
1998	0	10	23	148	217	322	725	838	472	381	0	3
1999	0	0	0	67	532	339	659	951	444	144	9	0
2000	0	1	2	219	303	368	138	206	201	27	1	0
2001	2	1	0	34	296	456	215	174	619	474	10	0
2002	11	5	162	380	137	755	865	215	307	27	6	0
2003	7	25	143	181	238	703	462	148	230	425	0	29
2004	4	0	21	138	435	546	735	253	340	313	1	1
2005	13	6	51	57	147	505	637	516	158	560	0	0
2006	0	0	2	90	633	525	211	74	404	76	20	18
2007	0	9	8	84	138	385	432	257	466	64	46	0
2008	32	1	19	29	253	572	453	408	128	44	0	0
2009	0	0	15	93	317	251	501	558	186	232	0	0
2010	0	0	0	131	202	642	288	263	259	163	2	1
2011	0	19	28	50	283	223	409	559	318	0	1	0

Station No. 6 (Ishurdi) had faced the wettest periods in 1997 and the driest periods in 2010. May, June, July, August and September were the months having the highest rainfalls. January, February, March, November and December had the lowest rainfalls over the last 21 years. April and October were the months having moderate rain fall (SI Table 6).

SI Table 6. Monthly rainfall data records (mm) for Station No. 6 (Ishurdi) from 1991-2011

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1991	2	9	28	42	173	360	248	189	424	141	2	79
1992	0	40	0	18	132	73	252	207	295	38	5	3
1993	2	6	53	120	213	299	248	189	358	102	22	0
1994	24	45	3	31	155	336	111	150	99	82	2	0
1995	8	24	20	1	105	215	224	307	345	8	70	3
1996	0	25	17	104	81	295	155	271	269	183	0	0
1997	4	43	42	110	132	199	486	301	473	53	15	20
1998	16	12	68	109	269	101	413	225	285	96	42	0
1999	0	0	0	2	203	386	407	249	297	205	3	0
2000	8	61	20	206	233	212	241	147	551	129	0	0
2001	0	0	20	52	257	409	165	158	334	74	10	0
2002	15	2	62	72	177	296	253	227	240	75	47	0
2003	0	24	73	89	58	353	134	87	145	134	0	5
2004	0	0	0	127	125	292	397	156	541	151	0	0
2005	14	3	75	13	89	199	378	246	137	664	0	1
2006	0	0	2	74	213	199	233	244	277	4	40	0
2007	0	35	22	30	50	269	516	285	220	131	15	0
2008	37	2	12	35	145	206	295	208	256	108	0	0
2009	0	4	71	16	134	73	299	278	350	67	0	0
2010	0	3	0	46	100	162	175	127	109	105	3	63
2011	4	1	30	96	155	253	289	645	261	2	0	0

Generation of rainfall rata using Markov generation technique

Each of the six stations had 21 years of record from 1991 to 2011. The Markov generation technique was used to generate data from 2012 to 2026, so that future stimulations could be made.

Calculation of the required parameters

In order to use the Markov generation equation in the generation of rainfall data, it was first necessary to calculate the required means, standard deviations and correlations for the given data on a monthly basis with reference to the period 1991 to 2011. Here, the parameters are calculated for Station no. 1 (Dinajpur) (Table 3) and then they are calculated in the same way for other stations.

Table 3. Calculated parameters for data generation for Station No. 1 (Dinajpur)

Month, j	Mean monthly precipitation, $\overline{Q}_j$ (mm)	Standard deviation, $Ó_j$	Correlation coefficient, r_j	b_j	$(1-r_j\hat{}2)\hat{}1/2$
Jan	9.9	12.5	-0.2	-0.1	1
Feb	11	11.9	0.4	0.4	0.9
Mar	11.6	14.8	0.3	1.1	0.9
Apr	69.2	52.2	0.1	0.2	1
May	211.2	105.4	0.1	0.1	1
Jun	397.2	123.1	0.1	0.2	1
Jul	389.7	171.1	0.1	0.1	1
Aug	341.7	162	0.3	0.4	1
Sep	374.3	225.1	-0.2	-0.2	1
Oct	163.6	193.1	-0.1	-0.1	1
Nov	8.9	19.3	-0.1	-0.1	1
Dec	6.2	13.2	0.3	0.3	1

Generation of the required values

Monthly rainfall values of 2011 were used as initial values for use in Equation 2 to generate values for the next year (2012). All calculations were done in Excel. Table 4 shows part of generation process with reference to the year 2013 for station no. 1 (Dinajpur). Then the generated rainfall values, covering the whole study period for the northern region of Bangladesh, have been attached in Table 5, 6, 7, 8, 9 and 10.

Table 4. Generation of synthetic monthly rainfall for Station No. 1 (Dinajpur)

Year i	Monthj	b_j	$Ó_j*(1-r_j\hat{}2)\hat{}1/2$	$\overline{Q}_j$ (mm)	$\overline{Q}_{j-1}$ (mm)	Random number	$Q_{j-1,i-1}$ (mm)	t_j	$b_j (Q_{j-1,i-1}-\overline{Q}_{j-1})$	$t_j* Ó_j*(1-r_j\hat{}2)\hat{}1/2$	$Q_{i,j}$ (mm)
2012	1	-0.1	12.3	9.9	6.2	0.5	0	0.1	0.62	1.2	11.7
2012	2	0.4	11.1	11	8.9	0.1	28	-1.8	7.64	-19.9	-1.3
2012	3	1.1	14	11.6	163.6	0.2	27	-0.9	-150.3	-12.6	-151.3
2012	4	0.2	51.9	69.2	374.3	0.6	61	0.2	-62.7	10.4	16.9
2012	5	0.1	105	211.2	341.7	0.1	250	-2	-9.2	-210	-8
2012	6	0.2	121.7	397.2	389.7	0.9	348	1.4	-8.3	170.4	559.3
2012	7	0.1	170.4	389.7	397.2	0.5	285	0.1	-11.2	17	395.5
2012	8	0.4	155	341.7	211.2	0.9	381	1.6	67.9	248	657.6
2012	9	-0.2	221.2	374.3	69.2	0.5	261	-0.1	-38.4	-22.1	313.8
2012	10	-0.1	193.1	163.6	11.6	0.4	0	-0.4	1.2	-77.1	87.7
2012	11	-0.1	19.2	8.9	11	0.4	3	-0.2	0.8	-3.8	5.9
2012	12	0.3	12.6	6.2	9.9	0.3	0	-0.5	-2.9	-6.3	-3.0
2013	1	-0.1	12.3	9.9	6.2	0.6	11.7	0.3	-0.6	3.7	13

2013	2	0.4	11.1	11	8.9	0.2	-1.3	-0.8	-4.1	-8.9	-2
2013	3	1.1	14	11.6	163.6	0.8	-151.3	0.8	-346.4	11.2	-323.6
2013	4	0.2	51.9	69.2	374.3	0.4	16.9	-0.3	-71.5	-15.6	-17.9
2013	5	0.1	105	211.2	341.7	0.5	-8	-1.4	-34.9	-147	293
2013	6	0.2	121.7	397.2	389.7	0.8	559.3	0.8	33.9	97.4	528.5
2013	7	0.1	170.4	389.7	397.2	0.7	395.5	0.5	-0.2	85.2	474.7
2013	8	0.4	155	341.7	211.2	0.2	657.6	-0.8	178.6	-124	396.3
2013	9	-0.2	221.2	374.3	69.2	0.4	313.8	-0.3	-48.9	-66.4	259
2013	10	-0.1	193.1	163.6	11.6	0.9	87.7	1.3	-7.6	251	407
2013	11	-0.1	19.2	8.9	11	0.6	5.9	0.3	0.5	5.8	15.2
2013	12	0.3	12.6	6.2	9.9	0.1	-3.0	-1.3	-3.9	-16.4	-14.1

Table 5. Synthetically generated rainfall values (in mm) for Station No. 1 (Dinajpur)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	11.7	0	0	16.9	0	559.3	395.5	657.6	313.8	87.7	5.9	0
2013	1.3	0	0	0	293	528.5	474.7	396.3	259	407	15.2	0
2014	21.5	3.3	0	0	111.8	473.6	533.8	338.2	358.5	568.2	0	16.6
2015	0	2.1	0	0	219.7	401.8	267.0	532	626.1	455.5	0	28.4
2016	14.0	0	0	87.1	115	95.4	342.6	206.5	0	293	0	7.0
2017	7.9	0	0	53.3	199	435.7	401.3	355.3	605.4	560.3	46.0	1.6
2018	8.5	0	0	46.5	207.4	503.8	407.2	414.8	421.9	533.6	41.9	0
2019	8.4	0	0	45.2	208.3	517.4	407.7	438.6	458.6	536.2	42.3	0
2020	8.5	0	0	44.9	208.4	520.1	407.8	448.2	451.3	535	42.3	0
2021	5	0	0	29.2	229.4	411.1	254.4	576	607.6	458.8	0	23.2
2022	6.3	0.7	0	26.2	231.5	389.3	239.1	627.1	576.3	466.5	0	30.4
2023	6.2	1.1	0	25.5	231.7	384.0	237.6	647.6	582.6	465.7	0	32.5
2024	8.7	0	0	40	210.7	493.4	390.8	547.3	426.5	0	0	30.6
2025	8.4	0	0	43.9	208.6	515.3	406.1	507.1	457.7	0	8.5	30.1
2026	8.5	0	0	44.6	208.4	519.7	407.6	491.1	451.4	0	0	29.9

Table 6. Synthetically generated rainfall values (in mm) for Station No. 2 (Rangpur)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	19.6	2.6	22.4	105	214.2	307	449	226.7	321.7	380.5	12.2	6.2
2013	17.6	0	25.3	129.1	214.2	307.1	449	258.2	326.1	343	11.1	8.1
2014	17.8	0	26.1	136.3	214.2	307.1	449	255.1	325.7	330.3	6.4	8.6
2015	17.8	0	26.4	138.5	214.2	307.1	449	255.4	325.7	331.6	6.9	8.8
2016	15	0	26.5	139.1	214.2	307.1	449	255.3	325.7	331.5	6.9	8.8
2017	15.3	0	26.5	139.3	214.2	307.1	449	255.4	325.7	331.5	6.9	8.8
2018	11.1	0	0	139.4	214.2	307.1	449	255.3	325.7	331.5	6.9	6.8
2019	11.5	0	0	180.4	227.4	410.6	432.5	337.2	251.9	380.8	0	7.2
2020	11.5	0	0	192.7	227.4	421	432.5	329	259	375.9	0	7.4
2021	11.5	0	0	196.4	227.4	422	432.5	329.9	258.6	376.3	0	7.4
2022	12.9	0	0	197.5	227.4	422.1	432.5	329.8	258.6	376.3	0	6.4
2023	12.7	0	0	197.8	227.4	422.1	432.5	329.8	258.6	376.3	0	6
2024	11.4	1	0	165.1	253.7	422.1	432.5	329.8	258.6	376.3	0	6
2025	12.9	4.7	0	179.9	240.5	481.3	465.5	288.8	314	179	6.4	5
2026	12.7	6.2	0	184.3	240.5	487.2	465.5	292.9	308.4	198.8	4.6	4.7

Table 7. Synthetically generated rainfall values (in mm) for Station No. 3 (Rajshahi)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	6.7	14.4	34.2	29.6	141	246.3	268.4	292.1	271.6	107.6	12.9	6.6
2013	6.7	12.8	31.8	21.1	145.6	258.0	296.4	261.6	264.8	100.4	11.7	5.9
2014	6.7	12.8	32.6	20.2	145.7	256.8	302.0	255.5	265.5	101.1	11.8	5.0
2015	6.7	12.5	33.1	20.9	182.9	255.8	309.3	260.1	266.8	104.2	12.2	6.1
2016	6.7	10.3	33.3	14.3	179.1	249.3	298.4	257.2	268.1	104.7	11.6	7.2
2017	6.7	11.3	32.2	15.1	151.1	255.5	308.6	246.0	266.5	102.3	12.7	6.5
2018	6.7	10.4	33.1	15.8	151.7	251.5	301.4	256.3	272.3	105.7	12.1	7.4
2019	6.7	11.3	32.2	14.8	152.8	256.4	296.8	252.6	266.1	101.4	11.6	6.0
2020	6.7	10.4	31	13.4	150.5	252.5	302.1	257.6	273.8	105	12.5	7.0
2021	6.7	13.0	31.9	15.3	153.4	256.3	315.6	260.5	264.6	99	11.6	6.1
2022	6.7	12.9	32.3	17.3	148.2	253.7	302.8	255.3	272.5	105.2	11.5	7
2023	6.7	13.7	30.9	19.2	145.5	252.8	290.9	258.1	280.2	102.2	11.9	6.1
2024	6.7	13.8	29.3	17.3	153.4	260.7	273.0	266.4	269.6	105.7	11.6	7.2
2025	6.7	12.4	32.6	18.5	145.5	258.8	291.1	277.7	266.4	104.6	12.7	7.8
2026	6.7	11.6	33.1	21.4	149	260.1	300.0	276.1	280.8	102.3	11.4	6

Table 8. Synthetically generated rainfall values (in mm) for Station No. 4 (Bogra)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	28.8	4.4	0	0	352.7	303.6	503.4	225.0	201.7	100.8	26.8	11.7
2013	31.6	7.9	0	0	289.3	336.7	634.7	264.1	220.5	90.8	23.7	10.5
2014	25	8.2	0	0	285.6	405.7	657.4	289.5	175.5	126.9	32	18
2015	34.2	10.9	0	0	243.5	367.4	636.6	287	179.0	123.3	30.4	17.3
2016	29.2	13.1	0	0	260.3	355.9	628.3	287.3	179.6	123.6	30.7	17.4
2017	28.7	14.8	0	0	253.6	352.4	624.0	287.2	179.6	123.6	30.6	17.4
2018	18.3	16.2	0	0	227.3	410.4	429	346	251.4	76.8	5.8	4.0
2019	17.2	17.3	0	0	237.8	427.8	351	340	244.2	81.4	10.8	6.3
2020	11.2	21.9	0	0	211.8	256	394.5	355.4	273.7	127.8	9.8	6.1
2021	10.6	25.6	0	0	222.2	204.5	411.9	353.9	270.7	123.2	9	6.1
2022	16.4	27.3	0	0	218.0	189	418.9	354.0	271.0	123.6	10.2	6.1
2023	11.1	31.2	0	0	190.7	228.6	481.4	309.9	242.3	100.2	11.5	6.1
2024	10.6	34.3	0	0	201.6	240.5	506.4	314.4	245.1	102.5	11.2	6.1
2025	13.5	34.3	0	0	219	273.6	471.6	446.2	187.4	137.4	9.7	3.6
2026	18.2	31.8	0	0	212.1	283.5	457.7	432.0	193.2	133.9	10	3.9

Table 9. Synthetically generated rainfall values (in mm) for Station No. 5 (Sydpur)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	12	11.5	0	143	217.3	327.4	434.6	493.5	302.5	140.4	19.2	5.9
2013	16.6	4.8	0	143	223.8	337.8	447.4	500.0	304.0	126.4	17.4	6.4
2014	10.9	5.8	0	152.9	443.7	474.7	191.4	362.1	516.1	0	0	5.5
2015	12	0	0	143	201.2	352.6	325.8	513.2	282.7	145.5	19	6.4
2016	8.6	1.1	0	117.2	266.8	459.2	374.3	292.2	344.6	142.1	7.1	8.5
2017	10.9	2.5	0	152.9	260.3	469.8	398.6	314.3	338.4	142.5	8.3	8.8
2018	12	0	0	143	219.5	352.1	429.4	517.9	300.4	126.2	18.4	6.7
2019	8.6	0	0	117.2	264	459.1	426.1	291.7	342.8	144.1	7.2	8.6
2020	12	0	0	143.0	219.2	350	443.2	520.2	299	126	18.6	6.7
2021	8.6	0	0	117.2	264	458.9	433	291.5	342.9	144.1	7.2	8.6
2022	16.6	0	0	108.3	191.6	418.9	577.9	360.1	319.3	174.8	14.5	10.8
2023	12	0	0	143	226.4	346	519.1	513.4	302.3	122	17.8	6.9
2024	8.6	0	0	117.2	264.3	458.5	470	292.2	342.6	144.5	7.3	8.6
2025	10.9	0	0	143.0	219.1	350.9	465.1	520.2	300.0	125	18.5	6.7
2026	12	0	0	143.0	223.7	340.2	462.7	497.4	304.3	127.9	17.4	6.5

Table 10. Synthetically generated rainfall values (in mm) for Station No. 6 (Ishurdi)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	8.4	11.7	30	15	118.1	195.9	305.3	334	219.5	120.3	20.2	11.0
2013	8.4	10.7	30	0	110.7	207.3	310.2	333	227.8	108.5	16.1	9.9
2014	5.4	23.8	19.2	0	127.8	271.4	300.9	220.5	252.8	111.6	12.1	14.3
2015	8.4	9.4	27.8	0	112.7	192.2	308.9	334	221.1	109.4	17.7	9.6
2016	7.4	23.9	0	0	208.7	283.9	160.2	258.3	374.0	88.7	5.1	8
2017	8.4	9.4	18.6	0	128.9	189.7	266.6	333.0	196.9	111.6	19.1	10.2
2018	5.4	23.9	16.9	0	131.5	274.9	287.8	220.5	258.0	111.3	11.5	14.2
2019	7.4	20.6	24.7	0	144.4	257.9	294.1	220.5	246.7	111.3	13.1	13.8
2020	8.4	9.8	28.9	0	116	194.9	306.8	334	222.3	109.4	17.5	9.7
2021	13.3	14.6	19	0	97.9	235.9	375.4	283.5	240.5	111.5	18.6	10.1
2022	8.4	10.4	27.8	0	106.7	199.3	331.2	333	223.6	109.4	16.4	10.0
2023	12.3	14.5	18.8	0	96.1	282.5	382.7	258.3	253.6	105.8	14	3.7
2024	7.4	14.1	27.8	0	106.3	190	333.4	333.0	221	110	17.4	10.7
2025	8.4	10.4	29.6	0	108.4	208.5	318.6	334	227.5	109.5	16.7	10
2026	5.4	23.8	19.1	0	127.4	271.2	303.4	220.5	252.8	111.5	12.0	14.3

Analysis of Drought

Standardized Precipitation Index (SPI) method

In the SPI method, the long term mean and standard deviation over the study period for each station were first calculated (Table 11).

Table 11. Calculated Long-term Mean and Standard Deviation for Station No. 1 (1991-2011)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Long term mean	9.9	11	11.6	69.2	211.2	397.2	389.7	341.7	374.3	163.6	8.9	6.2
Standard deviation	12.5	11.9	14.8	52.2	105.4	123.1	171.1	162	225.1	193.1	19.3	13.2

Then the SPI values for each month in each year for each station over the whole study period were calculated (Table 12, 13, 14, 15, 16 and 17).

Table 12. Calculated SPI values for Station No. 1 (Dinajpur) (1991-2011)

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1991	1.4	-0.6	-0.7	-1*	1.8	-0.2	-1.2*	-0.4	1.2	-0.7	-0.5	2.9
1992	-0.3	-0.4	-0.7	-1.2*	-1.2*	-1.5**	0.9	-0.7	0.5	-0.5	-0.2	-0.2
1993	2.6	-0.9	1.2	0.2	0.9	0.8	-1*	1.4	-0.1	-0.5	0.3	-0.5
1994	1	0.9	-0.8	-0.4	-0.6	-0.8	-1.4*	-1.4*	-0.6	-0.4	-0.5	-0.5
1995	-0.6	0.1	-0.1	-1.3*	-1.5**	-0.9	0.5	1.6	2.9	-0.5	3.4	-0.1
1996	0.5	-0.6	-0.8	-0.8	-1.3*	-0.6	0.2	0.1	1.6	-0.5	-0.5	-0.5
1997	0.9	-0.1	-0.6	-0.1	-1.2*	0.8	0.4	-0.1	-0.4	-0.8	-0.5	2.3
1998	-0.6	0.5	0.9	1.5	-0.6	-1.3*	1	1.3	-0.3	1.1	-0.5	-0.5
1999	-0.8	-0.9	-0.8	-0.1	1.5	-0.9	0.1	1.5	1	0.4	-0.2	-0.5
2000	-0.8	1.6	-0.7	1.5	1.1	0	-1.1*	-0.9	-0.8	-0.7	-0.5	-0.5
2001	-0.8	-0.9	-0.8	-1.2*	0.1	1.4	-1.4*	-0.2	0.4	1.1	2.3	-0.5
2002	-0.2	0.6	0.1	1.9	-1*	2.1	2.4	-0.6	0.5	-0.6	-0.2	-0.5
2003	0.1	1.9	2.8	0.7	-0.6	-0.5	0.8	-0.9	-0.6	1.1	-0.5	1.9
2004	-0.2	-0.9	0	1.8	0.6	1	1.2	-1.3*	-0.5	0.9	-0.5	-0.3
2005	-0.1	0.3	1.7	0.4	0.4	0.6	0.7	1.6	-0.7	3.1	-0.5	-0.5
2006	-0.8	-0.9	-0.7	-0.1	0.5	-1.4*	-1*	-1.3*	-0.2	-0.7	0.7	0.1
2007	-0.8	1.6	-0.7	-0.7	-0.9	0.6	0.1	-0.7	-0.6	-0.6	-0.5	-0.5
2008	1.9	-0.8	0.5	-0.8	0.1	-0.3	0.3	0.3	-0.6	-0.6	-0.5	-0.5
2009	-0.8	-0.9	-0.1	-0.5	1.5	0.5	-0.6	0.8	-1.1*	0.5	-0.4	-0.5
2010	-0.8	-0.9	-0.8	0.3	-0.1	1	-0.2	-0.3	-1.2*	-0.4	-0.4	-0.5
2011	-0.8	1.4	1	-0.2	0.4	-0.4	-0.6	0.2	-0.5	-0.9	-0.3	-0.5

* Moderate drought, ** Severe drought, *** Extreme drought

Table 13. Calculated SPI values for Station No. 2 (Rangpur) (1991-2011)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	1.9	-0.7	-0.8	-0.8	0.6	0.9	-1.5**	-0.5	2	-0.6	-0.3	2.1
1992	0.2	0.1	-0.8	-0.3	-0.2	-0.8	-1*	0.1	1	-0.4	-0.2	-0.3
1993	2.7	-0.7	0.3	-0.6	-1.1*	1.1	0.5	1	-0.1	-0.6	0.7	-0.5
1994	0.4	1.6	0.2	-0.7	-0.7	-0.3	-1.3*	-1.3*	-1.2*	-0.6	-0.4	-0.5
1995	-0.5	-0.5	-0.7	*-1.2	-1.6**	-0.7	0.9	0.2	2.4	-0.9	4.2	-0.2
1996	0.2	-0.7	-0.8	-0.8	-0.4	-0.5	0.4	-0.1	-0.2	-0.2	-0.4	-0.5
1997	0.6	0.4	-0.7	-0.1	-0.5	-1.3*	0.7	-0.1	0.2	-1.1*	-0.3	2.1
1998	-0.8	0.2	1	0.6	-0.9	-0.9	0.4	0.5	-0.6	1.3	-0.4	-0.5
1999	-0.8	-0.7	0.6	1.2	1.2	-0.1	0.1	2.3	-0.2	0.6	-0.1	-0.5
2000	-0.7	0.5	-0.7	1.8	2.4	-0.2	-1.5**	-0.6	-1*	-1.1*	-0.4	-0.5
2001	-0.8	-0.7	-0.1	-0.9	-0.4	0.1	-0.5	-0.1	1	1.6	-0.1	-0.5
2002	-0.2	-0.3	0.5	2.7	0.5	3	1	-0.3	0.8	-0.6	-0.1	-0.5
2003	-0.2	1.1	3.1	0.3	-1.5**	0.7	1.3	-0.9	-0.9	0.9	-0.4	1.8
2004	-0.1	-0.7	0.6	0.8	1.3	-0.8	1.4	-1.1*	0.5	1.7	-0.4	-0.2
2005	0	-0.1	1.4	-0.3	0.2	-0.3	1.6	0.2	-0.2	2.3	-0.4	-0.5
2006	-0.8	-0.7	-0.8	-0.4	1.6	0	-0.9	-1.3*	-0.7	-0.5	-0.1	1.9
2007	-0.8	3.1	-0.3	-0.8	-0.4	0.7	0.9	-1*	-0.5	-0.4	0.4	-0.5
2008	1.8	-0.7	0.9	-0.5	0.2	-0.2	-1.1*	0.2	-0.7	-0.1	-0.4	-0.5
2009	-0.8	-0.7	-0.5	0.4	0.2	-0.9	-0.7	2.3	-1.6**	0.2	-0.4	-0.5
2010	-0.8	-0.7	-0.8	0.5	-0.4	1.2	-0.4	-0.6	-0.2	-0.5	-0.2	-0.3
2011	-0.8	0.9	-0.4	-1	0	-1.1*	-0.2	0.9	0	-1.1*	-0.3	-0.5

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 14. Calculated SPI values for Station No. 3 (Rajshahi) (1991-2011)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1991	-0.1	-0.8	-0.2	-0.5	0.4	-0.4	0.0	-1.5**	1.4	0.1	-0.6	3.9
1992	-0.7	1.3	-0.8	-0.8	-0.3	-1.5**	-0.3	-0.6	-1.2*	-1.1*	-0.4	-0.4
1993	-0.9	-0.5	1.1	0.8	-1.3*	2.0	-0.2	-0.6	0.2	0.5	2.4	-0.4
1994	1.5	1.5	-0.7	-0.4	-0.4	-0.2	-0.7	-0.3	-0.8	0.2	0.6	-0.4
1995	1.4	1.2	-0.5	-1*	-0.8	0.3	0.0	0.3	0.6	-1.3*	1.9	-0.3
1996	-0.9	0.5	-0.7	0.9	-0.7	0.3	-1.2*	0.3	0.1	0.0	-0.6	-0.4
1997	0.2	1.4	-0.2	0.4	-1.5**	-0.1	3.1	2.4	0.4	-1.4*	1.9	0.7
1998	1.2	-0.5	1.0	-0.3	-1.1*	-1.5**	0.8	0.3	0.2	1.0	1.2	-0.4
1999	-0.9	-0.8	-0.8	-1*	0.2	0.8	0.4	1.2	1.5	0.5	-0.6	-0.4
2000	-0.4	2.2	0.1	2.7	1.2	-0.1	-1.1*	-0.5	2.5	-0.4	-0.6	-0.4
2001	-0.9	-0.8	-0.5	-0.9	1.4	0.6	0.3	-0.3	-1.4*	0.9	-0.6	-0.4
2002	0.4	-0.8	-0.1	1.5	1.1	-0.3	0.2	-0.1	-0.1	-0.8	0.3	-0.4
2003	-0.5	0.3	1.5	0.1	-0.9	0.2	-0.4	-1.2*	-0.2	2.2	-0.6	-0.1
2004	0.4	-0.8	-0.8	0.5	-0.8	2.3	0.4	0.4	0.5	0.5	-0.6	-0.4
2005	0.1	-0.8	2.9	-0.5	-0.5	-1.5**	1.3	-0.8	-1.1*	2.0	-0.6	-0.4
2006	-0.9	-0.8	-0.6	-0.2	1.0	-0.6	-1*	0.1	0.1	-1*	-0.1	-0.4
2007	-0.9	0.9	1.3	-0.9	2.3	0.5	0.5	-0.1	0.2	-0.5	-0.6	-0.4
2008	2.5	-0.8	-0.8	-0.4	0.2	-0.1	0.6	0.1	-1.1*	0.1	-0.6	-0.4
2009	-0.7	-0.4	0.2	-1.3*	-0.1	-1.2*	-0.7	0.0	-0.1	-0.9	-0.6	-0.4
2010	-0.9	-0.7	-0.8	-0.2	-1.1*	-0.4	-1.2*	-1.4*	-1.3*	0.2	-0.5	1.5
2011	-0.1	-0.8	-0.5	1.5	1.0	0.8	-0.9	2.2	-0.6	1.0	-0.6	-0.4

* Moderate drought, ** Severe drought, *** Extreme drought

Table 15. Calculated SPI values for Station No. 4 (Bogra) (1991-2011)

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
1991	-0.3	0.1	-0.5	-0.5	3.1	-0.5	0.4	-0.7	3.0	-0.4	-0.5	4.2
1992	-0.6	0.1	-0.8	-0.7	-0.7	-0.7	-0.3	-1*	-0.8	-0.4	-0.3	-0.3
1993	3.8	-0.3	-0.2	-0.3	1.1	1.0	0.6	-0.3	-0.4	-0.5	-0.4	-0.3
1994	0.4	1.0	-0.7	-0.7	-0.5	-0.1	-1.1*	-0.7	-0.3	0.3	-0.2	-0.3
1995	0.5	0.4	-0.2	-1.2*	-1.1*	0.9	1.2	0.9	1.2	-0.3	0.4	-0.3
1996	-0.4	1.1	-0.5	0.4	-0.1	-0.2	0.0	-0.9	0.4	0.2	-0.5	-0.3
1997	0.1	-0.1	-0.5	0.9	-1.2*	-0.8	-0.2	-0.5	-0.6	-1.1*	-0.4	0.8
1998	0.1	0.1	0.3	0.1	-0.6	0.3	2.5	1.7	-0.1	1.6	0.1	-0.3
1999	-0.6	-0.8	-0.8	-1.0*	1.0	-0.2	0.0	0.6	-1.1*	-0.2	0.6	-0.3
2000	0.6	1.7	2.4	1.2	1.1	-0.4	-0.9	-0.2	1.1	-0.6	-0.5	-0.3
2001	-0.6	-0.8	-0.8	-0.8	0.5	-0.1	-0.9	-1.3*	0.3	0.4	0.0	-0.3
2002	-0.1	-0.8	-0.3	3.0	-0.8	-0.4	0.9	1.2	0.1	-1.1*	0.8	-0.3
2003	-0.3	2.9	2.2	0.5	0.3	0.3	-0.7	-0.6	-1.0*	0.9	-0.5	0.2
2004	-0.6	-0.8	1.1	0.2	-0.7	2.1	1.2	-0.3	-0.7	0.8	-0.5	-0.3
2005	-0.3	-0.2	1.6	-0.1	-0.7	-1.2*	0.8	0.1	0.4	3.1	-0.5	-0.3
2006	-0.6	-0.8	-0.3	0.9	0.0	-0.9	-0.9	-1.2*	-0.9	-0.7	-0.4	-0.3
2007	-0.6	0.4	0.2	-0.7	-1.3*	2.7	-0.1	-0.4	-0.1	-0.2	0.4	-0.3
2008	1.2	-0.8	0.1	-0.9	0.3	0.5	0.8	0.4	-1.4*	0.0	-0.5	-0.3
2009	-0.6	-0.6	-0.7	-0.4	0.2	-1.2*	-0.9	1.7	-0.9	-0.6	-0.5	-0.3
2010	-0.6	-0.8	-0.8	-0.8	-0.1	-0.2	-1.5**	-0.6	-0.4	0.3	-0.3	0.5
2011	-0.5	-0.8	-0.5	1.0	0.1	-0.8	-1*	2.0	0.6	-1.3*	0.2	-0.3

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 16. Calculated SPI values for Station No. 5 (Sydpur) (1991-2011)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0.3	-0.7	-0.2	-1*	-0.1	0.3	-1.6**	-0.7	1.9	-0.9	-0.5	2.2
1992	0.6	-0.2	-0.6	-1*	-0.9	-1.4*	-0.5	-0.1	0.6	-0.6	-0.4	0.6
1993	2.5	-0.7	0.4	-0.4	-0.4	1.5	-0.7	0.1	0 .0	-0.5	1.3	-0.6
1994	0.8	3.2	-0.1	-0.5	-0.8	-1.3*	-1.2*	-1.2*	-0.7	0.4	-0.5	-0.6
1995	-0.4	0.4	-0.5	-1*	-1.5**	0.7	-0.1	-0.1	2.6	-0.5	3.4	-0.2
1996	0.7	-0.7	-0.6	-0.9	-0.4	-1.1*	0.3	-0.5	0.4	-0.4	-0.5	-0.6
1997	1.3	0.3	-0.6	-0.2	-0.3	-0.3	0.9	-0.4	-0.6	-0.8	-0.4	2.0
1998	-0.8	0.3	-0.1	0.6	-0.3	-0.8	1.3	2.2	0.5	1.3	-0.5	-0.3
1999	-0.8	-0.7	-0.6	-0.3	2.0	-0.7	1.0	2.7	0.3	-0.2	-0.1	-0.6
2000	-0.8	-0.6	-0.6	1.4	0.4	-0.5	-1.4*	-0.6	-0.9	-0.9	-0.5	-0.6
2001	-0.7	-0.6	-0.6	-0.6	0.3	0.0	-1*	-0.7	1.2	1.8	-0.1	-0.6
2002	0.1	-0.2	3.0	3.2	-0.8	1.8	2.0	-0.5	-0.4	-0.9	-0.2	-0.6
2003	-0.2	1.8	2.6	1.0	-0.1	1.5	0.1	-0.8	-0.8	1.5	-0.5	2.2
2004	-0.5	-0.7	-0.1	0.5	1.3	0.6	1.4	-0.4	-0.2	0.9	-0.5	-0.5
2005	0.3	-0.1	0.5	-0.4	-0.8	0.3	0.9	0.8	-1.2*	2.3	-0.5	-0.6
2006	-0.8	-0.7	-0.6	-0.1	2.7	0.4	-1*	-1.2*	0.1	-0.6	0.5	1.2
2007	-0.8	0.2	-0.4	-0.1	-0.8	-0.4	-0.1	-0.4	-0.4	-0.6	1.7	-0.6
2008	1.9	-0.6	-0.2	-0.7	0.0	0.7	0.1	0.3	-1.3*	-0.8	-0.5	-0.5
2009	-0.8	-0.7	-0.3	0.0	0.5	-1.2*	0.3	0.9	-1*	0.4	-0.5	-0.6
2010	-0.8	-0.7	-0.6	0.5	-0.4	1.1	-0.7	-0.3	-0.6	-0.1	-0.4	-0.5
2011	0.8	1.2	0.0	-0.5	0.2	-1.3*	-0.1	0.9	-0.3	-1*	-0.5	-0.6

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 17. Calculated SPI values for Station No. 6 (Ishurdi) (1991-2011)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1991	-0.4	-0.4	-0.1	-0.5	0.3	1.2	-0.3	-0.4	1.0	0.1	-0.6	3.3
1992	-0.6	1.3	-1.1*	-0.9	-0.3	-1.8**	-0.3	-0.2	-0.1	-0.6	-0.4	-0.2
1993	-0.4	-0.5	0.9	1.0	1.0	0.5	-0.3	-0.4	0.5	-0.1	0.4	-0.4
1994	1.8	1.5	-1*	-0.7	0.0	0.9	-1.5**	-0.7	-1.6**	-0.3	-0.6	-0.4
1995	0.2	0.4	-0.3	-1.3*	-0.8	-0.3	2.0	0.7	0.4	-0.8	2.9	-0.2
1996	-0.6	0.5	-0.5	0.7	-1.1*	0.5	-1.1*	0.3	-0.2	0.5	-0.7	-0.4
1997	-0.2	1.4	0.5	0.8	-0.3	-0.5	1.8	0.6	1.4	-0.5	0.1	0.5
1998	1.0	-0.2	1.4	0.8	1.9	-1.5**	3.7	-0.1	-0.1	-0.2	1.4	-0.4
1999	-0.6	-0.9	-1.1*	-1.2*	0.8	1.4	1.1	0.1	-0.1	0.6	-0.5	-0.4
2000	0.2	2.4	-0.3	2.7	1.3	-0.4	-0.4	-0.8	2.0	0.1	-0.7	-0.4
2001	-0.6	-0.9	-0.3	-0.3	1.7	1.7	-1.0*	-0.7	0.3	-0.3	-0.2	-0.4
2002	0.9	-0.8	1.2	0.1	0.4	0.5	-0.3	-0.1	-0.5	-0.3	1.7	-0.4
2003	-0.6	0.4	1.6	0.4	-1.5**	1.1	-1.3*	-1.3*	-1.2*	0.1	-0.7	-0.2
2004	-0.6	-0.9	-1.1*	1.2	-0.4	0.5	1.0	-0.7	1.9	0.2	-0.7	-0.4
2005	0.8	-0.7	1.7	-1.0*	-1*	-0.5	0.8	0.1	-1.3*	4.0	-0.7	-0.3
2006	-0.6	-0.9	-1.0	0.1	1.0	-0.5	2.1	0.1	-0.2	-0.9	1.3	-0.4
2007	-0.6	1.0	-0.3	-0.7	-1.6**	0.2	2.1	0.5	-0.6	0.1	0.1	-0.4
2008	3.1	-0.8	-0.6	-0.6	-0.1	-0.4	0.1	-0.2	-0.3	-0.1	-0.7	-0.4
2009	-0.6	-0.6	1.5	-1*	-0.3	-1.8**	0.2	0.4	0.4	-0.4	-0.7	-0.4
2010	-0.6	-0.7	-1.1*	-0.4	-0.8	-0.9	-0.9	-0.9	-1.5**	-0.1	-0.5	2.5
2011	-0.2	-0.8	1.1	0.6	0.0	0.1	0.1	3.7	-0.3	-0.9	-0.7	-0.4

** Moderate drought, ** Severe drought, *** Extreme drought*

Future analysis of drought using SPI

For future analysis of drought, SPI values from 2012 to 2026 were calculated for the six stations and are shown in Table 18, 19, 20, 21, 22 and 23.

Table 18. Calculated SPI values for Station No. 1 (Dinajpur) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	0.5	-0.3	0	-0.7	-2.8***	1.0	0.3	1.4	-0.8	-1.2*	-0.4	-1.1*
2013	0.8	-0.3	0	-1.4*	1.5	0.7	1.2	-0.7	-1.1*	0.2	0.1	-1.1*
2014	2.6	3.0	0	-1.4*	-1.2*	0.2	1.9	-1.1*	-0.5	1.0	-0.7	0.1
2015	-1.9**	1.8	0	-1.4*	0.4	-0.4	-1.2*	0.4	1.1	0.4	-0.7	0.9
2016	1.0	-0.3	0	2.3	-1.1*	-3.1***	-0.3	-2.2***	-2.7***	-0.3	-0.7	-0.6
2017	-0.3	-0.3	0	0.8	0.1	-0.1	0.3	-1*	1.0	0.9	1.7	-1*
2018	-0.1	-0.3	0	0.6	0.2	0.5	0.4	-0.5	-0.1	0.8	1.5	-1.1*
2019	-0.1	-0.3	0	0.5	0.2	0.6	0.4	-0.3	0.1	0.8	1.5	-1.1*
2020	-0.1	-0.3	0	0.5	0.2	0.6	0.4	-0.2	0.1	0.8	1.5	-1.1*
2021	-0.9	-0.3	0	-0.2	0.5	-0.3	-1.3*	0.8	1.0	0.5	-0.7	0.5
2022	-0.6	0.4	0	-0.3	0.6	-0.5	-1.5**	1.2	0.8	0.5	-0.7	1.1
2023	-0.6	0.8	0	-0.3	0.6	-0.6	-1.5**	1.3	0.9	0.5	-0.7	1.2
2024	-0.1	-0.3	0	0.3	0.3	0.4	0.2	0.5	-0.1	-1.6**	-0.7	1.1
2025	-0.1	-0.3	0	0.4	0.2	0.6	0.4	0.2	0.1	-1.6**	-0.3	1.0
2026	-0.1	-0.3	0	0.5	0.2	0.6	0.4	0.1	0.1	-1.6**	-0.7	1.0

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 19. Calculated SPI values for Station No. 2 (Rangpur) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	1.9	0.8	0.9	-1.9**	-0.9	-1*	0.4	-1.6**	0.8	0.7	1.8	-0.6
2013	1.2	-0.5	1.2	-1.1*	-0.9	-1*	0.4	-0.8	0.9	0.1	1.5	0.7
2014	1.3	-0.5	1.2	-0.8	-0.9	-1*	0.4	-0.9	0.9	-0.1	0.4	1.1
2015	1.3	-0.5	1.2	-0.8	-0.9	-1*	0.4	-0.9	0.9	-0.1	0.6	1.3
2016	0.3	-0.5	1.3	-0.7	-0.9	-1*	0.4	-0.9	0.9	-0.1	0.6	1.3
2017	0.4	-0.5	1.3	-0.7	-0.9	-1*	0.4	-0.9	0.9	-0.1	0.6	1.3
2018	-1.0*	-0.5	-0.8	-0.7	-0.9	-1*	0.4	-0.9	0.9	-0.1	0.6	-0.2
2019	-0.9	-0.5	-0.8	0.6	-0.9	0.5	-1*	1.3	-1.3*	0.7	-1.1*	0.1
2020	-0.9	-0.5	-0.8	1	-0.9	0.6	-1*	1	-1.1*	0.7	-1.1*	0.2
2021	-0.9	-0.5	-0.8	1.2	0.2	0.7	-1*	1.1	-1.1*	0.7	-1.1*	0.2
2022	-0.4	-0.5	-0.8	1.2	0.2	0.7	-1*	1.1	-1.1*	0.7	-1.1*	-0.5
2023	-0.5	-0.5	-0.8	1.2	0.2	0.7	-1*	1.1	-1.1*	0.7	-1.1*	-0.8
2024	-0.9	0	-0.8	0.1	2.3	0.7	-1*	1.1	-1.1*	0.7	-1.1*	-0.8
2025	-0.4	1.9	-0.8	0.6	1.3	1.5	1.8	0	0.5	-2.5***	0.4	-1.5**
2026	-0.5	2.7	-0.8	0.8	1.3	1.6	1.8	0.1	0.4	-2.2***	0	-1.7**

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 20. Calculated SPI values for Station No. 3 (Rajshahi) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	3.6	1.7	1.7	2.8	-1*	-2.2***	4.5	2.6	0.3	1.8	1.8	0.1
2013	-0.3	0.4	-0.4	0.7	-0.6	0.8	6.7	-0.1	-1*	-1.3*	-0.6	-0.9
2014	-0.3	0.4	0.3	0.5	-0.6	0.5	7.1	-0.6	-0.9	-1*	-0.4	-2.1***
2015	-0.3	0.2	0.7	0.6	2.5	0.2	7.7	-0.2	-0.6	0.3	0.4	-0.6
2016	-0.3	-1.5**	0.9	-1*	2.2	-1.4*	6.9	-0.4	-0.4	0.5	-0.8	0.9
2017	-0.3	-0.7	-0.1	0.8	-0.2	0.1	7.7	-1.4*	-0.7	-0.5	1.4	-0.1
2018	-0.3	-1.4*	0.7	-0.6	-0.1	-0.9	7.1	-0.5	0.4	1	0.2	1.2
2019	-0.3	-0.7	-0.1	-0.8	-0.1	0.4	6.7	-0.8	-0.7	-0.9	-0.8	-0.7
2020	-0.3	-1.4*	-1*	-1.2*	-0.2	-0.6	7.1	-0.4	0.7	0.7	1	0.6
2021	-0.3	0.6	-0.3	-0.7	0	0.3	8.2	-0.1	-1*	-1.9**	-0.8	-0.6
2022	-0.3	0.5	0.1	-0.2	-0.4	-0.3	7.2	-0.6	0.5	0.7	-1*	0.6
2023	-0.3	1.1	-1.1*	0.2	-0.6	-0.5	6.3	-0.4	2	-0.5	-0.2	-0.6
2024	-0.3	1.2	-2.5***	-0.2	0	1.4	4.8	0.4	-0.1	1	-0.8	0.9
2025	-0.3	0.1	0.3	0.1	-0.6	1	6.3	1.3	-0.7	0.5	1.4	1.7
2026	-0.3	-0.5	0.7	0.8	-0.3	1.3	6.9	1.2	2.1	-0.5	-1.2*	-0.7

* Moderate drought, ** Severe drought, *** Extreme drought

Table 21. Calculated SPI values for Station No. 4 (Bogra) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	1	-1.5**	0	0	2.6	-0.1	-0.1	-1.7**	-0.5	-0.6	0.9	0.4
2013	1.3	-1.2*	0	0	1.1	0.4	0.3	-1.0*	-0.1	-1.2*	0.6	0.2
2014	0.6	-1.1*	0	0	1	1.3	0.4	-0.6	-1.2*	0.7	1.4	1.6
2015	1.6	-0.9	0	0	0	0.8	0.3	-0.7	-1.1*	0.5	1.3	1.4
2016	1.1	-0.7	0	0	0.4	0.6	0.3	-0.7	-1.1*	0.5	1.3	1.5
2017	1	-0.5	0	0	0.3	0.6	0.3	4.9	-1.1*	0.5	1.3	1.5
2018	-0.2	-0.4	0	0	-0.3	1.3	-0.2	0.3	0.8	-1.9**	-1.2*	-1*
2019	-0.4	-0.3	0	0	-0.1	1.5	-0.4	0.2	0.6	-1.6**	-0.7	-0.6
2020	-1.1*	0.2	0	0	-0.7	-0.7	-0.3	0.5	1.4	0.8	-0.8	-0.6
2021	-1.1*	0.6	0	0	-0.5	-1.4*	-0.2	0.5	1.3	0.5	-0.8	-0.6
2022	-0.5	0.7	0	0	-0.6	-1.6**	-0.2	0.5	1.3	0.5	-0.7	-0.6
2023	-1.1*	1.1	0	0	-1.2*	-1.0*	-0.1	-0.3	0.6	-0.7	-0.6	-0.6
2024	-1.1*	1.4	0	0	-1*	-0.9	-0.1	-0.2	0.6	-0.5	-0.6	-0.6
2025	-0.8	1.4	0	0	-0.5	-0.5	-0.1	2	-0.9	1.3	-0.8	-1*
2026	-0.2	1.2	0	0	-0.7	-0.3	-0.1	1.8	-0.7	1.1	-0.7	-1*

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 22. Calculated SPI values for Station No. 5 (Sydpur) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	0.2	3	0	0.5	-0.5	-1.2*	0.1	0.7	-0.5	0.3	1	-1*
2013	2	0.9	0	0.5	-0.4	-1*	0.2	0.8	-0.5	-0.1	0.7	-0.7
2014	-0.2	1.2	0	1.2	3.3	1.3	-2.7***	-0.5	3.4	3.4	-2.1***	-1.3*
2015	0.2	-0.5	0	0.5	-0.8	-0.7	-1.2*	0.9	-0.8	0.4	0.9	-0.7
2016	-1.1*	-0.2	0	-1.2*	0.3	1.0	-0.6	-1.2*	0.3	0.4	-1*	0.7
2017	-0.2	0.2	0	1.2	0.2	1.2	-0.3	-1*	0.2	0.4	-0.8	0.9
2018	0.2	-0.5	0	0.5	-0.5	-0.8	0.0	1	-0.5	-0.1	0.8	-0.5
2019	-1.1*	-0.5	0	-1.2*	0.3	1.0	-0.1	-1.2*	0.2	0.4	-1*	0.8
2020	0.2	-0.5	0	0.5	-0.5	-0.8	0.2	1	-0.5	-0.1	0.9	-0.5
2021	-1.1*	-0.5	0	-1.2*	0.3	1	0.1	-1.2*	0.2	0.4	-1*	0.8
2022	2	-0.5	0	-1.8**	-0.9	0.4	1.7	-0.6	-0.2	1.2	0.2	2.3
2023	0.2	-0.5	0	0.5	-0.3	-0.9	1.1	0.9	-0.5	-0.2	0.7	-0.4
2024	-1.1*	-0.5	0	-1.2*	0.3	1	0.5	-1.2*	0.2	0.4	-0.9	0.8
2025	-0.2	-0.5	0	0.5	-0.5	-0.8	0.4	1	-0.5	-0.1	0.8	-0.5
2026	0.2	-0.5	0	0.5	-0.4	-1*	0.4	0.8	-0.5	-0.1	0.7	-0.6

** Moderate drought, ** Severe drought, *** Extreme drought*

Table 23. Calculated SPI values for Station No. 6 (Ishurdi) (2012-2026)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2012	0.1	-0.6	0.9	3.6	-0.1	-0.9	-0.1	0.9	-0.6	1.7	1.3	0.1
2013	0.1	-0.8	0.9	-0.3	-0.1	-0.6	0.1	0.8	-0.4	-0.1	0.2	-0.3
2014	-1.3*	1.4	-0.4	-0.3	0.0	1.1	-0.1	-1.4*	0.3	0.4	-0.8	1.3
2015	0.1	-1*	0.7	-0.3	-0.1	-1*	0.1	0.9	-0.5	0	0.6	-0.4
2016	-0.4*	1.4	-2.8***	-0.3	0.7	1.4	-2.9***	-0.6	3.3	-3.2***	-2.6***	-0.9
2017	0.1	-1*	-0.5	-0.3	0	-1.1*	-0.8	0.8	-1.1*	0.4	1	-0.2
2018	-1.3*	1.4	-0.7	-0.3	0.7	1.2	-0.4	-1.4*	0.4	0.3	-0.9	1.3
2019	-0.4	0.9	0.3	-0.3	0.2	0.7	-0.2	-1.4*	0.1	0.3	-0.5	1.1
2020	0.1	-0.9	0.8	-0.3	-0.1	-0.9	0.2	0.9	-0.5	0.0	0.6	-0.3
2021	2.3	-0.1	-0.4	-0.3	-0.2	0.1	1.4	-0.1	-0.1	0.3	0.9	-0.2
2022	0.1	-0.8	0.7	-0.3	-0.1	-0.8	0.5	0.8	-0.5	0	0.3	-0.2
2023	1.9	-0.1	-0.5	-0.3	-0.2	1.4	1.5	-0.6	0.3	-0.5	-0.3	-2.5***
2024	-0.4	-0.2	0.7	-0.3	-0.1	-1*	0.5	0.8	-0.5	0.1	0.6	0.0
2025	0.1	-0.8	0.9	-0.3	-0.1	-0.6	0.3	0.9	-0.4	0.0	0.4	-0.2
2026	-1.3*	1.4	-0.4	-0.3	0	1.1	-0.1	-1.4*	0.3	0.3	-0.8	1.3

** Moderate drought, ** Severe drought, *** Extreme drought*

Conclusions

The droughts in the northern region of Bangladesh over the study period varied from moderately dry to severely dry conditions in most years. In future, normally it may vary from moderately dry to severely dry conditions but sometimes extremely dry condition may also occur according to the calculated SPI values. From the study it is observed that the Dinajpur region had faced moderate drought in 1992, 1996, 1997, 1998, 2001, 2006, 2009, 2010; severe drought in 1995, 1992; and this region may face moderate drought in 2013, 2014, 2015, 2021; severe drought in 2015, 2022, 2023, 2024, 2025, 2026; and extreme drought in 2016. The Rangpur region had experienced moderate drought in 1992, 1993, 1994, 1995, 1997, 2000, 2003, 2004, 2007, 2008, 2011; severe drought in 1991, 2000, 2009; and this region may face moderate drought in 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024; severe drought in 2012, 2025, 2026. The Rajshahi region had faced moderate drought in 1992, 1995, 1997, 1998, 1999, 2000, 2003, 2006, 2008, 2010; severe drought in 1991, 1992, 1997, 1998, 2005; and this region may face moderate drought in 2012, 2013, 2014, 2016, 2020, 2022, 2023, 2026; severe drought in 2016, 2021; extreme drought in 2024. The Bogra region had experienced moderate drought in 1992, 1994, 1995, 1997, 1999, 2001, 2002, 2005, 2007, 2009, 2011; severe drought in 2010; and this region may face moderate drought in 2013, 2014, 2015, 2016, 2017, 2018, 2021, 2023, 2024, 2025; severe drought in 2012, 2018, 2019, 2022. The Sydpur region had experience moderate drought in 1991, 1992, 1994, 1995, 2001, 2005, 2006, 2008, 2009, 2011; severe drought in 1991, 1995, 2000; and this region may face moderate drought in 2012, 2014, 2016, 2017, 2019, 2021, 2024; severe drought in 2022 and extreme drought in 2014. The Ishurdi region had experienced moderate drought in 1992, 1994, 1995, 1996, 1999, 2001, 2003, 2005, 2006, 2010; severe drought in 1992, 1994, 1998, 2003, 2007, 2009, 2010; and this region may face moderate drought in 2014, 2015, 2017, 2019, 2024, 2026 and extreme drought in 2016.

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